Activity Report Nancy - Grand Est 2019

Edition: 2020-03-23

List of Inria's Research Teams

Team ALICE

Geometry and Lighting

Inria teams are typically groups of researchers working on the definition of a common project, and objectives, with the goal to arrive at the creation of a project-team. Such project-teams may include other partners (universities or research institutions).

RESEARCH CENTER
Nancy - Grand Est

THEME
Interaction and visualization

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Team ALICE

Creation of the Team: 2019 January 01

Keywords:

Computer Science and Digital Science:

A5.5.1. - Geometrical modeling

A5.5.2. - Rendering

A6.2.8. - Computational geometry and meshes

A8.1. - Discrete mathematics, combinatorics

A8.3. - Geometry, Topology

Other Research Topics and Application Domains:

B3.3.1. - Earth and subsoil

B5.1. - Factory of the future

B5.7. - 3D printing

B9.2.2. - Cinema, Television

B9.2.3. - Video games

1. Team, Visitors, External Collaborators

Research Scientists

Laurent Alonso [Inria, Researcher]
Nicolas Ray [Inria, Researcher]
Etienne Corman [CNRS, Researcher]

Faculty Members

Dmitry Sokolov [Team leader, Univ de Lorraine, Associate Professor, HDR]
Dobrina Boltcheva [Univ de Lorraine, Associate Professor]

PhD Students

Justine Basselin [Inria, PhD Student, from Dec 2019]
Francois Protais [Inria, PhD Student, from Oct 2019]

Post-Doctoral Fellow

Sebastian Von Hausegger [Inria, Post-Doctoral Fellow, from Nov 2019]

Administrative Assistants

Virginie Priester [CNRS, Administrative Assistant]
Céline Simon [Inria, Administrative Assistant]

2. Overall Objectives

2.1. Overall Objectives

ALICE is a team founded in 2004 by Bruno Lévy. The main scientific goal of ALICE was to develop new algorithms for computer graphics, with a special focus on geometry processing. From 2004 to 2006, we developed new methods for automatic texture mapping (LSCM, ABF++, PGP), that became the de-facto standards. Then we realized that these algorithms could be used to create an abstraction of shapes, that could be used for geometry processing and modeling purposes, which we developed from 2007 to 2013 within the GOODSHAPE StG ERC project. We transformed the research prototype stemming from this project into an industrial geometry processing software, with the VORPALINE PoC ERC project, and commercialized it (TOTAL, Dassault Systems, + GeonX and ANSYS currently under discussion). From 2013 to 2018, we developed more contacts and cooperations with the "scientific computing" and "meshing" research communities.

After a part of the team "spun off" around Sylvain Lefebvre and his ERC project SHAPEFORGE to become the MFX team (on additive manufacturing and computer graphics), we progressively moved the center of gravity of the rest of the team from computer graphics towards scientific computing and computational physics, in terms of cooperations, publications and industrial transfer.

We realized that *geometry* plays a central role in numerical simulation, and that "cross-pollinization" with methods from our field (graphics) will lead to original algorithms. In particular, computer graphics routinely uses irregular and dynamic data structures, more seldom encountered in scientific computing. Conversely, scientific computing routinely uses mathematical tools that are not well spread and not well understood in computer graphics. Our goal is to establish a stronger connection between both domains, and exploit the fundamental aspects of both scientific cultures to develop new algorithms for computational physics.

2.2. Scientific grounds

Mesh generation is a notoriously difficult task. A quick search on the NSF grant web page [0] with "mesh generation AND finite element" keywords returns more than 30 currently active grants for a total of $8 million. **NASA indicates mesh generation as one of the major challenges for 2030 [36], and estimates that it costs 80% of time and effort in numerical simulation.** This is due to the need for constructing supports that match both the geometry and the physics of the system to be modeled. In our team we pay a particular attention to scientific computing, because we believe it has a world changing impact.

It is very unsatisfactory that meshing, i.e. just "preparing the data" for the simulation, eats up the major part of the time and effort. Our goal is to make the situation evolve, by studying the influence of shapes and discretizations, and inventing new algorithms to automatically generate meshes that can be directly used in scientific computing. This goal is a result of our progressive shift from pure graphics ("Geometry and Lighting") to real world problems ("Shape Fidelity").

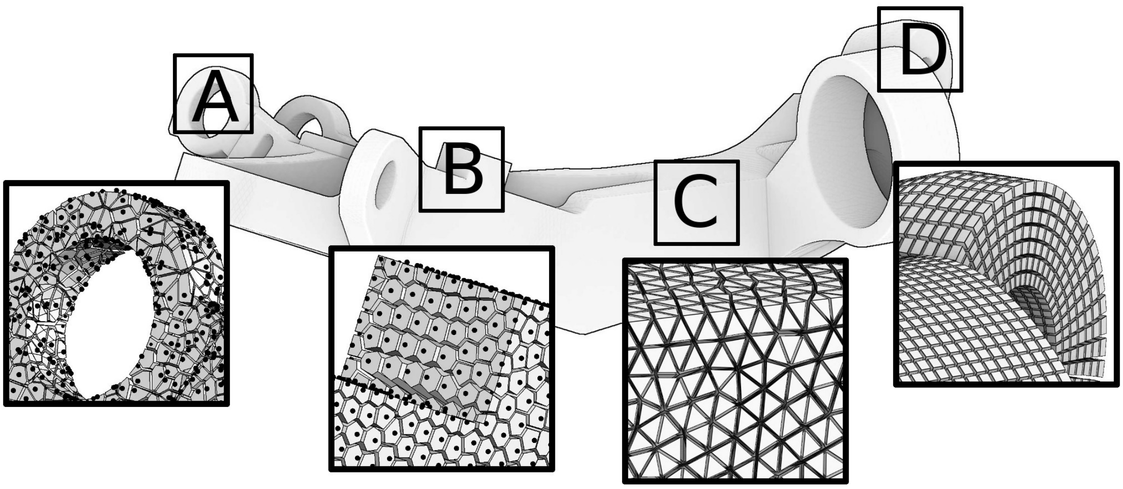

Figure 1. There is a wide range of possibilities to discretize a given domain. ***(A)*** *Completely unstructured, white noise point sampling;* ***(B)*** *Blue noise point sampling exhibits some structure;* ***(C)*** *tetrahedral mesh;* ***(D)*** *hexahedral mesh.*

[0] https://www.nsf.gov/awardsearch

Meshing is so central in geometric modeling because it provides a way to represent functions on the objects studied (texture coordinates, temperature, pressure, speed, etc.). There are numerous ways to represent functions, but if we suppose that the functions are piecewise smooth, the most versatile way is to discretize the domain of interest. Ways to discretize a domain range from point clouds to hexahedral meshes; let us list a few of them sorted by the amount of structure each representation has to offer (refer to Figure 1).

- At one end of the spectrum there are **point clouds:** they exhibit no structure at all (white noise point samples) or very little (blue noise point samples). Recent explosive development of acquisition techniques (e.g. scanning or photogrammetry) provides an easy way to build 3D models of real-world objects that range from figurines and cultural heritage objects to geological outcrops and entire city scans. These technologies produce massive, unstructured data (billions of 3D points per scene) that can be directly used for visualization purposes, but this data is not suitable for high-level geometry processing algorithms and numerical simulations that usually expect meshes. Therefore, at the very beginning of the acquisition-modeling-simulation-analysis pipeline, powerful scan-to-mesh algorithms are required.

  During the last decade, many solutions have already been proposed [16], [12], [14], [15], [13], but the problem of building a good mesh from scattered 3D points is far from being solved. Beside the fact that the data is unusually large, the existing algorithms are challenged also by the extreme variation of data quality. Raw point clouds have many defects, they are often corrupted with noise, redundant, incomplete (due to occlusions): *they all are uncertain*.

- **Triangulated surfaces** are ubiquitous, they are the most widely used representation for 3D objects. Some applications like 3D printing do not impose heavy requirements on the surface: typically it has to be watertight, but triangles can have an arbitrary shape. Other applications like texturing require very regular meshes, because they suffer from elongated triangles with large angles.

  While being a common solution for many problems, triangle mesh generation is still an active topic of research. The diversity of representations (meshes, NURBS, ...) and file formats often results in a “Babel” problem when one has to exchange data. The only common representation is often the mesh used for visualization, that has in most cases many defects, such as overlaps, gaps or skinny triangles. Re-injecting this solution into the modeling-analysis loop is non-trivial, since again this representation is not well adapted to analysis.

- **Tetrahedral meshes** are the volumic equivalent of triangle meshes, they are very common in the scientific computing community. Tetrahedral meshing is now a mature technology. It is remarkable that still today all the existing software used in the industry is built on top of a handful of kernels, all written by a small number of individuals [23], [34], [40], [25], [33], [35], [24], [11]. Meshing requires a long-term, focused, dedicated research effort, that combines deep theoretical studies with advanced software development. We have the ambition bring to this kind of maturity a different type of mesh (structured, with hexahedra), which is highly desirable for some simulations, and for which, unlike tetrahedra, no satisfying automatic solution exists. In the light of recent contributions, we believe that the domain is ready to overcome the principal difficulties.

- Finally, at the most structured end of the spectrum there are **hexahedral meshes** composed of deformed cubes (hexahedra). They are preferred for certain physics simulations (deformation mechanics, fluid dynamics ...) because they can significantly improve both speed and accuracy. This is because (1) they contain a smaller number of elements (5-6 tetrahedra for a single hexahedron), (2) the associated tri-linear function basis has cubic terms that can better capture higher order variations, (3) they avoid the locking phenomena encountered with tetrahedra [18], (4) hexahedral meshes exploit inherent tensor product structure and (5) hexahedral meshes are superior in direction dominated physical simulations (boundary layer, shock waves, etc). Being extremely regular, hexahedral meshes are often claimed to be The Holy Grail for many finite element methods [19], outperforming tetrahedral meshes both in terms of computational speed and accuracy.

  Despite 30 years of research efforts and important advances, mainly by the Lawrence Livermore National Labs in the U.S. [39], [38], hexahedral meshing still requires considerable manual intervention in most cases (days, weeks and even months for the most complicated domains). Some automatic methods exist [28], [42], that constrain the boundary into a regular grid, but they are not fully satisfactory either, since the grid is not aligned with the boundary. The advancing front method [17] does not have this problem, but generates irregular elements on the medial axis, where the fronts collide. Thus, *there is no fully automatic algorithm that results in satisfactory boundary alignment*.

3. Research Program

3.1. Point clouds

Currently, transforming the raw point cloud into a triangular mesh is a long pipeline involving disparate geometry processing algorithms:

- *Point pre-processing:* colorization, filtering to remove unwanted background, first noise reduction along acquisition viewpoint;
- *Registration:* cloud-to-cloud alignment, filtering of remaining noise, registration refinement;
- *Mesh generation:* triangular mesh from the complete point cloud, re-meshing, smoothing.

The output of this pipeline is a locally structured model which is used in downstream mesh analysis methods such as feature extraction, segmentation in meaningful parts or building CAD models.

It is well known that point cloud data contains measurement errors due to factors related to the external environment and to the measurement system itself [37], [32], [20]. These errors propagate through all processing steps: pre-processing, registration and mesh generation. Even worse, the heterogeneous nature of different processing steps makes it extremely difficult to know *how* these errors propagate through the pipeline. To give an example, for cloud-to-cloud alignment it is necessary to estimate normals. However, the normals are forgotten in the point cloud produced by the registration stage. Later on, when triangulating the cloud, the normals are re-estimated on the modified data, thus introducing uncontrollable errors.

We plan to develop new reconstruction, meshing and re-meshing algorithms, with a specific focus on the accuracy and resistance to all defects present in the input raw data. We think that pervasive treatment of uncertainty is the missing ingredient to achieve this goal. We plan to rethink the pipeline with the position uncertainty maintained during the whole process. Input points can be considered either as error ellipsoids [41] or as probability measures [27]. In a nutshell, our idea is to start by computing an error ellipsoid [43], [29] for each point of the raw data, and then to cumulate the errors (approximations) committed at each step of the processing pipeline while building the mesh. In this way, the final users will be able to take the uncertainty knowledge into account and rely on this confidence measure for further analysis and simulations. Quantifying uncertainty for reconstruction algorithms, and propagating them from input data to high-level geometry processing algorithms has never been considered before, possibly due to the very different methodologies of the approaches involved. At the very beginning we will re-implement the entire pipeline, and then attack the weak links through all three reconstruction stages.

3.2. Parameterizations

One of the favorite tools we use in our team are parameterizations. They provide a very powerful way to reveal structures on objects. The most omnipresent application of parameterizations is texture mapping: texture maps provide a way to represent in 2D (on the map) information related to a surface. Once the surface is equipped with a map, we can do much more than a mere coloring of the surface: we can approximate geodesics, edit the mesh directly in 2D or transfer information from one mesh to another.

Parameterizations constitute a family of methods that involve optimizing an objective function, subject to a set of constraints (equality, inequality, being integer, etc.). Computing the exact solution to such problems is beyond any hope, therefore approximations are the only resort. This raises a number of problems, such as the minimization of highly nonlinear functions and the definition of direction fields topology, without forgetting the robustness of the software that puts all this into practice.

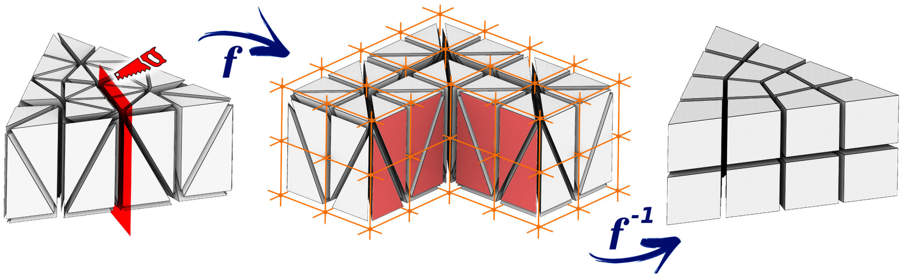

Figure 2. Hex-remeshing via global parameterization. ***Left:*** *Input tetrahedral mesh. To allow for a singular edge in the center, the mesh is cut open along the red plane.* ***Middle:*** *Mesh in parametric space.* ***Right:*** *Output mesh defined by parameterization.*

We are particularly interested in a specific instance of parameterization: hexahedral meshing. The idea [4] is to build a transformation f from the domain to a parametric space, where the deformed domain can be meshed by a regular grid. The inverse transformation f^{-1} applied to this grid produces the hexahedral mesh of the domain, aligned with the boundary of the object. The strength of this approach is that the transformation may admit some discontinuities. Let us show an example: we start from a tetrahedral mesh (Figure 2, left) and we want deform it in a way that its boundary is aligned with the integer grid. To allow for a singular edge in the output (the valency 3 edge, Figure 2, right), the input mesh is cut open along the highlighted faces and the central edge is mapped onto an integer grid line (Figure 2, middle). The regular integer grid then induces the hexahedral mesh with the desired topology.

Current global parameterizations allow grids to be positioned inside geometrically simple objects whose internal structure (the singularity graph) can be relatively basic. We wish to be able to handle more configurations by improving three aspects of current methods:

- Local grid orientation is usually prescribed by minimizing the curvature of a 3D steering field. Unfortunately, this heuristic does not always provide singularity curves that can be integrated by the parameterization. We plan to explore how to embed integrability constraints in the generation of the direction fields. To address the problem, we already identified necessary validity criteria, for example, the permutation of axes along elementary cycles that go around a singularity must preserve one of the axes (the one tangent to the singularity). The first step to enforce this (necessary) condition will be to split the frame field generation into two parts: first we will define a locally stable vector field, followed by the definition of the other two axes by a 2.5D directional field (2D advected by the stable vector field).
- The grid combinatorial information is characterized by a set of integer coefficients whose values are currently determined through numerical optimization of a geometric criterion: the shape of the hexahedra must be as close as possible to the steering direction field. Thus, the number of layers of hexahedra between two surfaces is determined solely by the size of the hexahedra that one wishes to generate. In this setting degenerate configurations arise easily, and we want to avoid them. In practice, mixed integer solvers often choose to allocate a negative or zero number of layers of hexahedra between two constrained sheets (boundaries of the object, internal constraints or singularities). We will study how to inject strict positivity constraints into these cases, which is a very complex problem because of the subtle interplay between different degrees of freedom of the system. Our first results for quad-meshing of surfaces give promising leads, notably thanks to *motorcycle graphs* [21], a notion we wish to extend to volumes.
- Optimization for the geometric criterion makes it possible to control the average size of the hexahedra, but it does not ensure the bijectivity (even locally) of the resulting parameterizations.

Considering other criteria, as we did in 2D [26], would probably improve the robustness of the process. Our idea is to keep the geometry criterion to find the global topology, but try other criteria to improve the geometry.

3.3. Hexahedral-dominant meshing

All global parameterization approaches are decomposed into three steps: frame field generation, field integration to get a global parameterization, and final mesh extraction. Getting a full hexahedral mesh from a global parameterization means that it has positive Jacobian everywhere except on the frame field singularity graph. To our knowledge, there is no solution to ensure this property, but some efforts are done to limit the proportion of failure cases. An alternative is to produce hexahedral dominant meshes. Our position is in between those two points of view:

1. We want to produce full hexahedral meshes;
2. We consider as pragmatic to keep hexahedral dominant meshes as a fallback solution.

The global parameterization approach yields impressive results on some geometric objects, which is encouraging, but not yet sufficient for numerical analysis. Note that while we attack the remeshing with our parameterizations toolset, the wish to improve the tool itself (as described above) is orthogonal to the effort we put into making the results usable by the industry. To go further, our idea (as opposed to [30], [22]) is that the global parameterization should not handle all the remeshing, but merely act as a guide to fill a large proportion of the domain with a simple structure; it must cooperate with other remeshing bricks, especially if we want to take final application constraints into account.

For each application we will take as an input domains, sets of constraints and, eventually, fields (e.g. the magnetic field in a tokamak). Having established the criteria of mesh quality (per application!) we will incorporate this input into the mesh generation process, and then validate the mesh by a numerical simulation software.

4. Application Domains

4.1. Geometric Tools for Simulating Physics with a Computer

Numerical simulation is the main targeted application domain for the geometry processing tools that we develop. Our mesh generation tools will be tested and evaluated within the context of our cooperation with Hutchinson, experts in vibration control, fluid management and sealing system technologies. We think that the hex-dominant meshes that we generate have geometrical properties that make them suitable for some finite element analyses, especially for simulations with large deformations.

We also have a tight collaboration with Wan Chiu Li, a geophysical modeling specialist. He is creating a start-up company MESHSPACE whose goal is to transfer to the industry remeshing tools we developed in the ALICE team. In particular, he uses hexahedral-dominant meshes for geomechanical simulations of gas and oil reservoirs. From a scientific point of view, this use case introduces new types of constraints (alignments with faults and horizons), and allows certain types of nonconformities that we did not consider until now.

Our cooperation with RhinoTerrain pursues the same goal: reconstruction of buildings from point cloud scans allows to perform 3D analysis and studies on insolation, floods and wave propagation, wind and noise simulations necessary for urban planification.

5. Highlights of the Year

5.1. Highlights of the Year

5.1.1. Awards

Dmitry Sokolov has won the "best expertise" nomination for TechnoText 2019, the challenge for the best russian language IT-related text of 2019. The award was given for the article on understandable raytracing [0].

[0] https://github.com/ssloy/tinyraytracer/wiki

6. New Software and Platforms

6.1. VORPALINE

VORPALINE mesh generator

KEYWORDS: 3D modeling - Unstructured heterogeneous meshes

SCIENTIFIC DESCRIPTION: This software is the result of the team's work on the parameterization of surfaces and volumes, on the generation of Voronoi diagrams and mesh generation.

FUNCTIONAL DESCRIPTION: VORPALINE is a surfacic and volumetric mesh generator, for simplicial meshes (triangles and tetrahedra), for quad-dominant and hex-dominant meshes. It also contains surfacic and volumic parameterization modules.

RELEASE FUNCTIONAL DESCRIPTION: Computer vision algorithms allow us to reconstruct surfaces in a 3d scene. The colours associated with these surfaces can be stored in textures, but these are often incomplete due to a lack of reliable data. For example, some points on the surface are not present in the images, are insufficiently illuminated or, on the contrary, in a reflection that does not give the true color of the object. We have developed in Vorpaline an algorithm capable of generating these missing colors from those present in their vicinity. The originality of our approach is the optimization according to the neighbourhoods defined on the surface and not in the texture space.

- Participants: Bruno Lévy, Dmitry Sokolov and Nicolas Ray
- Contact: Bruno Lévy
- URL: http://alice.loria.fr/index.php/erc-vorpaline.html

7. New Results

7.1. Curved slicing

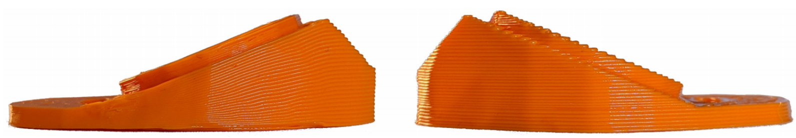

Figure 3. Sides views of curved slicing print (left) and adaptive slicing (right). Curved slicing eliminates all staircasing while closely following the input.

When printing 3D objects with Fused Filament Fabrication technology, the plastic is deposited by following a 2D path for producing the first layer. Each following layer is printed with the same method on the top of the previous layers. For technical reasons, it is convenient to use horizontal layers with constant height, but this generates aliasing errors that are especially visible (Figure 3, right) when the object's surface is close to horizontal. The objective of this project is to reduce these artefacts by printing curved layers (Figure 3, left). Printing curved layers is a challenging task because all technical aspects of printing have to be adapted to the curved case. The key idea of our approach is to (virtually) deform the object in such a way that the surface that is close to horizontal becomes exactly horizontal, then define all the printing instructions (tool path, slicing, pressure, etc.) in this deformed space with standard algorithms. The final printing instructions are obtained by coming back to the original space. In collaboration with MFX team, we have worked on the problem of finding the deformation by a global optimization method that tries to make horizontal large portions of the object's surface under constraints of layer thickness, tools collisions, object self-intersections, etc. The results were published at SIGGRAPH this year [7].

7.2. Coarse polycube meshes

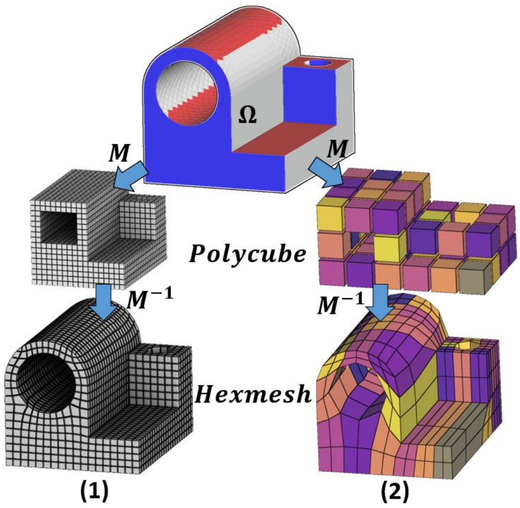

*Figure 4. The state of the art allows us to create fine polycube meshes (**left**), whereas we are trying to create meshes as coarse as possible (**right**).*

This work is done as part of an informal (soon to be formalized) collaboration between our team and CEA. Many simulation codes require block-structured meshes. This requires decomposing the geometric domain into a set of hexahedral blocks, each one being discretized by a regular grid. Our approach to generate such structures is to generate global parameterizations. Those methods give promising results in many cases, but still face many robustness issues. To tackle those issues, we are currently working on a subset of those methods, called Polycube deformation. The idea is to deform our original domain Ω to align its boundary with a regular grid. We start by determining a set of constraints on the boundary of Ω. We then compute a map M that deforms the interior according to those constraints into a polycube. The inverse deformation M^{-1} applied to the polycube produces a structured hexmesh of the domain Ω, refer to Figure 4. While relying on valid boundary constraints, this method is more robust than global parameterizations methods and gives good results on many models. We focus on obtaining coarse block structures, a very challenging problem with many robustness issues. Now we are able to generate as-coarse-as-possible hexahedral meshes (Figure 4, right). We are preparing a publication of these results.

7.3. Roof fitting

This work is done as part of an informal (soon to be formalized) collaboration between our team and RhinoTerrain. We have roof models in the form of surface meshes (Figure 5). Our data are LIDAR point clouds. Based on this data and a roof model chosen by the user, we seek to optimize the position of the model so that it "best" matches the data. This optimization must comply with two constraints:

- It is important to ignore possible outliers in the point cloud, such as parts that do not belong to the roof (trees, electrical wires, *etc.*) or should not be taken into account by the model (chimney, skylight, parabolic antenna, *etc.*);
- The roof geometry is subject to certain constraints, such as the planarity of certain rectangular faces or the alignment of certain axes.

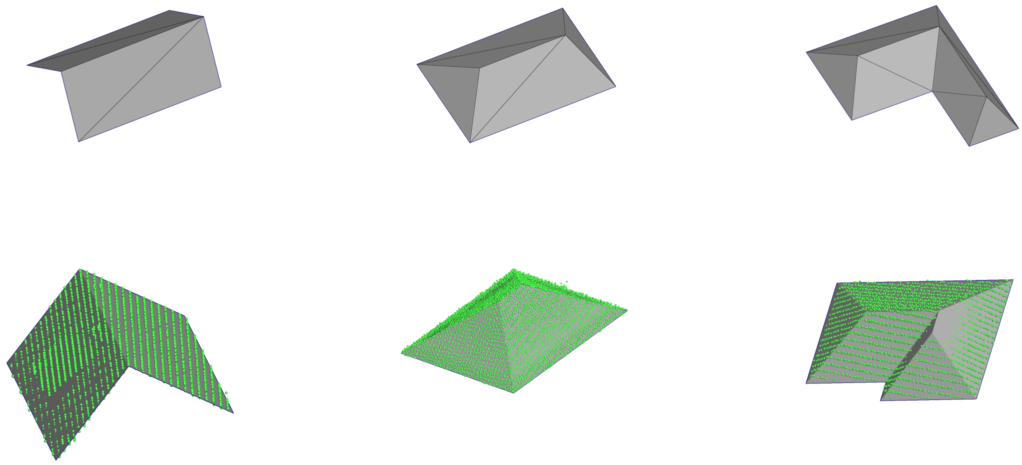

Figure 5. Top row: examples of different roof patterns. Bottom row: fitting of the patterns on LIDAR scans.

This work is an extension of the VSDM algorithm (*Voronoï Squared Distance Minimization*) developed by the team [31]. The idea is to optimize a well-chosen energy function, the overall minimum of which corresponds to the desired position for the mesh size. The preliminary results are very promising, and we are preparing a publication.

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

- *Company:* Polygonal Design
  Duration: 01/02/2018 – 01/08/2020
  Participants: Bruno Lévy and Laurent Alonso
  Amount: 38k euros
  Abstract: The goal of this project is to provide a scientific and technical expertise to Polygonal Design. In particular this concerns the Unfold3d software, developed and marketed by the company. This software is built based on our algorithms developed in 2002–2006.

9. Partnerships and Cooperations

9.1. Regional Initiatives

- We coordinate a work package for the CPER CyberEntreprise 2017–2020 ($\approx$ 30k euros). The application goal is to develop modelling methods, which are of interest to oil companies in order to optimize oil production.
  Program: CPER (Contrat de Plan État Région)
  Project title: Cyber-Entreprises
  Duration: 01/07/2015 – 31/12/2020
  Participants: Bruno Lévy, Dmitry Sokolov and Nicolas Ray
  Coordinator: Emmanuel Thomé and Marc Jungers (CRAN)

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events: Organisation

The team has organized the “2nd Workshop of the Grand-Est in Computer Graphics and Virtual Reality” (50 participants).

10.1.2. Scientific Events: Selection

10.1.2.1. Member of the Conference Program Committees

Members of the team were IPC members for SPM and ISVC.

10.1.2.2. Reviewer

Members of the team were reviewers for Eurographics, SIGGRAPH, SIGGRAPH Asia, ISVC, Pacific Graphics, and SPM.

10.1.3. Journal

10.1.3.1. Reviewer - Reviewing Activities

Members of the team were reviewers for Computer Aided Design (CAD), Journal of Computational Physics (Elsevier), Transactions on Visualization and Computer Graphics (IEEE), Transactions on Graphics (ACM), and Computers & Graphics (Elsevier).

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Licence : Dobrina Boltcheva, Computer Graphics, 30h, 3A, IUT Saint-Dié-des-Vosges

Licence : Dobrina Boltcheva, Advanced Object Oriented Programming & UML, 60h, 2A, IUT SaintDié-des-Vosges

Licence : Dobrina Boltcheva, Advanced algorithmics, 50h, 2A, IUT Saint-Dié-des-Vosges

Licence : Dobrina Boltcheva, Image Processing, 30h, 2A, IUT Saint-Dié-des-Vosges

Licence : Dobrina Boltcheva, UML Modeling, 20h, 1A, IUT Saint-Dié-des-Vosges

Licence : Dobrina Boltcheva, Algorithmics, 30h, 3A, PolyTech Nancy

Licence : Dobrina Boltcheva, Computer Graphics, 12h, 5A, PolyTech Nancy

Licence : Dmitry Sokolov, Computer Graphics, 12h, 5A, PolyTech Nancy

Licence : Dmitry Sokolov, C++, 40h, 2A, University of Lorraine

Licence : Dmitry Sokolov, Programming, 30h, 1A, University of Lorraine

Licence : Dmitry Sokolov, Logic, 30h, 3A, University of Lorraine

Master : Dmitry Sokolov, Logic, 22h, M1, University of Lorraine

Master : Dmitry Sokolov, 3D printing, 12h, M2, University of Lorraine

Master : Dmitry Sokolov, Numerical modeling, 12h, M2, University of Lorraine

10.2.2. Supervision

PhD in progress: Justine Basselin, *“Reconstruction of buildings from 3D point clouds”*, since December 2019, Dmitry Sokolov, Nicolas Ray and Hervé Barthélémy.

PhD in progress: François Protais, *“Polycube-dominant meshing”*, since October 2019, Dmitry Sokolov and Franck Ledoux.

10.2.3. Juries

Dmitry Sokolov participated in the PhD jury of Lucas Morlet as an examinator.

10.3. Popularization

Dmitry Sokolov continues to develop TinyRenderer [0] computer graphics lectures. More than 1M views in 2019, 14k GitHub stars in total.

11. Bibliography

Major publications by the team in recent years

[1] N. RAY, D. SOKOLOV, S. LEFEBVRE, B. LÉVY.*Meshless Voronoi on the GPU*, in "ACM Trans. Graph.", December 2018, vol. 37, n^{o} 6, p. 265:1–265:12, http://doi.acm.org/10.1145/3272127.3275092

[2] N. RAY, D. SOKOLOV, B. LÉVY.*Practical 3D Frame Field Generation*, in "ACM Trans. Graph.", November 2016, vol. 35, n^{o} 6, p. 233:1–233:9, http://doi.acm.org/10.1145/2980179.2982408

[3] N. RAY, D. SOKOLOV.*Robust Polylines Tracing for N-Symmetry Direction Field on Triangulated Surfaces*, in "ACM Trans. Graph.", June 2014, vol. 33, n^{o} 3, p. 30:1–30:11, http://doi.acm.org/10.1145/2602145

[4] D. SOKOLOV, N. RAY, L. UNTEREINER, B. LÉVY.*Hexahedral-Dominant Meshing*, in "ACM Transactions on Graphics", 2016, vol. 35, n^{o} 5, p. 1 - 23 [*DOI :* 10.1145/2930662], https://hal.inria.fr/hal-01397846

Publications of the year

Articles in International Peer-Reviewed Journal

[5] S. ARANOVSKIY, A. BIRYUK, E. NIKULCHEV, I. RYADCHIKOV, D. SOKOLOV.*Observer Design for an Inverted Pendulum with Biased Position Sensors*, in "Izvestia Rossiiskoi Akademii Nauk.Teoriya i Systemy Upravleniya / Journal of Computer and Systems Sciences International", March 2019, vol. 58, n^{o} 2, p. 297-304 [*DOI :* 10.1134/S1064230719020023], https://hal.inria.fr/hal-02282919

[6] S. ARANOVSKIY, R. ORTEGA, J. G. ROMERO, D. SOKOLOV.*A Globally Exponentially Stable Speed Observer for a Class of Mechanical Systems: Experimental and Simulation Comparison with High-Gain and Sliding Mode Designs*, in "International Journal of Control", July 2019, vol. 92, n^{o} 7, p. 1620-1633 [*DOI :* 10.1080/00207179.2017.1404130], https://hal.inria.fr/hal-01658753

[7] J. ETIENNE, N. RAY, D. PANOZZO, S. HORNUS, C. C. WANG, J. MARTÍNEZ, S. MCMAINS, M. ALEXA, B. WYVILL, S. LEFEBVRE.*CurviSlicer: Slightly curved slicing for 3-axis printers*, in "ACM Transactions on Graphics", 2019, vol. 38, forthcoming [*DOI :* 10.1145/3306346.3323022], https://hal.archives-ouvertes.fr/hal-02120033

Conferences without Proceedings

[8] I. RYADCHIKOV, S. ARANOVSKIY, E. NIKULCHEV, J. WANG, D. SOKOLOV.*Differentiator-based velocity observer with sensor bias estimation: an inverted pendulum case study*, in "11th IFAC Symposium on Nonlinear Control Systems", Vienna, Austria, September 2019, https://hal-centralesupelec.archives-ouvertes.fr/hal-02383471

[0] https://github.com/ssloy/tinyrenderer/wiki

Scientific Books (or Scientific Book chapters)

[9] I. RYADCHIKOV, S. SECHENEV, N. MIKHALKOV, A. BIRYUK, A. SVIDLOV, A. GUSEV, D. SOKOLOV, E. NIKULCHEV.*Feedback Control with Equilibrium Revision for CMG-Actuated Inverted Pendulum*, in "Proceedings of 14th International Conference on Electromechanics and Robotics "Zavalishin's Readings"", August 2020, p. 431-440 [*DOI :* 10.1007/978-981-13-9267-2_35], https://hal.inria.fr/hal-02282908

Other Publications

[10] D. SOKOLOV, S. ARANOVSKIY, A. A. GUSEV, I. RYADCHIKOV.*Experimental comparison of velocity estimators for a control moment gyroscope inverted pendulum*, November 2019, working paper or preprint, https://hal.inria.fr/hal-02313600

References in notes

[11] CGAL, *Computational Geometry Algorithms Library*, http://www.cgal.org

[12] *Cloud Compare*, http://www.danielgm.net/cc/release/

[13] *GRAPHITE*, http://alice.loria.fr/software/graphite/doc/html/

[14] *Meshlab*, http://www.meshlab.net/

[15] *MeshMixer*, http://www.meshmixer.com/

[16] *Point Cloud Library*, http://www.pointclouds.org/downloads/

[17] T. C. BAUDOUIN, J. REMACLE, E. MARCHANDISE, F. HENROTTE, C. GEUZAINE.*A frontal approach to hex-dominant mesh generation*, in "Adv. Model. and Simul. in Eng. Sciences", 2014, vol. 1, n^o 1, p. 8:1–8:30, https://doi.org/10.1186/2213-7467-1-8

[18] S. E. BENZLEY, K. ERNEST PERRY, B. C. MERKLEY, G. SJAARDEMA.*A Comparison of All-Hexahedral and All-Tetrahedral Finite Element Meshes for Elastic and Elasto-Plastic Analysis*, in "International Meshing Roundtable conf. proc.", 1995

[19] T. BLACKER.*Meeting the Challenge for Automated Conformal Hexahedral Meshing*, in "9th International Meshing Roundtable", 2000, p. 11–20

[20] Z. DU, M. ZHU, Z. WU, J. YANG.*Measurement uncertainty on the circular features in coordinate measurement system based on the error ellipse and Monte Carlo methods*, in "Measurement Science and Technology", 2016, vol. 27, n^o 12, 125016, http://stacks.iop.org/0957-0233/27/i=12/a=125016

[21] D. EPPSTEIN, M. T. GOODRICH, E. KIM, R. TAMSTORF.*Motorcycle Graphs: Canonical Quad Mesh Partitioning*, in "Proceedings of the Symposium on Geometry Processing", Aire-la-Ville, Switzerland, Switzerland, SGP '08, Eurographics Association, 2008, p. 1477–1486, http://dl.acm.org/citation.cfm?id=1731309.1731334

[22] X. GAO, W. JAKOB, M. TARINI, D. PANOZZO.*Robust Hex-Dominant Mesh Generation using Field-Guided Polyhedral Agglomeration*, in "ACM Transactions on Graphics (Proceedings of SIGGRAPH)", July 2017, vol. 36, n^{o} 4 [*DOI :* 10.1145/3072959.3073676]

[23] P. L. GEORGE, F. HECHT, E. SALTEL.*Fully Automatic Mesh Generator for 3D Domains of Any Shape*, in "IMPACT Comput. Sci. Eng.", December 1990, vol. 2, n^{o} 3, p. 187–218, http://dx.doi.org/10.1016/0899-8248(90)90012-Y

[24] C. GEUZAINE, J.-F. REMACLE.*Gmsh: a three-dimensional finite element mesh generator*, in "International Journal for Numerical Methods in Engineering", 2009, vol. 79, n^{o} 11, p. 1309-1331

[25] Y. ITO, A. M. SHIH, B. K. SONI.*Reliable Isotropic Tetrahedral Mesh Generation Based on an Advancing Front Method*, in "International Meshing Roundtable conf. proc.", 2004

[26] B. LÉVY, S. PETITJEAN, N. RAY, J. MAILLOT.*Least squares conformal maps for automatic texture atlas generation*, in "ACM transactions on graphics (TOG)", ACM, 2002, vol. 21, p. 362–371

[27] B. LÉVY, E. SCHWINDT.*Notions of Optimal Transport theory and how to implement them on a computer*, in "Computer and Graphics", 2018

[28] L. MARÉCHAL.*A New Approach to Octree-Based Hexahedral Meshing*, in "International Meshing Roundtable conf. proc.", 2001

[29] C. MEZIAN, B. VALLET, B. SOHEILIAN, N. PAPARODITIS.*Uncertainty Propagation for Terrestrial Mobile Laser Scanner*, in "SPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences", 2016

[30] M. NIESER, U. REITEBUCH, K. POLTHIER.*CubeCover - Parameterization of 3D Volumes*, in "Computer Graphics Forum", 2011, vol. 30, n^{o} 5, p. 1397-1406, https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1467-8659.2011.02014.x

[31] V. NIVOLIERS, D.-M. YAN, B. LÉVY.*Fitting polynomial surfaces to triangular meshes with Voronoi squared distance minimization*, in "Engineering with Computers", 2014, vol. 30, n^{o} 3, p. 289–300

[32] J.-H. PARK, Y.-D. SHIN, J.-H. BAE, M.-H. BAEG.*Spatial Uncertainty Model for Visual Features Using a Kinect Sensor*, 2012

[33] SCHÖBERL.*NETGEN An advancing front 2D/3D-mesh generator based on abstract rules*, in "Computing and visualization in science", 1997, vol. 1

[34] M. SHEPHARD, M. GEORGES.*Automatic three-dimensional mesh generation by the finite octree technique*, in "International Journal for Numerical Methods in Engineering", 1991, vol. 32

[35] H. SI.*TetGen, a Delaunay-Based Quality Tetrahedral Mesh Generator*, in "ACM Trans. on Mathematical Software", 2015, vol. 41

[36] J. SLOTNICK, A. KHODADOUST, J. ALONSO, D. DARMOFAL, G. WILLIAM, L. ELIZABETH, D. MAVRIPLIS.*CFD Vision 2030 Study: A Path to Revolutionary Computational Aerosciences*, NASA/CR-2014-218178, NF1676L-18332, 2014

[37] S. SOUDARISSANANE, R. LINDENBERGH, M. MENENTI, P. TEUNISSEN.*Scanning geometry: Influencing factor on the quality of terrestrial laser scanning points*, in "ISPRS Journal of Photogrammetry and Remote Sensing", 2011, vol. 66, n^o 4, p. 389 - 399 [*DOI :* 10.1016/J.ISPRSJPRS.2011.01.005], http://www.sciencedirect.com/science/article/pii/S0924271611000098

[38] M. L. STATEN, S. J. OWEN, T. BLACKER.*Unconstrained Paving & Plastering: A New Idea for All Hexahedral Mesh Generation*, in "International Meshing Roundtable conf. proc.", 2005

[39] T. J. TAUTGES, T. BLACKER, S. A. MITCHELL.*The whisker weaving algorithm*, in "International Journal of Numerical Methods in Engineering", 1996

[40] N. P. WEATHERILL, O. HASSAN.*Efficient three-dimensional Delaunay triangulation with automatic point creation and imposed boundary constraints*, in "International Journal for Numerical Methods in Engineering", 1994, vol. 37, n^o 12, p. 2005–2039, http://dx.doi.org/10.1002/nme.1620371203

[41] M. YLIMÄKI, J. KANNALA, J. HEIKKILÄ.*Robust and Practical Depth Map Fusion for Time-of-Flight Cameras*, in "Image Analysis", Cham, P. SHARMA, F. M. BIANCHI (editors), Springer International Publishing, 2017, p. 122–134

[42] Y. ZHANG, C. BAJAJ.*Adaptive and Quality Quadrilateral/Hexahedral Meshing from Volumetric Data*, in "International Meshing Roundtable conf. proc.", 2004

[43] D. ZHENGCHUN, W. ZHAOYONG, Y. JIANGUO.*Point cloud uncertainty analysis for laser radar measurement system based on error ellipsoid model*, in "Optics and Lasers in Engineering", 2016, vol. 79, p. 78 - 84 [*DOI :* 10.1016/J.OPTLASENG.2015.11.010], http://www.sciencedirect.com/science/article/pii/S0143816615002675

Project-Team BIGS

Biology, genetics and statistics

IN COLLABORATION WITH: Institut Elie Cartan de Lorraine (IECL)

IN PARTNERSHIP WITH:
CNRS

Université de Lorraine

RESEARCH CENTER
Nancy - Grand Est

THEME
Computational Biology

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Project-Team BIGS

Creation of the Team: 2009 January 01, updated into Project-Team: 2011 January 01

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1. Team, Visitors, External Collaborators

Research Scientist

Bruno Scherrer [Inria, Researcher, HDR]

Faculty Members

Anne Gégout Petit [Team leader, Univ de Lorraine, Professor, HDR]
Thierry Bastogne [Univ de Lorraine, Associate Professor, HDR]
Sandie Ferrigno [Univ de Lorraine, Associate Professor]
Sophie Mezieres [Univ de Lorraine, Associate Professor]
Jean-Marie Monnez [Univ de Lorraine, Emeritus Professor, HDR]
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Technical Staff

Benoît Lalloué [Univ de Lorraine, Engineer]

PhD Students

Florine Greciet [SAFRAN Aircraft Engines]
Pauline Guyot [Univ de Lorraine, until Nov 2019]
Clémence Karmann [Inria]
Nassim Sahki [Inria]

Post-Doctoral Fellows

Lionel Lenôtre [Univ de Lorraine, until Aug 2019]
Emma Horton [from Dec 2019]

Administrative Assistant

Céline Cordier [Inria]

2. Overall Objectives

2.1. Overall Objectives

BIGS is a joint team of Inria, CNRS and Université Lorraine, via the Institut Élie Cartan, UMR 7502 CNRS-UL laboratory in mathematics, of which Inria is a strong partner. One member of BIGS, T. Bastogne, comes from the Research Center of Automatic Control of Nancy (CRAN), with which BIGS has strong relations in the domain "Health-Biology-Signal". Our research is mainly focused on stochastic modeling and statistics but also aiming at a better understanding of biological systems. BIGS involves applied mathematicians whose research interests mainly concern probability and statistics. More precisely, our attention is directed on (1) stochastic modeling, (2) estimation and control for stochastic processes, (3) algorithms and estimation for graph data and (4) regression and machine learning. The main objective of BIGS is to exploit these skills in applied mathematics to provide a better understanding of issues arising in life sciences, with a special focus on (1) tumor growth, (2) photodynamic therapy, (3) population studies of genomic data and of micro-organisms genomics, (4) epidemiology and e-health.

3. Research Program

3.1. Introduction

We give here the main lines of our research that belongs to the domains of probability and statistics. For clarity, we made the choice to structure them in four items. Although this choice was not arbitrary, the outlines between these items are sometimes fuzzy because each of them deals with modeling and inference and they are all interconnected.

3.2. Stochastic modeling

Our aim is to propose relevant stochastic frameworks for the modeling and the understanding of biological systems. The stochastic processes are particularly suitable for this purpose. Among them, Markov chains give a first framework for the modeling of population of cells [80], [57]. Piecewise deterministic processes are non diffusion processes also frequently used in the biological context [47], [56], [49]. Among Markov model, we developed strong expertise about processes derived from Brownian motion and Stochastic Differential Equations [72], [55]. For instance, knowledge about Brownian or random walk excursions [79], [71] helps to analyse genetic sequences and to develop inference about it. However, nature provides us with many examples of systems such that the observed signal has a given Hölder regularity, which does not correspond to the one we might expect from a system driven by ordinary Brownian motion. This situation is commonly handled by noisy equations driven by Gaussian processes such as fractional Brownian motion of fractional fields. The basic aspects of these differential equations are now well understood, mainly thanks to the so-called rough paths tools [63], but also invoking the Russo-Vallois integration techniques [73]. The specific issue of Volterra equations driven by fractional Brownian motion, which is central for the subdiffusion within proteins problem, is addressed in [48]. Many generalizations (Gaussian or not) of this model have been recently proposed for some Gaussian locally self-similar fields, or for some non-Gaussian models [60], or for anisotropic models [44].

3.3. Estimation and control for stochastic processes

We develop inference about stochastic processes that we use for modeling. Control of stochastic processes is also a way to optimise administration (dose, frequency) of therapy.

There are many estimation techniques for diffusion processes or coefficients of fractional or multifractional Brownian motion according to a set of observations [59], [40], [46]. But, the inference problem for diffusions driven by a fractional Brownian motion is still in its infancy. Our team has a good expertise about inference of the jump rate and the kernel of Piecewise Deterministic Markov Processes (PDMP) [37], [38], [36], [39]. However, there are many directions to go further into. For instance, previous works made the assumption of a complete observation of jumps and mode, that is unrealistic in practice. We tackle the problem of inference of "Hidden PDMP". As an example, in pharmacokinetics modeling inference, we want to take into account for presence of timing noise and identification from longitudinal data. We have expertise on this subjects [41], and we also used mixed models to estimate tumor growth [42].

We consider the control of stochastic processes within the framework of Markov Decision Processes [70] and their generalization known as multi-player stochastic games, with a particular focus on infinite-horizon problems. In this context, we are interested in the complexity analysis of standard algorithms, as well as the proposition and analysis of numerical approximate schemes for large problems in the spirit of [43]. Regarding complexity, a central topic of research is the analysis of the Policy Iteration algorithm, which has made significant progress in the last years [82], [69], [54], [78], but is still not fully understood. For large problems, we have a long experience of sensitivity analysis of approximate dynamic programming algorithms for Markov Decision Processes [76], [75], [77], [62], [74], and we currently investigate whether/how similar ideas may be adapted to multi-player stochastic games.

3.4. Algorithms and estimation for graph data

A graph data structure consists of a set of nodes, together with a set of pairs of these nodes called edges. This type of data is frequently used in biology because they provide a mathematical representation of many concepts such as biological structures and networks of relationships in a population. Some attention has recently been focused in the group on modeling and inference for graph data.

Network inference is the process of making inference about the link between two variables taking into account the information about other variables. [81] gives a very good introduction and many references about network inference and mining. Many methods are available to infer and test edges in Gaussian graphical models [81], [64], [52], [53]. However, when dealing with abundance data, because inflated zero data, we are far from gaussian assumption and we want to develop inference in this case.

Among graphs, trees play a special role because they offer a good model for many biological concepts, from RNA to phylogenetic trees through plant structures. Our research deals with several aspects of tree data. In particular, we work on statistical inference for this type of data under a given stochastic model. We also work on lossy compression of trees via directed acyclic graphs. These methods enable us to compute distances between tree data faster than from the original structures and with a high accuracy.

3.5. Regression and machine learning

Regression models and machine learning aim at inferring statistical links between a variable of interest and covariates. In biological study, it is always important to develop adapted learning methods both in the context of *standard* data and also for data of high dimension (with sometimes few observations) and very massive or online data.

Many methods are available to estimate conditional quantiles and test dependencies [68], [58]. Among them we have developed nonparametric estimation by local analysis via kernel methods [50], [51] and we want to study properties of this estimator in order to derive a measure of risk like confidence band and test. We study also many other regression models like survival analysis, spatio temporal models with covariates. Among the multiple regression models, we want to develop omnibus tests that examine several assumptions together.

Concerning the analysis of high dimensional data, our view on the topic relies on the *French data analysis school*, specifically on Factorial Analysis tools. In this context, stochastic approximation is an essential tool [61], which allows one to approximate eigenvectors in a stepwise manner [67], [65], [66]. BIGS aims at performing accurate classification or clustering by taking advantage of the possibility of updating the information "online" using stochastic approximation algorithms [45]. We focus on several incremental procedures for regression and data analysis like linear and logistic regressions and PCA (Principal Component Analysis).

We also focus on the biological context of high-throughput bioassays in which several hundreds or thousands of biological signals are measured for a posterior analysis. We have to account for the inter-individual variability within the modeling procedure. We aim at developing a new solution based on an ARX (Auto Regressive model with eXternal inputs) model structure using the EM (Expectation-Maximisation) algorithm for the estimation of the model parameters.

4. Application Domains

4.1. Tumor growth-oncology

On this topic, we want to propose branching processes to model appearance of mutations in tumor through new collaborations with clinicians. The observed process is the "circulating DNA" (ctDNA). The final purpose is to use ctDNA as a early biomarker of the resistance to an immunotherapy treatment. It is the aim of the ITMO project. Another topic is the identification of dynamic network of expression. In the ongoing work on low-grade gliomas, a local database of 400 patients will be soon available to construct models. We plan to extend it through national and international collaborations (Montpellier CHU, Montreal CRHUM). Our aim is to build a decision-aid tool for personalised medicine. In the same context, there is a topic of clustering analysis of a brain cartography obtained by sensorial simulations during awake surgery.

4.2. Genomic data and micro-organisms population

Despite of his 'G' in the name of BIGS, Genetics is not central in the applications of the team. However, we want to contribute to a better understanding of the correlations between genes trough their expression data and of the genetic bases of drug response and disease. We have contributed to methods detecting proteomics and transcriptomics variables linked with the outcome of a treatment.

4.3. Epidemiology and e-health

We have many works to do in our ongoing projects in the context of personalized medicine with CHU Nancy. They deal with biomarkers research, prognostic value of quantitative variables and events, scoring, and adverse events. We also want to develop our expertise in rupture detection in a project with APHP (Assistance Publique Hôpitaux de Paris) for the detection of adverse events, earlier than the clinical signs and symptoms. The clinical relevance of predictive analytics is obvious for high-risk patients such as those with solid organ transplantation or severe chronic respiratory disease for instance. The main challenge is the rupture detection in multivariate and heterogeneous signals (for instance daily measures of electrocardiogram, body temperature, spirometry parameters, sleep duration, etc. Other collaborations with clinicians concern foetopathology and we want to use our work on conditional distribution function to explain fetal and child growth. We have data from the "Service de foetopathologie et de placentologie" of the "Maternité Régionale Universitaire" (CHU Nancy).

4.4. Dynamics of telomeres

Telomeres are disposable buffers at the ends of chromosomes which are truncated during cell division; so that, over time, due to each cell division, the telomere ends become shorter. By this way, they are markers of aging. Trough a collaboration with Pr A. Benetos, geriatrician at CHU Nancy, we recently obtained data on the distribution of the length of telomeres from blood cells. With members of Inria team TOSCA, we want to work in three connected directions: (1) refine methodology for the analysis of the available data; (2) propose a dynamical model for the lengths of telomeres and study its mathematical properties (long term behavior, quasi-stationarity, etc.); and (3) use these properties to develop new statistical methods. A slot of postdoc position is already planned in the Lorraine Université d'Excellence, LUE project GEENAGE (managed by CHU Nancy).

5. Highlights of the Year

5.1. Highlights of the Year

5.1.1. Awards

BIGS participated to the organization the JdS 2019 (Journées de Statistique 2019) http://www.jds2019.sfds.asso.fr/ in Nancy.

B. Scherrer and his co-authors received the Outstanding paper award for AAAI-2019“ from the AAAI (Association for the Advancement of Artificial Intelligence.
BEST PAPERS AWARDS :
[9]
Y. EFRONI, G. DALAL, B. SCHERRER, S. MANNOR.*How to Combine Tree-Search Methods in Reinforcement Learning*, in "AAAI 19 - Thirty-Third AAAI Conference on Artificial Intelligence", Honolulu, Hawai, United States, January 2019, https://arxiv.org/abs/1809.01843 - AAAI 2019, https://hal.inria.fr/hal-02273713

6. New Software and Platforms

6.1. Angio-Analytics

KEYWORDS: Health - Cancer - Biomedical imaging

SCIENTIFIC DESCRIPTION: This tool allows the pharmacodynamic characterization of anti-vascular effects in anti-cancer treatments. It uses time series of in vivo images provided by intra-vital microscopy. Such in vivo images are obtained owing to skinfold chambers placed on mice skin. The automatized analysis is split up into two steps that were completely performed separately and manually before. The first steps corresponds to image processing to identify characteristics of the vascular network. The last step is the system identification of the pharmacodynamic response and the statistical analysis of the model parameters.

FUNCTIONAL DESCRIPTION: Angio-Analytics allows the pharmacodynamic characterization of anti-vascular effects in anti-cancer treatments.

- Participant: Thierry Bastogne
- Contact: Thierry Bastogne

6.2. ARMADA

A Statistical Methodology to Select Covariates in High-Dimensional Data under Dependence

KEYWORDS: Biostatistics - Aggregated methods - High Dimensional Data - Personalized medicine - Variable selection

FUNCTIONAL DESCRIPTION: Two steps variable selection procedure in a context of high-dimensional dependent data but few observations. First step is dedicated to eliminate dependence between variables (clustering of variables, followed by factor analysis inside each cluster). Second step is a variable selection using by aggregation of adapted methods. https://hal.archives-ouvertes.fr/hal-02173568

NEWS OF THE YEAR: This package is a new one.

- Participants: Aurélie Muller and Anne Gégout-Petit
- Contact: Aurélie Muller
- Publication: Package 'armada' : A Statistical Methodology to Select Covariates in High-Dimensional Data under Dependence
- URL: https://cran.r-project.org/web/packages/armada/

6.3. kosel

Variable Selection by Revisited Knockoffs Procedures

KEYWORDS: Variable selection - Regression

FUNCTIONAL DESCRIPTION: Performs variable selection for many types of L1-regularised regressions using the revisited knockoffs procedure. This procedure uses a matrix of knockoffs of the covariates independent from the response variable Y. The idea is to determine if a covariate belongs to the model depending on whether it enters the model before or after its knockoff. The procedure suits for a wide range of regressions with various types of response variables. Regression models available are exported from the R packages 'glmnet' and 'ordinalNet'. Based on the paper linked to via the URL below: Gegout A., Gueudin A., Karmann C. (2019) https://arxiv.org/abs/1907.03153

NEWS OF THE YEAR: This package is a new one.

- Participants: Clémence Karmann, Aurélie Muller and Anne Gégout-Petit
- Contact: Aurélie Muller
- Publication: The revisited knockoffs method for variable selection in L_1-penalised regressions.
- URL: https://cran.r-project.org/web/packages/kosel/kosel.pdf

6.4. SesIndexCreatoR

FUNCTIONAL DESCRIPTION: This package allows computing and visualizing socioeconomic indices and categories distributions from datasets of socioeconomic variables (These tools were developed as part of the EquitArea Project, a public health program).

- Participants: Benoît Lalloué, Jean-Marie Monnez, Nolwenn Le Meur and Severine Deguen
- Contact: Benoît Lalloué
- URL: http://www.equitarea.org/documents/packages_1.0-0/

6.5. In silico

In silico design of nanoparticles for the treatment of cancers by enhanced radiotherapy

KEYWORDS: Bioinformatics - Cancer - Drug development

FUNCTIONAL DESCRIPTION: To speed up the preclinical development of medical engineered nanomaterials, we have designed an integrated computing platform dedicated to the virtual screening of nanostructured materials activated by X-ray making it possible to select nano-objects presenting interesting medical properties faster. The main advantage of this in silico design approach is to virtually screen a lot of possible formulations and to rapidly select the most promising ones. The platform can currently handle the accelerated design of radiation therapy enhancing nanoparticles and medical imaging nano-sized contrast agents as well as the comparison between nano-objects and the optimization of existing materials.

- Participant: Thierry Bastogne
- Contact: Thierry Bastogne

6.6. HSPOR

Hidden Smooth Polynomial Regression for Rupture Detection

KEYWORDS: Polynomial regression - Rupture detection

FUNCTIONAL DESCRIPTION: Several functions that allow by different methods to infer a piecewise polynomial regression model under regularity constraints, namely continuity or differentiability of the link function. The implemented functions are either specific to data with two regimes, or generic for any number of regimes, which can be given by the user or learned by the algorithm.

NEWS OF THE YEAR: This package is a new one

- Participants: Florine Greciet, Romain Azais and Anne Gégout-Petit
- Contact: Florine Greciet
- URL: https://cran.r-project.org/web/packages/HSPOR/

7. New Results

7.1. Stochastic modelling

Participants: A. Gégout-Petit, S. Mézières, P. Vallois

In the framework of the esca-illness of vines, we developed different spatial models and spatio-temporal models for different purposes: (1) study the distribution and the dynamics of esca vines in order to tackle the aggregation and the potential spread of the illness (2) propose a spatio-temporal model in order to capture the dynamics of cases and measure the effects of environmental covariates. For purpose (2), we developed an autologistic model (centered in a new way), have proposed estimators of the parameters and showed their properties and proposed a way to choose between several neighborhood models. These results were published in Spatial Statistics [4].

In a collaboration with physicists from Nancy CHRU, we have worked about the interest to use the whole distribution of telomeres lengths until the mean that is usually used to characterise ageing of a cell. We have shown that the shape of the distribution can be seen as a individuals's signature. It is the object of the paper published in Scientific Reports [8].

After preliminary suggestions on the building of models for low-grade gliomas [3], we focused our attention on the diffuse character of such tumors. We characterized the infiltrating phenotype (infiltration rate, direction of infiltration, evolution of morphology over time) as a new variable to consider in a context of multifactorial modelling (submitted article). A monocentric retrospective study has been conducted on the local database, estimating survival paramaters and comparing the effects of treatments (writing article). A brain cartography obtained by sensorial simulations during awake surgery with the aid of clustering analysis has been published in “Brain - A Journal of Neurology” [6].

7.2. Optimal Control of Markov Processes

Participants: B. Scherrer

Finite-horizon lookahead policies are abundantly used in Reinforcement Learning and demonstrate impressive empirical success. Usually, the lookahead policies are implemented with specific planning methods such as Monte Carlo Tree Search (e.g. in AlphaZero). Referring to the planning problem as tree search, a reasonable practice in these implementations is to back up the value only at the leaves while the information obtained at the root is not leveraged other than for updating the policy. Here, we question the potency of this approach. Namely, the latter procedure is non-contractive in general, and its convergence is not guaranteed. Our proposed enhancement, in [9], published in AAAI'2019, is straightforward and simple: use the return from the optimal tree path to back up the values at the descendants of the root. This leads to a γ^h-contracting procedure, where γ is the discount factor and h is the tree depth. To establish our results, we first introduce a notion called *multiple-step greedy consistency*. We then provide convergence rates for two algorithmic instantiations of the above enhancement in the presence of noise injected to both the tree search stage and value estimation stage.

Value iteration is a method to generate optimal control inputs for generic nonlinear systems and cost functions. Its implementation typically leads to approximation errors, which may have a major impact on the closed-loop system performance. We talk in this case of approximate value iteration (AVI). In [24], published in CDC'2019, we investigate the stability of systems for which the inputs are obtained by AVI. We consider deterministic discrete-time nonlinear plants and a class of general, possibly discounted, costs. We model the closed-loop system as a family of systems parameterized by tunable parameters, which are used for the approximation of the value function at different iterations, the discount factor and the iteration step at which we stop running the algorithm. It is shown, under natural stabilizability and detectability properties as well as mild conditions on the approximation errors, that the family of closed-loop systems exhibit local practical stability properties. The analysis is based on the construction of a Lyapunov function given by the sum of the approximate value function and the Lyapunov-like function that characterizes the detectability of the system. By strengthening our conditions, asymptotic and exponential stability properties are guaranteed.

Many recent successful (deep) reinforcement learning algorithms make use of regularization, generally based on entropy or Kullback-Leibler divergence. In [10], published in ICML'2019, we propose a general theory of regularized Markov Decision Processes that generalizes these approaches in two directions: we consider a larger class of regularizers, and we consider the general modified policy iteration approach, encompassing both policy iteration and value iteration. The core building blocks of this theory are a notion of regularized Bellman operator and the Legendre-Fenchel transform, a classical tool of convex optimization. This approach allows for error propagation analyses of general algorithmic schemes of which (possibly variants of) classical algorithms such as Trust Region Policy Optimization, Soft Q-learning, Stochastic Actor Critic or Dynamic Policy Programming are special cases. This also draws connections to proximal convex optimization, especially to Mirror Descent.

7.3. Algorithms and Estimation for graph data

Participants: A. Gégout-Petit, A. Gueudin, C. Karmann

We consider the problem of graph estimation in a zero-inflated Gaussian model. In this model, zero-inflation is obtained by double truncation (right and left) of a Gaussian vector. The goal is to recover the latent graph structure of the Gaussian vector with observations of the zero-inflated truncated vector. We propose a two step estimation procedure. The first step consists in estimating each term of the covariance matrix by maximising the corresponding bivariate marginal log-likelihood of the truncated vector. The second one uses the graphical lasso procedure to estimate the sparsity of the precision matrix, which encodes the graph structure. We then state some theoretical results about the convergence rate of the covariance matrix and precision matrix estimators. These results allow us to establish consistency of our procedure with respect to graph structure recovery. We also present some simulation studies to corroborate the efficiency of our procedure. It is the object of the submitted paper [29], a part of the PhD thesis [1] and the communications [16] [15].

7.4. Regression and machine learning

Participants: E. Albuisson, T. Bastogne, S. Ferrigno, A. Gégout-Petit, F. Greciet, P. Guyot, C. Karmann, J.-M. Monnez, N. Sahki, S. Mézières, B. Lalloué

Through a collaboration with the pharmaceutical company Transgene (Strasbourg, France), we have developed a method for selecting covariates. The problem posed by Transgene was to establish patient profiles on the basis of their response to a treatment developed by Transgene. We have then proposed a new methodology for selecting and ranking covariates associated with a variable of interest in a context of high-dimensional data under dependence but few observations. The methodology successively intertwines the clustering of covariates, decorrelation of covariates using Factor Latent Analysis, selection using aggregation of adapted methods and finally ranking. A simulation study shows the interest of the decorrelation inside the different clusters of covariates. We have applied our method to the data of Transgene. For instance, transcriptomic data of 37 patients with advanced non-small-cell lung cancer who have received chemotherapy, to select the transcriptomic covariates that explain the survival outcome of the treatment. Our method has also been applied in another collaboration with biologists (CRAN laboratory, Nancy, France). In that case, our method has been applied to transcriptomic data of 79 breast tumor samples, to define patient profiles for a new metastatic biomarker and associated gene network. Our developed method is a contribution to the development of personalized medicine. We have published the method, as well as the two applications in [27].

In order to detect change of health state for lung-transplanted patient, we have begun to work on breakdowns in multivariate physiological signals. We consider the score-based CUSUM statistic and propose to evaluate the detection performance of some thresholds on simulation data. Two thresholds come from the literature: Wald's constant and Margavio's instantaneous threshold, and three contribution thresholds built by a simulation-based procedure: the first one is constant, the second instantaneous and the third is a dynamical version of the previous one. The threshold's performance is evaluated for several scenarii, according to the detection objective and the real change in the data. The simulation results show that Margavio's threshold is the best at minimizing the detection delay while maintaining the given false alarm rate. But on real data, we suggest to use the dynamic instantaneous threshold because it is the easiest to build for practical implementation. It is the purpose of the communication [11] and the submitted paper [35].

We consider the problem of variable selection in regression models. In particular, we are interested in selecting explanatory covariates linked with the response variable and we want to determine which covariates are relevant, that is which covariates are involved in the model. In this framework, we deal with L1-penalised regression models. To handle the choice of the penalty parameter to perform variable selection, we develop a new method based on knockoffs. This revisited knockoffs method is general, suitable for a wide range of regressions with various types of response variables. Besides, it also works when the number of observations is smaller than the number of covariates and gives an order of importance of the covariates. Finally, we provide many experimental results to corroborate our method and compare it with other variable selection methods. It is the object of communication [17], the submitted paper [30] and a chapter of the PhD thesis [1].

In order to model crack propagation rate, continuous physical phenomenon that presents several regimes, we proposed a piecewise polynomial regression model under continuity and/or derivability assumptions as well as a statistical inference method to estimate the transition times and the parameters of each regime. We proposed several algorithms and studied their efficiency. The most efficient algorithm relies on dynamic programming. It is the object of the communication [14] and the PhD thesis of Florine Greciet.

Let consider a regression model $Y = m(X) + \sigma(X)\varepsilon$ to explain Y from X, where $m(\cdot)$ is the regression function, $\sigma^2(\cdot)$ the variance function and ε the random error term. Methods to assess how well a model fits a set of observations fall under the banner of goodness-of-fit tests. Many tests have been developed to assess the different assumptions for this kind of model. Most of them are "directional" in that they detect departures from mainly a given assumption of the model. Other tests are "global" in that they assess whether a model fits a data set on all its assumptions. We focus on the task of choosing the structural part $m(\cdot)$. It gets most attention because it contains easily interpretable information about the relationship between X and Y. To validate the form of the regression function, we consider three nonparametric tests based on a generalization of the Cramér-von Mises statistic. The first two are directional tests, while the third is a global test. To perform these goodness-of-fit tests based on a generalization of the Cramér-von Mises statistic, we have used Wild bootstrap methods and we also proposed a method to choose the bandwidth parameter used in nonparametric estimations. Then, we have developed the cvmgof R package, an easy-to-use tool for many users. The use of the package is described and illustrated using simulations to compare the three implemented tests in a paper in progress.

In epidemiology, we are working with INSERM clinicians and biostatisticians to study fetal development in the last two trimesters of pregnancy. Reference or standard curves are required in this kind of biomedical problems. Values which lie outside the limits of these reference curves may indicated the presence of disorder. Data are from the French EDEN mother-child cohort (INSERM). It is a mother-child cohort study investigating the prenatal and early postnatal determinants of child health and development. 2002 pregnant women were recruited before 24 weeks of amenorrhoea in two maternity clinics from middle-sized French cities (Nancy and Poitiers). From May 2003 to September 2006, 1899 newborns were then included. The main outcomes of interest are fetal (via ultra-sound) and postnatal growth, adiposity development, respiratory health, atopy, behaviour and bone, cognitive and motor development. We are studying fetal weight that depends on the gestional age in the second and the third trimesters of mother's pregnancy. Some classical empirical and parametric methods as polynomials are first used to construct these curves. Polynomial regression is one of the most common parametric approach for modelling growth data espacially during the prenatal period. However, some of them require strong assumptions. So, we propose to work with semi-parametric LMS method, by modifying the response variable (fetal weight) with a Box-cox transformation. Nonparametric methods as Nadaraya-Watson kernel estimation or local polynomial estimation are also proposed to construct these curves. It is the object of the communication [28] and a paper is in progress. In addition, we want to develop a test, based on Z-scores, to detect any slope breaks in the fetal development curves (work in progress).

Many articles were devoted to the problem of recursively estimating eigenvectors corresponding to eigenvalues in decreasing order of the expectation of a random matrix using an i.i.d. sample of it. The present study makes the following contributions: the convergence of processes to normed eigenvectors is proved under two sets of more general assumptions, the observed random matrices are no more supposed i.i.d.; moreover, the scope of these processes is widened. The application to online principal component analysis of a data stream is treated, assuming that data are realizations of a random vector Z whose expectation is unknown and is estimated online, as well as possibly the metric used when it depends on unknown characteristics of Z; two types of processes are studied: we are no more bound to use a data mini-batch at each step, but we can use all previously observed data up to the current step without storing them, thus taking into account all the information contained in previous data. The conducted experiments have shown that processes of the second type are faster than those of the first type. It is the object of the submitted paper [32] and the communication [21].

The study addresses the problem of constrained binary logistic regression, particularly in the case of a data stream, using a stochastic approximation process. To avoid a numerical explosion which can be encountered, we propose to use a process with online standardized data instead of raw data. This type of process can also be used when we have to standardize the explanatory variables, for example in the case of a shrinkage method such as LASSO. Herein, we define and study the almost sure convergence of an averaged constrained stochastic gradient process with online standardized data. Moreover we propose to use a piecewise constant step-size in order that the step-size does not decrease too quickly and reduce the speed of convergence. Processes of this type are compared to classical processes on real and simulated datasets. The results of conducted experiments confirm the validity of the choices made. This will be used in an ongoing application to online updating of a score in heart failure patients. It is the object of the submitted paper [31] and the communications [20],[19].

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

Bruno Scherrer has done some consulting for EDF. This was a skill transfer activity involving training and consulting on the theory and algorithms for reinforcement learning, for the Research & Development team of EDF lead by Lorenzo Audibert. This R&D team wants to apply reinforcement learning to several EDF problems: optimizing maintenance of uranium rods in the cores of nuclear power plants, optimization of load profiles for a network of electric vehicles. Bruno Scherrer's role was to give them the basics of reinforcement learning theory, and help them to use the algorithms of the literature. It was a one-shot action, running in 2018 and 2019, and contractualized via a "framework agreement" Inria-EDF. This contract brings in approximately 12,000 euros to BIGS team (among which 2,000 for mission expenses).

R. Azaïs, A. Gégout-Petit, F. Greciet collaborated with SAFRAN Aircraft Engines (through a 2016-2019 contract). SAFRAN Aircraft Engines designs and products aircraft engines. For the design of pieces, they have to understand the mechanism of crack propagation under different conditions. BIGS models crack propagation with Piecewise Deterministic Markov Processes (PDMP).

9. Partnerships and Cooperations

9.1. Regional Initiatives

- Lorraine Université d'Excellence LUE, Impact Project GEENAGE (Functional **G**enomic, **E**pigenomic and **EN**vironment interplay to imptact the understanding, diagnosis and management of healthy and pathological **AGE**ing). Anne Gégout-Petit, Lionel Lenôtre, Emma Horton.

9.2. National Initiatives

- FHU CARTAGE (Fédération Hospitalo Universitaire Cardial and ARTerial AGEing ; leader : Pr Athanase Benetos), Jean-Marie Monnez, Benoît Lalloué, Anne Gégout-Petit.
- RHU Fight HF (Fighting Heart Failure ; leader : Pr Patrick Rossignol), located at the University Hospital of Nancy, Jean-Marie Monnez, Benoît Lalloué.
- Project "Handle your heart", team responsible for the creation of a drug prescription support software for the treatment of heart failure, head: Jean-Marie Monnez
- A. Gégout-Petit, N. Sahki, S. Mézières are involved in the learning aspect of the clinical protocol "EOLEVAL" with Assistance Publique des Hopitaux de Paris (APHP)
- "ITMO Physics, mathematics applied to Cancer" (2017-2019): "Modeling ctDNA dynamics for detecting targeted therapy", Funding organisms: ITMO Cancer, ITMO Technologies pour la santé de l'alliance nationale pour les sciences de la vie et de la santé (AVIESAN), INCa, Leader: N. Champagnat (Inria TOSCA), Participants: A. Gégout-Petit, A. Muller-Gueudin, P. Vallois.
- PEPS AMIES (2019-2020), Etude Biométrique en foetopathologie et développement de l'enfant, Collaboration between Institut Elie Cartan and the CRESS INSERM, S. Ferrigno.
- Modular, multivalent and multiplexed tools for dual molecular imaging (2017-2020), Funding organism: ANR, Leader: B Kuhnast (CEA). Participant: T. Bastogne.
- Sophie Mézières belongs to GDR 720 ISIS, Funding organism: CNRS, leader: Laure Blanc-Féraud.

9.3. International Research Visitors

9.3.1. Visits of International Scientists

Juhyun Park from Bath University spent a week in Nancy in June 2019 to work on tests for paired distributions in the framework of functional analysis with Anne Gégout-Petit.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events: Organisation

10.1.1.1. Member of the Organizing Committees

- Sandie Ferrigno, Anne Gégout-Petit, Clémence Karmann, Aurélie Muller-Gueudin, Nassim Sahki,Bruno Scherrer and Sophie Wantz-Mézières were very active members of the organizing committee of the "Journées de Statistique de la SFdS" at FST in Nancy, June 2019.
- Anne Gégout-Petit, Aurélie Muller-Gueudin, and Pierre Vallois were in the organizing committee of the workshop "Modélisation de l'hétérogénéité tumorale et thérapies ciblées" at FST in Nancy, September 2019.
- Sophie Wantz-Mézières was part of the organizing committee of the national workshop of the "Fédération Charles Hermite": "Sécurité et confiance dans les échanges des données de santé", at the "Ecole de Chirugie" in Nancy, November 2019.

10.1.2. Scientific Events: Selection

10.1.2.1. Chair of Conference Program Committees

A. Gégout-Petit was ETC program coordinator of the European Meeting of Statisticians, Palermo, July 2019.

10.1.2.2. Member of the Conference Program Committees

A. Gégout-Petit was part of the program committee of the CFIES (Colloque francophone international sur l'enseignement de la statistique), Strasbourg, Septembre 2019.

10.1.3. Journal

10.1.3.1. Reviewer - Reviewing Activities

All BIGS members are regular reviewers for journals in probability, statistics and machine learning: Bernoulli, Scandinavian Journal of statistics, Stochastics, Journal of Statistical Planning Inference, Journal of theoretical Biology, IEEE Trans. Biomedical Eng., Theoretical Biology and Medical Modelling, Royal Society of Chemistry, Signal Processing: Image Communication, Mathematical Biosciences, LIDA, Annals of Applied Probability, Annals of Operations Research and Journal of Machine Learning Research, as well as conferences such as ICML, World IFAC Congress, FOSBE, ALCOSP...

10.1.4. Invited Talks

- Talk "Agrégation de méthodes statistiques pour la sélection de variables corrélées et en grande dimension". Séminaire AgroParisTech, Paris, May 2019, Aurélie Muller-Gueudin.
- Talk "Modélisation de réseaux de régulation de gènes par processus déterministes par morceaux". Journée de la Fédération Charles Hermite, Nancy, June 2019, Aurélie Muller-Gueudin.

10.1.5. Research Administration

Anne Gégout-Petit is member of "Bureau du comité des projets", centre Inria Nancy Grand-Est.

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

B. Scherrer excepted, BIGS members have teaching obligations at "Université Lorraine" and are teaching at least 192 hours each year. They teach probability and statistics at different levels (Licence, Master, Engineering school). Many of them have pedagogical responsibilities.

- A. Gégout-Petit : Head of the Master 2 "Ingénierie Mathématique et Outils Informatiques (Mathematical Engineering and Computer Tools)", Université de Lorraine
- A. Gégout-Petit created and is now in charge of cursus CMI in applied mathematics for Lorraine University
- T. Bastogne is in charge of the spécialité Systèmes & TIC du master Ingénierie de Systèmes Complexes
- T. Bastogne is in charge of professional master: CIIBLE (Cybernétique, Instrumentation, Image en Biologie et medecinE) en M2 with Medicine Faculty of Université de Lorraine
- T. Bastogne is in charge research master "Biosanté Numérique" with engineering school "Telecom Nancy"
- Master: S. Ferrigno, Experimental designs, 4.5h, M1, fourth year of EEIGM, Université de Lorraine, France
- Master: S. Ferrigno, Data analyzing and mining, 63h, M2, third year of Ecole des Mines, Université de Lorraine, France
- Master: S.Ferrigno, Modeling and forecasting, 43h, M1, second year of Ecole des Mines, Université de Lorraine, France
- Master: S.Ferrigno, Training projects, 18h, M1/M2, second and third year of Ecole des Mines, Université de Lorraine, France
- Master: A. Muller-Gueudin, Probability and Statistics, 160h, second year of ENSEM and ENSAIA, University of Lorraine, France.
- Master: A. Muller-Gueudin, Scientific calculation with Matlab, 20h, second year of ENSAIA, University of Lorraine, France.
- Master: A.Gégout-Petit, Statistics, modeling, 15h, future teacher, Université de Lorraine, France
- Master: A.Gégout-Petit, Statistics, modeling, data analysis, 80h, master in applied mathematics, Université de Lorraine, France
- Licence: S. Wantz-Mézières, Applied mathematics for management, financial mathematics, Probability and Statistics, 160h, I.U.T. (L1/L2/L3)
- Licence: S. Wantz-Mézières, Probability, 100h, first year in Telecom Nancy engineering school (initial and apprenticeship cursus)
- Licence: A. Muller-Gueudin, Statistics, 60h, first year of ENSAIA, University of Lorraine, France.
- Licence: S. Ferrigno, Descriptive and inferential statistics, 60h, L2, second year of EEIGM, Université de Lorraine, France
- Licence: S. Ferrigno, Statistical modeling, 60h, L2, second year of EEIGM, Université de Lorraine, France
- Licence: S. Ferrigno, Mathematical and computational tools, 20h, L3, third year of EEIGM, Université de Lorraine, France
- Licence: S. Ferrigno, Training projects, 20h, L1/L3, first, second and third year of EEIGM, Université de Lorraine, France

10.2.2. Supervision

- PhD : Clémence Karmann, "Network inference for zero-inflated models", Grant : Inria-Cordis. Advisors: A. Gégout-Petit, A. Muller-Gueudin, Université de Lorraine, defended on November 25, 2019.
- PhD : Florine Greciet, "Modèles markoviens déterministes par morceaux cachés pour la propagation de fissures", grant CIFRE SAFRAN AIRCRAFT ENGINES, Advisors : R. Azaïs, A. Gégout-Petit, Université de Lorraine, defense on January, 2020.
- PhD : Kévin Duarte, "Aide à la décision médicale et télémédecine dans le suivi de l'insuffisance cardiaque", Advisors : J.-M. Monnez and E. Albuisson.
- PhD : Pauline Guyot, "Modélisation et Simulation de l'Electrocardiogramme d'un Patient Numérique", Grant : CIFRE-Cybernano. Advisors: T. Bastogne, E. H. Djermoune.
- PhD: Nassim Shaki, "Détection de rupture dans des signaux multivariés pour la prédiction d'événement redouté à partir de paramètres physiologiques recueillis par capteurs connectés après greffe pulmonaire", grant Inria-Cordis. Advisors: A. Gégout-Petit, S. Mézières, M. d'Ortho.
- Benoît Lalloué, contract research engineer for two years, RHU Fight RF, supervised by Jean-Marie Monnez.
- Postdoc: Lionel Lenôtre, Telomer Modelling, grant LUE GEENAGE. Advisors: A. Gégout-Petit, D. Villemonais.
- Postdoc: Emma Horton, Telomer Modelling, grant LUE GEENAGE. Advisors: A. Gégout-Petit, D. Villemonais.
- Master: all BIGS members regularly supervise project and internship of master IMOI students.
- Engineering school: all BIGS members regularly supervise project of "Ecole des Mines ", ENSEM or EEIGM students.

10.2.3. Juries

- Anne Gégout-Petit participated to the jury of the Phd defense of Edouard Fournier, Paul Sabatier University, Toulouse, October 8th
- Anne Gégout-Petit participated to the jury of the HDR defense of Denis Villemonais, Lorraine Université, November 18th
- Anne Gégout-Petit was reviewer and participated to the jury of the Phd defense of Candy Abboud, INRA d'Avignon, Université d'Aix-MArseille, December 11th.
- Anne Gégout-Petit participated to the jury of the HDR defense of Adrien Coulet, Lorraine Université, December 16th.
- Anne Gégout-Petit is member of the "Jury du prix de thèse AMIES".

10.3. Popularization

10.3.1. Interventions

- Anne Gégout-Petit participated in a round table on Artificial Intelligence and Health as part of "La fête de la science" 2019
- Anne Gégout-Petit participated at the "Brunch Données de santé et thermalisme" Janvier 2019
- Sandie Ferrigno: Advisor of a group of students (EEIGM), "La main à la Pâte" project, elementary schools, Nancy, January-June 2019
- Sandie Ferrigno: Advisor of a group of students (EEIGM), "Energies renouvelables", "La main à la Pâte" project, Institut médico-éducatif (IME), Commercy, October 2019-January 2020
- Sandie Ferrigno: Advisor of a group of students (EEIGM), "L'Astronomie" Cgénial project, Collège Paul Verlaine, Malzéville, November 2019-February 2020.

- Sandie Ferrigno: Advisor of a group of students (EEIGM), "Le Chocolat" Cgénial project, Collège de la Craffe, Nancy, November 2019-January 2020.
- Sophie Wantz-Mézières was part of the organization of a thematic and multidisciplinary week "Neurosciences, neuro-oncologie et numérique", for students from Telecom-Nancy and Faculté de Médecine de Nancy, May 2019.

11. Bibliography

Publications of the year

Doctoral Dissertations and Habilitation Theses

[1] C. KARMANN.*Network inference for zero-inflated models*, Université de Lorraine (Nancy), November 2019, https://hal.archives-ouvertes.fr/tel-02384511

Articles in International Peer-Reviewed Journal

[2] J.-B. BARBRY, A.-S. POINSARD, T. BASTOGNE, O. BALLAND.*Short-term effects of ocular 2% dorzolamide, 0.5% timolol or 0.005% latanoprost on the anterior segment architecture in healthy cats: a prospective study*, in "Open Veterinary Journal", 2020, forthcoming, https://hal.archives-ouvertes.fr/hal-02396549

[3] M. BEN ABDALLAH, M. BLONSKI, S. WANTZ-MÉZIÈRES, Y. GAUDEAU, L. TAILLANDIER, J.-M. MOUREAUX, A. DARLIX, N. MENJOT DE CHAMPFLEUR, H. DUFFAU.*Data-driven predictive models of diffuse low-grade gliomas under chemotherapy*, in "IEEE Journal of Biomedical and Health Informatics", January 2019, vol. 23, n^o 1, p. 38-46 [*DOI :* 10.1109/JBHI.2018.2834159], https://hal.archives-ouvertes.fr/hal-02097695

[4] A. GÉGOUT-PETIT, L. GUÉRIN-DUBRANA, S. LI.*A new centered spatio-temporal autologisticregression model with an application to local spread of plant diseases*, in "Spatial Statistics", May 2019, n^o 31, https://arxiv.org/abs/1811.06782 , https://hal.inria.fr/hal-01926115

[5] A. LEJAY, L. LENÔTRE, G. PICHOT.*An exponential timestepping algorithm for diffusion with discontinuous coefficients*, in "Journal of Computational Physics", November 2019, vol. 396, p. 888-904 [*DOI :* 10.1016/J.JCP.2019.07.013], https://hal.inria.fr/hal-01806465

[6] F. RECH, G. HERBET, Y. GAUDEAU, S. WANTZ-MÉZIÈRES, J.-M. MOUREAUX, S. MORITZ-GASSER, H. DUFFAU.*A probabilistic map of negative motor areas of the upper limb and face: a brain stimulation study*, in "Brain - A Journal of Neurology ", April 2019, vol. 142, n^o 4, p. 952-965 [*DOI :* 10.1093/BRAIN/AWZ021], https://hal.archives-ouvertes.fr/hal-02314548

[7] A. TACCOEN, C. C. PIEDALLU, I. SEYNAVE, V. V. PEREZ, A. GÉGOUT-PETIT, L.-M. NAGELEISEN, J.-D. BONTEMPS, J.-C. GÉGOUT.*Background mortality drivers of European tree species: climate change matters*, in "Proceedings of the Royal Society B: Biological Sciences", April 2019, vol. 286, n^o 1900, 20190386 [*DOI :* 10.1098/RSPB.2019.0386], https://hal.archives-ouvertes.fr/hal-02095574

[8] S. TOUPANCE, D. VILLEMONAIS, D. GERMAIN, A. GÉGOUT-PETIT, E. ALBUISSON, A. BENETOS.*The individual's signature of telomere length distribution*, in "Scientific Reports", January 2019, vol. 9, n^o 1, 8 [*DOI :* 10.1038/S41598-018-36756-8], https://hal.inria.fr/hal-01925000

International Conferences with Proceedings

[9] *Best Paper*
Y. EFRONI, G. DALAL, B. SCHERRER, S. MANNOR.*How to Combine Tree-Search Methods in Reinforcement Learning*, in "AAAI 19 - Thirty-Third AAAI Conference on Artificial Intelligence", Honolulu, Hawai, United States, January 2019, https://arxiv.org/abs/1809.01843 - AAAI 2019, https://hal.inria.fr/hal-02273713.

[10] M. GEIST, B. SCHERRER, O. PIETQUIN.*A Theory of Regularized Markov Decision Processes*, in "ICML 2019 - Thirty-sixth International Conference on Machine Learning", Long Island, United States, June 2019, https://arxiv.org/abs/1901.11275 - ICML 2019, https://hal.inria.fr/hal-02273741

[11] N. SAHKI, A. GÉGOUT-PETIT, S. WANTZ-MÉZIÈRES.*Détection Statistique de Rupture dans le Cadre Online*, in "JdS 2019 - 51èmes Journées de Statistique", Nancy, France, June 2019, https://hal.inria.fr/hal-02289680

Conferences without Proceedings

[12] B. BASTIEN, A. GÉGOUT-PETIT, A. MULLER-GUEUDIN.*Aggregation of statistical methods for the selection of correlated and high dimensional variables*, in "Séminaire AgroParisTech", Paris, France, May 2019, https://hal.archives-ouvertes.fr/hal-02360968

[13] J. DELEFORTERIE, Y. KOLASA, L. BATISTA, J. HUTIN, T. BASTOGNE.*Quality-by-Design for the safe development of medical devices containing nanomaterials. A study case in photodynamic therapy*, in "NanoMed Europe, NME 2019", Braga, Portugal, June 2019, Présentation Poster, https://hal.archives-ouvertes.fr/hal-02396520

[14] F. GRECIET, R. AZAÏS, A. GÉGOUT-PETIT.*Régression polynomiale par morceaux sous contrainte de régularité pour la propagation de fissures*, in "JdS 2019 - 51èmes Journées de Statistique", Nancy, France, June 2019, p. 1-5, https://hal.archives-ouvertes.fr/hal-02172747

[15] A. GÉGOUT-PETIT, A. GUEUDIN, C. KARMANN.*Network inference for truncated gaussian data*, in "European Meeting of Statisticians", Palermo, Italy, July 2019, https://hal.archives-ouvertes.fr/hal-02369239

[16] C. KARMANN, A. GÉGOUT-PETIT, A. MULLER-GUEUDIN.*Inférence de réseaux pour des données gaussiennes inflatées en zéros par double troncature*, in "Journées de statistique 2019", Nancy, France, June 2019, https://hal.archives-ouvertes.fr/hal-02335105

[17] C. KARMANN, A. GÉGOUT-PETIT, A. MULLER-GUEUDIN.*Méthode des knockoffs revisités pour la sélection de variables. Application à l'inférence de réseaux pour modèles inflatés en zéro*, in "Journées NETBIO Saclay", Saclay, France, October 2019, https://hal.archives-ouvertes.fr/hal-02354748

[18] C. KARMANN, A. GÉGOUT-PETIT, A. MULLER-GUEUDIN.*Penalized ordinal logistic regression using cumulative logits*, in "Journée scientifique FCH : "Méthodes et modèles pour comprendre les réseaux biologiques"", Nancy, France, 2019, https://hal.archives-ouvertes.fr/hal-02354731

[19] B. LALLOUÉ, J.-M. MONNEZ, E. ALBUISSON.*Actualisation en ligne d'un score d'ensemble*, in "51e Journées de Statistique", Nancy, France, Société Française de Statistique, June 2019, https://hal.archives-ouvertes.fr/hal-02152352

[20] B. LALLOUÉ, J.-M. MONNEZ, E. ALBUISSON.*Streaming constrained binary logistic regression with online standardized data*, in "SFC 2019 - 26émes Rencontres de la Société Francophone de Classification", Nancy, France, September 2019, https://hal.archives-ouvertes.fr/hal-02278090

[21] J.-M. MONNEZ.*Convergence du processus de Oja et ACP en ligne*, in "51èmes Journées de Statistique, Nancy, 2019", NANCY, France, Efoevi Koudou, June 2019, https://hal.archives-ouvertes.fr/hal-02383570

[22] A. MULLER-GUEUDIN, A. DEBUSSCHE, A. CRUDU.*Modeling of gene regulation networks by deterministic processes by pieces*, in "Journée de la Fédération Charles Hermite", Vandoeuvre-les-Nancy, France, June 2019, p. 1-37, https://hal.archives-ouvertes.fr/hal-02360992

[23] A. MULLER-GUEUDIN, A. GÉGOUT-PETIT.*Aggregation of statistical methods for the selection of correlated variables, in large dimension*, in "JdS 2019 - 51emes Journées de Statistique de la SFDS", Vandoeuvre-les-Nancy, France, June 2019, https://hal.archives-ouvertes.fr/hal-02360974

[24] R. POSTOYAN, M. GRANZOTTO, L. BUŞONIU, B. SCHERRER, D. NEŠIĆ, J. DAAFOUZ.*Stability guarantees for nonlinear discrete-time systems controlled by approximate value iteration*, in "58th IEEE Conference on Decision and Control, CDC 2019", Nice, France, December 2019, Version longue de l'article du même titre et des mêmes auteurs des proceedings de l'IEEE Conference on Decision on Control 2019, Nice, France, https://hal.archives-ouvertes.fr/hal-02271268

[25] V. ROULETTE, G. DELPLANQUE, J. DELEFORTERIE, T. BASTOGNE.*A contribution in nanoinformatics to facilitate the collection of structured data for Quality-by-Design in nanomedicine*, in "NanoMed Europe, NME 2019", Braga, Portugal, June 2019, https://hal.archives-ouvertes.fr/hal-02396540

[26] N. SAHKI, A. GÉGOUT-PETIT, S. WANTZ-MÉZIÈRES.*New Detection Thresholds and Stop Rules for CUSUM Online Detection*, in "ENBIS 2019 - 19th Annual Conference of the European Network for Business and Industrial Statistics", Budapest, Hungary, September 2019, https://hal.archives-ouvertes.fr/hal-02289501

Other Publications

[27] B. BASTIEN, T. BOUKHOBZA, H. DUMOND, A. GÉGOUT-PETIT, A. MULLER-GUEUDIN, C. THIÉBAUT.*A statistical methodology to select covariates in high-dimensional data under dependence. Application to the classification of genetic profiles in oncology*, September 2019, https://arxiv.org/abs/1909.05481 - working paper or preprint, https://hal.archives-ouvertes.fr/hal-02173568

[28] S. FERRIGNO, M. MAUMY-BERTRAND.*Estimation of reference curves for fetal weight*, December 2019, CMStatistics 2019, Poster, https://hal.inria.fr/hal-02389157

[29] A. GÉGOUT-PETIT, A. MULLER-GUEUDIN, C. KARMANN.*Graph estimation for Gaussian data zero-inflated by double truncation*, November 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-02367344

[30] A. GÉGOUT-PETIT, A. MULLER-GUEUDIN, C. KARMANN.*The revisited knockoffs method for variable selection in L_1-penalised regressions*, November 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-01799914

[31] B. LALLOUÉ, J.-M. MONNEZ, E. ALBUISSON.*Streaming constrained binary logistic regression with online standardized data. Application to scoring heart failure*, June 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-02156324

[32] J.-M. MONNEZ, A. SKIREDJ.*Convergence of a normed eigenvector stochastic approximation process and application to online principal component analysis of a data stream*, May 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-01844419

[33] A. MULLER-GUEUDIN, A. GÉGOUT-PETIT.*Package 'armada' : A Statistical Methodology to Select Covariates in High-Dimensional Data under Dependence*, April 2019, An R package, available on the CRAN. A Statistical Methodology to Select Covariates in High-Dimensional Data under Dependence, https://hal.archives-ouvertes.fr/hal-02363338

[34] N. SAHKI, A. GÉGOUT-PETIT, S. WANTZ-MÉZIÈRES.*Change-point detection method for the prediction of dreaded events during online monitoring of lung transplant patients*, December 2019, Annual PhD students conference IAEM Lorraine, APIL 2019, Poster, https://hal.inria.fr/hal-02392756

[35] N. SAHKI, A. GÉGOUT-PETIT, S. WANTZ-MÉZIÈRES.*Performance Study of Detection Thresholds for CUSUM statistic in a Sequential Context*, December 2019, working paper or preprint, https://hal.inria.fr/hal-02389331

References in notes

[36] R. AZAÏS.*A recursive nonparametric estimator for the transition kernel of a piecewise-deterministic Markov process*, in "ESAIM: Probability and Statistics", 2014, vol. 18, p. 726–749

[37] R. AZAÏS, F. DUFOUR, A. GÉGOUT-PETIT.*Nonparametric estimation of the jump rate for non-homogeneous marked renewal processes*, in "Annales de l'Institut Henri Poincaré, Probabilités et Statistiques", Institut Henri Poincaré, 2013, vol. 49, n^{o} 4, p. 1204–1231

[38] R. AZAÏS, F. DUFOUR, A. GÉGOUT-PETIT.*Non-Parametric Estimation of the Conditional Distribution of the Interjumping Times for Piecewise-Deterministic Markov Processes*, in "Scandinavian Journal of Statistics", December 2014, vol. 41, n^{o} 4, p. 950–969 [*DOI :* 10.1111/SJOS.12076], https://hal.archives-ouvertes.fr/hal-01103700

[39] R. AZAÏS, A. MULLER-GUEUDIN.*Optimal choice among a class of nonparametric estimators of the jump rate for piecewise-deterministic Markov processes*, in "Electronic journal of statistics ", 2016, https://hal.archives-ouvertes.fr/hal-01168651

[40] J. M. BARDET, G. LANG, G. OPPENHEIM, A. PHILIPPE, S. STOEV, M. TAQQU.*Semi-parametric estimation of the long-range dependence parameter: a survey*, in "Theory and applications of long-range dependence", Birkhauser Boston, 2003, p. 557-577

[41] T. BASTOGNE, S. MÉZIÈRES-WANTZ, N. RAMDANI, P. VALLOIS, M. BARBERI-HEYOB.*Identification of pharmacokinetics models in the presence of timing noise*, in "Eur. J. Control", 2008, vol. 14, n^{o} 2, p. 149–157, http://dx.doi.org/10.3166/ejc.14.149-157

[42] T. BASTOGNE, A. SAMSON, P. VALLOIS, S. WANTZ-MÉZIÈRES, S. PINEL, D. BECHET, M. BARBERI-HEYOB.*Phenomenological modeling of tumor diameter growth based on a mixed effects model*, in "Journal of theoretical biology", 2010, vol. 262, n^{o} 3, p. 544–552

[43] D. BERTSEKAS, J. TSITSIKLIS.*Neurodynamic Programming*, Athena Scientific, 1996

[44] H. BIERMÉ, C. LACAUX, H.-P. SCHEFFLER.*Multi-operator Scaling Random Fields*, in "Stochastic Processes and their Applications", 2011, vol. 121, n^{o} 11, p. 2642-2677, MAP5 2011-01 [*DOI :* 10.1016/J.SPA.2011.07.002], http://hal.archives-ouvertes.fr/hal-00551707/en/

[45] H. CARDOT, P. CÉNAC, J.-M. MONNEZ.*A fast and recursive algorithm for clustering large datasets with k-medians*, in "Computational Statistics & Data Analysis", 2012, vol. 56, n^{o} 6, p. 1434–1449

[46] J. F. COEURJOLLY.*Simulation and identification of the fractional brownian motion: a bibliographical and comparative study*, in "Journal of Statistical Software", 2000, vol. 5, p. 1–53

[47] M. H. DAVIS.*Piecewise-deterministic Markov processes: A general class of non-diffusion stochastic models*, in "Journal of the Royal Statistical Society. Series B (Methodological)", 1984, p. 353–388

[48] A. DEYA, S. TINDEL.*Rough Volterra equations. I. The algebraic integration setting*, in "Stoch. Dyn.", 2009, vol. 9, n^{o} 3, p. 437–477, http://dx.doi.org/10.1142/S0219493709002737

[49] M. DOUMIC, M. HOFFMANN, N. KRELL, L. ROBERT.*Statistical estimation of a growth-fragmentation model observed on a genealogical tree*, in "Bernoulli", 2015, vol. 21, n^{o} 3, p. 1760–1799

[50] S. FERRIGNO, G. R. DUCHARME.*Un test d'adéquation global pour la fonction de répartition conditionnelle*, in "Comptes Rendus Mathematique", 2005, vol. 341, n^{o} 5, p. 313–316

[51] S. FERRIGNO, M. MAUMY-BERTRAND, A. MULLER-GUEUDIN.*Uniform law of the logarithm for the local linear estimator of the conditional distribution function*, in "C. R. Math. Acad. Sci. Paris", 2010, vol. 348, n^{o} 17-18, p. 1015–1019, http://dx.doi.org/10.1016/j.crma.2010.08.003

[52] J. FRIEDMAN, T. HASTIE, R. TIBSHIRANI.*Sparse inverse covariance estimation with the graphical lasso*, in "Biostatistics", 2008, vol. 9, n^{o} 3, p. 432–441

[53] C. GIRAUD, S. HUET, N. VERZELEN.*Graph selection with GGMselect*, in "Statistical applications in genetics and molecular biology", 2012, vol. 11, n^{o} 3

[54] T. HANSEN, U. ZWICK.*Lower Bounds for Howard's Algorithm for Finding Minimum Mean-Cost Cycles*, in "ISAAC (1)", 2010, p. 415-426

[55] S. HERRMANN, P. VALLOIS.*From persistent random walk to the telegraph noise*, in "Stoch. Dyn.", 2010, vol. 10, n^{o} 2, p. 161–196, http://dx.doi.org/10.1142/S0219493710002905

[56] J. HU, W.-C. WU, S. SASTRY.*Modeling subtilin production in bacillus subtilis using stochastic hybrid systems*, in "Hybrid Systems: Computation and Control", Springer, 2004, p. 417–431

[57] R. KEINJ, T. BASTOGNE, P. VALLOIS.*Multinomial model-based formulations of TCP and NTCP for radiotherapy treatment planning*, in "Journal of Theoretical Biology", June 2011, vol. 279, n^{o} 1, p. 55-62 [*DOI :* 10.1016/J.JTBI.2011.03.025], http://hal.inria.fr/hal-00588935/en

[58] R. KOENKER.*Quantile regression*, Cambridge university press, 2005, n^{o} 38

[59] Y. A. KUTOYANTS.*Statistical inference for ergodic diffusion processes*, Springer Series in Statistics, Springer-Verlag London Ltd., London, 2004, xiv+481

[60] C. LACAUX.*Real Harmonizable Multifractional Lévy Motions*, in "Ann. Inst. Poincaré.", 2004, vol. 40, n^{o} 3, p. 259–277

[61] L. LEBART.*On the Benzecri's method for computing eigenvectors by stochastic approximation (the case of binary data)*, in "Compstat 1974 (Proc. Sympos. Computational Statist., Univ. Vienna, Vienna, 1974)", Vienna, Physica Verlag, 1974, p. 202–211

[62] B. LESNER, B. SCHERRER.*Non-Stationary Approximate Modified Policy Iteration*, in "ICML 2015", Lille, France, July 2015, https://hal.inria.fr/hal-01186664

[63] T. LYONS, Z. QIAN.*System control and rough paths*, Oxford mathematical monographs, Clarendon Press, 2002, http://books.google.com/books?id=H9fRQNIngZYC

[64] N. MEINSHAUSEN, P. BÜHLMANN.*High-dimensional graphs and variable selection with the lasso*, in "The Annals of Statistics", 2006, p. 1436–1462

[65] J.-M. MONNEZ.*Approximation stochastique en analyse factorielle multiple*, in "Ann. I.S.U.P.", 2006, vol. 50, n^{o} 3, p. 27–45

[66] J.-M. MONNEZ.*Stochastic approximation of the factors of a generalized canonical correlation analysis*, in "Statist. Probab. Lett.", 2008, vol. 78, n^{o} 14, p. 2210–2216, http://dx.doi.org/10.1016/j.spl.2008.01.088

[67] J.-M. MONNEZ.*Convergence d'un processus d'approximation stochastique en analyse factorielle*, in "Publ. Inst. Statist. Univ. Paris", 1994, vol. 38, n^{o} 1, p. 37–55

[68] E. NADARAYA.*On non-parametric estimates of density functions and regression curves*, in "Theory of Probability & Its Applications", 1965, vol. 10, n^{o} 1, p. 186–190

[69] I. POST, Y. YE.*The simplex method is strongly polynomial for deterministic Markov decision processes*, arXiv:1208.5083v2, 2012

[70] M. PUTERMAN.*Markov Decision Processes*, Wiley, New York, 1994

[71] B. ROYNETTE, P. VALLOIS, M. YOR.*Brownian penalisations related to excursion lengths, VII*, in "Annales de l'IHP Probabilités et statistiques", 2009, vol. 45, n^{o} 2, p. 421–452

[72] F. RUSSO, P. VALLOIS.*Stochastic calculus with respect to continuous finite quadratic variation processes*, in "Stochastics: An International Journal of Probability and Stochastic Processes", 2000, vol. 70, n^{o} 1-2, p. 1–40

[73] F. RUSSO, P. VALLOIS.*Elements of stochastic calculus via regularization*, in "Séminaire de Probabilités XL", Berlin, Lecture Notes in Math., Springer, 2007, vol. 1899, p. 147–185, http://dx.doi.org/10.1007/978-3-540-71189-6_7

[74] B. SCHERRER, M. GHAVAMZADEH, V. GABILLON, B. LESNER, M. GEIST.*Approximate Modified Policy Iteration and its Application to the Game of Tetris*, in "Journal of Machine Learning Research", 2015, vol. 16, p. 1629–1676, A paraître, https://hal.inria.fr/hal-01091341

[75] B. SCHERRER, B. LESNER.*On the Use of Non-Stationary Policies for Stationary Infinite-Horizon Markov Decision Processes*, in "NIPS 2012 - Neural Information Processing Systems", South Lake Tahoe, United States, December 2012, https://hal.inria.fr/hal-00758809

[76] B. SCHERRER.*Performance Bounds for Lambda Policy Iteration and Application to the Game of Tetris*, in "Journal of Machine Learning Research", January 2013, vol. 14, p. 1175-1221, https://hal.inria.fr/hal-00759102

[77] B. SCHERRER.*Approximate Policy Iteration Schemes: A Comparison*, in "ICML - 31st International Conference on Machine Learning - 2014", Pékin, China, June 2014, https://hal.inria.fr/hal-00989982

[78] B. SCHERRER.*Improved and Generalized Upper Bounds on the Complexity of Policy Iteration*, in "Mathematics of Operations Research", February 2016, Markov decision processes ; Dynamic Programming ; Analysis of Algorithms [*DOI :* 10.1287/MOOR.2015.0753], https://hal.inria.fr/hal-00829532

[79] P. VALLOIS, C. S. TAPIERO.*Memory-based persistence in a counting random walk process*, in "Phys. A.", 2007, vol. 386, n^{o} 1, p. 303–307, http://dx.doi.org/10.1016/j.physa.2007.08.027

[80] P. VALLOIS.*The range of a simple random walk on Z*, in "Advances in applied probability", 1996, p. 1014–1033

[81] N. VILLA-VIALANEIX.*An introduction to network inference and mining*, 2015, http://wikistat.fr/, (consulté le 22/07/2015), http://www.nathalievilla.org/doc/pdf//wikistat-network_compiled.pdf

[82] Y. YE.*The Simplex and Policy-Iteration Methods Are Strongly Polynomial for the Markov Decision Problem with a Fixed Discount Rate*, in "Math. Oper. Res.", 2011, vol. 36, n^{o} 4, p. 593-603

Project-Team CAMUS

Compiling Architectures of Multicores

IN COLLABORATION WITH: ICube

IN PARTNERSHIP WITH:
Université de Strasbourg

RESEARCH CENTER
Nancy - Grand Est

THEME
Architecture, Languages and Compilation

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Project-Team CAMUS

Creation of the Team: 2009 July 01, updated into Project-Team: 2019 March 01

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Other Research Topics and Application Domains:

B4.5.1. - Green computing
B6.1.1. - Software engineering
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1. Team, Visitors, External Collaborators

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Arthur Charguéraud [Inria, Researcher]
Jens Gustedt [Inria, Senior Researcher, HDR]

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Maxime Schmitt [Univ de Strasbourg, until Sep 2019]

Post-Doctoral Fellow

Damien Rouhling [Inria, from Oct 2019]

2. Overall Objectives

2.1. Overall Objectives

The CAMUS team is focusing on developing, adapting and extending automatic parallelization and optimization techniques, as well as proof and certification methods, for the efficient use of current and future multicore processors.

The team's research activities are organized into four main issues that are closely related to reach the following objectives: performance, correctness and productivity. These issues are: static parallelization and optimization of programs (where all statically detected parallelisms are expressed as well as all "hypothetical" parallelisms which would be eventually taken advantage of at runtime), profiling and execution behavior modeling (where expressive representation models of the program execution behavior will be used as engines for dynamic parallelizing processes), dynamic parallelization and optimization of programs (such transformation processes running inside a virtual machine), and finally program transformation proofs (where the correctness of many static and dynamic program transformations has to be ensured).

3. Research Program

3.1. Research Directions

The various objectives we are expecting to reach are directly related to the search of adequacy between the sofware and the new multicore processors evolution. They also correspond to the main research directions suggested by Hall, Padua and Pingali in [56]. Performance, correctness and productivity must be the users' perceived effects. They will be the consequences of research works dealing with the following issues:

- Issue 1: Static Parallelization and Optimization
- Issue 2: Profiling and Execution Behavior Modeling
- Issue 3: Dynamic Program Parallelization and Optimization, Virtual Machine
- Issue 4: Proof of Program Transformations for Multicores

The development of efficient and correct applications for multicore processors requires stepping in every application development phase, from the initial conception to the final run.

Upstream, all potential parallelism of the application has to be exhibited. Here static analysis and transformation approaches (issue 1) must be performed, resulting in *multi-parallel* intermediate code advising the running virtual machine about all the parallelism that can be taken advantage of. However the compiler does not have much knowledge about the execution environment. It obviously knows the instruction set, it can be aware of the number of available cores, but it does not know the actual available resources at any time during the execution (memory, number of free cores, etc.).

That is the reason why a "virtual machine" mechanism will have to adapt the application to the resources (issue 3). Moreover the compiler will be able to take advantage only of a part of the parallelism induced by the application. Indeed some program information (variables values, accessed memory adresses, etc.) being available only at runtime, another part of the available parallelism will have to be generated on-the-fly during the execution, here also, thanks to a dynamic mechanism.

This on-the-fly parallelism extraction will be performed using speculative behavior models (issue 2), such models allowing to generate speculative parallel code (issue 3). Between our behavior modeling objectives, we can add the behavior monitoring, or profiling, of a program version. Indeed, the complexity of current and future architectures avoids assuming an optimal behavior regarding a given program version. A monitoring process will make it possible to select on-the-fly the best parallelization.

These different parallelization steps are schematized in figure 1.

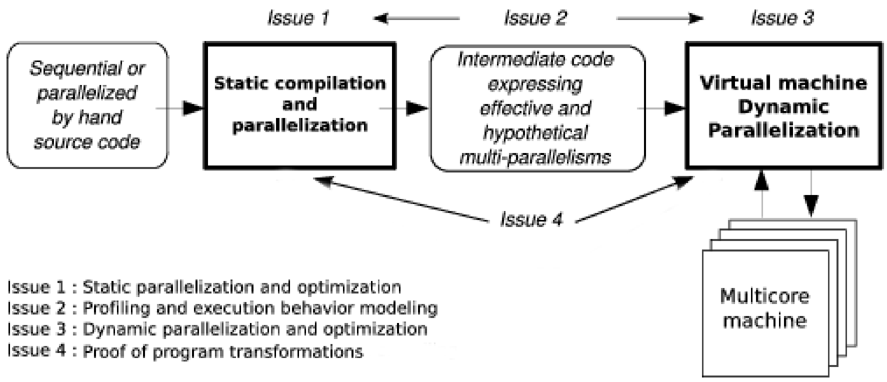

Figure 1. Steps for Automatic parallelization on multicore architectures.

Our project relies on the conception of a production chain for efficient execution of an application on a multicore architecture. Each link of this chain has to be formally verified in order to ensure correctness as well as efficiency. More precisely, it has to be ensured that the compiler produces a correct intermediate code, and that the virtual machine actually performs the parallel execution semantically equivalent to the source code: every transformation applied to the application, either statically by the compiler or dynamically by the virtual machine, must preserve the initial semantics. This must be proved formally (issue 4).

In the following, those different issues are detailed while forming our global, long term vision of what has to be done.

3.2. Static Parallelization and Optimization

Participants: Vincent Loechner, Philippe Clauss, Éric Violard, Cédric Bastoul, Arthur Charguéraud, Bérenger Bramas, Harenome Ranaivoarivony-Razanajato.

Static optimizations, from source code at compile time, benefit from two decades of research in automatic parallelization: many works address the parallelization of loop nests accessing multi-dimensional arrays, and these works are now mature enough to generate efficient parallel code [53]. Low-level optimizations, in the assembly code generated by the compiler, have also been extensively dealt with for single-core and require few adaptations to support multicore architectures. Concerning multicore specific parallelization, we propose to explore two research directions to take full advantage of these architectures: adapting parallelization to multicore architectures and expressing many potential parallelisms.

3.3. Profiling and Execution Behavior Modeling

Participants: Alain Ketterlin, Philippe Clauss, Salwa Kobeissi.

The increasing complexity of programs and hardware architectures makes it ever harder to characterize beforehand a given program's run time behavior. The sophistication of current compilers and the variety of transformations they are able to apply cannot hide their intrinsic limitations. As new abstractions like transactional memories appear, the dynamic behavior of a program strongly conditions its observed performance. All these reasons explain why empirical studies of sequential and parallel program executions have been considered increasingly relevant. Such studies aim at characterizing various facets of one or several program runs, *e.g.*, memory behavior, execution phases, etc. In some cases, such studies characterize more the compiler than the program itself. These works are of tremendous importance to highlight all aspects that escape static analysis, even though their results may have a narrow scope, due to the possible incompleteness of their input data sets.

3.4. Dynamic Parallelization and Optimization, Virtual Machine

Participants: Philippe Clauss, Salwa Kobeissi, Jens Gustedt, Alain Ketterlin, Muthena Abdul-Wahab, Daniel Salas, Bérenger Bramas.

Dynamic parallelization and optimization has become essential with the advent of the new multicore architectures. When using a dynamic scheme, the performed instructions are not only dedicated to the application functionalities, but also to its control and its transformation, and so in its own interest. Behaving like a computer virus, such a scheme should rather be qualified as a "vitamin". It perfectly knows the current characteristics of the execution environment and owns some qualitative information thanks to a behavior modeling process (issue 2). It provides a significant optimization ability compared to a static compiler, while observing the evolution of the availability of live resources.

3.5. Proof of Program Transformations for Multicores

Participants: Éric Violard, Alain Ketterlin, Julien Narboux, Nicolas Magaud, Arthur Charguéraud.

Our main objective consists in certifying the critical modules of our optimization tools (the compiler and the virtual machine). First we will prove the main loop transformation algorithms which constitute the core of our system.

The optimization process can be separated into two stages: the transformations consisting in optimizing the sequential code and in exhibiting parallelism, and those consisting in optimizing the parallel code itself. The first category of optimizations can be proved within a sequential semantics. For the other optimizations, we need to work within a concurrent semantics. We expect the first stage of optimization to produce data-race free code. For the second stage of optimization we will first assume that the input code is data-race free. We will prove those transformations using Appel's concurrent separation logic [57]. Proving transformations involving programs which are not data-race free will constitute a longer term research goal.

4. Application Domains

4.1. Application Domains

Computational performance being our main objective, our target applications are characterized by intensive computation phases. Such applications are numerous in the domains of scientific computations, optimization, data mining and multimedia.

Applications involving intensive computations are necessarily high energy consumers. However this consumption can be significantly reduced thanks to optimization and parallelization. Although this issue is not our prior objective, we can expect some positive effects for the following reasons:

- Program parallelization tries to distribute the workload equally among the cores. Thus an equivalent performance, or even a better performance, to a sequential higher frequency execution on one single core, can be obtained.
- Memory and memory accesses are high energy consumers. Lowering the memory consumption, lowering the number of memory accesses and maximizing the number of accesses in the low levels of the memory hierarchy (registers, cache memories) have a positive consequence on execution speed, but also on energy consumption.

5. Highlights of the Year

5.1. Highlights of the Year

One of the main challenges of parallelization is the selection of the appropriate granularity to balance between the ideal degree of parallelism and the mitigation of the runtime system's overhead. We have worked on the granularity control for parallel applications focusing on two different paradigms. In the first one, which is the tasks with spawn/sync mechanism, we combined the use of asymptotic complexity functions provided by the programmer, with runtime measurements to predict the execution time of tasks with reasonable accuracy. This estimation can then be used to select the proper task granularity, while making sure to put enough work inside each task. In the second one, which is related to the tasks with dependencies paradigm, we have improved an existing algorithm to cluster a graph of tasks to obtain a meta-graph with larger tasks. This approach was used in an application in collaboration with the TONUS team, and we have demonstrated that it allows for a significant speedup.

6. New Software and Platforms

6.1. CLooG

Code Generator in the Polyhedral Model

KEYWORDS: Polyhedral compilation - Optimizing compiler - Code generator

FUNCTIONAL DESCRIPTION: CLooG is a free software and library to generate code (or an abstract syntax tree of a code) for scanning Z-polyhedra. That is, it finds a code (e.g. in C, FORTRAN...) that reaches each integral point of one or more parameterized polyhedra. CLooG has been originally written to solve the code generation problem for optimizing compilers based on the polyhedral model. Nevertheless it is used now in various area e.g. to build control automata for high-level synthesis or to find the best polynomial approximation of a function. CLooG may help in any situation where scanning polyhedra matters. While the user has full control on generated code quality, CLooG is designed to avoid control overhead and to produce a very effective code. CLooG is widely used (including by GCC and LLVM compilers), disseminated (it is installed by default by the main Linux distributions) and considered as the state of the art in polyhedral code generation.

RELEASE FUNCTIONAL DESCRIPTION: It mostly solves building and offers a better OpenScop support.

- Participant: Cédric Bastoul
- Contact: Cédric Bastoul
- URL: http://www.cloog.org

6.2. OpenScop

A Specification and a Library for Data Exchange in Polyhedral Compilation Tools

KEYWORDS: Polyhedral compilation - Optimizing compiler

FUNCTIONAL DESCRIPTION: OpenScop is an open specification that defines a file format and a set of data structures to represent a static control part (SCoP for short), i.e., a program part that can be represented in the polyhedral model. The goal of OpenScop is to provide a common interface to the different polyhedral compilation tools in order to simplify their interaction. To help the tool developers to adopt this specification, OpenScop comes with an example library (under 3-clause BSD license) that provides an implementation of the most important functionalities necessary to work with OpenScop.

- Participant: Cédric Bastoul
- Contact: Cédric Bastoul
- URL: http://icps.u-strasbg.fr/people/bastoul/public_html/development/openscop/

6.3. ORWL

Ordered Read-Write Lock

KEYWORDS: Task scheduling - Deadlock detection

FUNCTIONAL DESCRIPTION: ORWL is a reference implementation of the Ordered Read-Write Lock tools. The macro definitions and tools for programming in C99 that have been implemented for ORWL have been separated out into a toolbox called P99.

- Participants: Jens Gustedt, Mariem Saied and Stéphane Vialle
- Contact: Jens Gustedt
- Publications: Iterative Computations with Ordered Read-Write Locks - Automatic, Abstracted and Portable Topology-Aware Thread Placement - Resource-Centered Distributed Processing of Large Histopathology Images - Automatic Code Generation for Iterative Multi-dimensional Stencil Computations

6.4. musl

KEYWORDS: Standards - Library

SCIENTIFIC DESCRIPTION: musl provides consistent quality and implementation behavior from tiny embedded systems to full-fledged servers. Minimal machine-specific code means less chance of breakage on minority architectures and better success with "write once run everywhere" C development.

musl's efficiency is unparalleled in Linux libc implementations. Designed from the ground up for static linking, musl carefully avoids pulling in large amounts of code or data that the application will not use. Dynamic linking is also efficient, by integrating the entire standard library implementation, including threads, math, and even the dynamic linker itself into a single shared object, most of the startup time and memory overhead of dynamic linking have been eliminated.

FUNCTIONAL DESCRIPTION: We participate in the development of musl, a re-implementation of the C library as it is described by the C and POSIX standards. It is lightweight, fast, simple, free, and strives to be correct in the sense of standards-conformance and safety. Musl is production quality code that is mainly used in the area of embedded devices. It gains more market share also in other areas, e.g. there are now Linux distributions that are based on musl instead of Gnu LibC.

- Participant: Jens Gustedt
- Contact: Jens Gustedt
- URL: http://www.musl-libc.org/

6.5. Modular C

KEYWORDS: Programming language - Modularity

FUNCTIONAL DESCRIPTION: The change to the C language is minimal since we only add one feature, composed identifiers, to the core language. Our modules can import other modules as long as the import relation remains acyclic and a module can refer to its own identifiers and those of the imported modules through freely chosen abbreviations. Other than traditional C include, our import directive ensures complete encapsulation between modules. The abbreviation scheme allows to seamlessly replace an imported module by another one with an equivalent interface. In addition to the export of symbols, we provide parameterized code injection through the import of "snippets". This implements a mechanism that allows for code reuse, similar to X macros or templates. Additional features of our proposal are a simple dynamic module initialization scheme, a structured approach to the C library and a migration path for existing software projects.

- Author: Jens Gustedt
- Contact: Jens Gustedt
- Publications: Modular C - Arbogast: Higher order automatic differentiation for special functions with Modular C - Futex based locks for C11's generic atomics
- URL: http://cmod.gforge.inria.fr/

6.6. arbogast

KEYWORD: Automatic differentiation

SCIENTIFIC DESCRIPTION: This high-level toolbox for the calculus with Taylor polynomials is named after L.F.A. Arbogast (1759-1803), a French mathematician from Strasbourg (Alsace), for his pioneering work in derivation calculus. Its modular structure ensures unmatched efficiency for computing higher order Taylor polynomials. In particular it permits compilers to apply sophisticated vector parallelization to the derivation of nearly unmodified application code.

FUNCTIONAL DESCRIPTION: Arbogast is based on a well-defined extension of the C programming language, Modular C, and places itself between tools that proceed by operator overloading on one side and by rewriting, on the other. The approach is best described as contextualization of C code because it permits the programmer to place his code in different contexts – usual math or AD – to reinterpret it as a usual C function or as a differential operator. Because of the type generic features of modern C, all specializations can be delegated to the compiler.

- Author: Jens Gustedt
- Contact: Jens Gustedt
- Publications: Arbogast: Higher order automatic differentiation for special functions with Modular C - Arbogast – Origine d'un outil de dérivation automatique
- URL: https://gforge.inria.fr/projects/arbo

6.7. CFML

Interactive program verification using characteristic formulae

KEYWORDS: Coq - Software Verification - Deductive program verification - Separation Logic

FUNCTIONAL DESCRIPTION: The CFML tool supports the verification of OCaml programs through interactive Coq proofs. CFML proofs establish the full functional correctness of the code with respect to a specification. They may also be used to formally establish bounds on the asymptotic complexity of the code. The tool is made of two parts: on the one hand, a characteristic formula generator implemented as an OCaml program that parses OCaml code and produces Coq formulae, and, on the other hand, a Coq library that provides notations and tactics for manipulating characteristic formulae interactively in Coq.

- Participants: Arthur Charguéraud, Armaël Guéneau and François Pottier
- Contact: Arthur Charguéraud
- URL: http://www.chargueraud.org/softs/cfml/

6.8. SPETABARU

SPEculative TAsk-BAsed RUntime system

KEYWORDS: HPC - Parallel computing - Task-based algorithm

FUNCTIONAL DESCRIPTION: SPETABARU is a task-based runtime system for multi-core architectures that includes speculative execution models. It is a pure C++11 product without external dependency. It uses advanced meta-programming and allows for an easy customization of the scheduler. It is also capable to generate execution traces in SVG to better understand the behavior of the applications.

- Contact: Bérenger Bramas
- URL: https://gitlab.inria.fr/bramas/spetabaru

6.9. APAC

KEYWORDS: Source-to-source compiler - Automatic parallelization - Parallelisation - Parallel programming

SCIENTIFIC DESCRIPTION: APAC is a compiler for automatic parallelization that transforms C++ source code to make it parallel by inserting tasks. It uses the tasks+dependencies paradigm and relies on OpenMP or SPETABARU as runtime system. Internally, it is based on Clang-LLVM.

FUNCTIONAL DESCRIPTION: Automatic task-based parallelization compiler

- Participants: Bérenger Bramas, Stéphane Genaud and Garip Kusoglu
- Contact: Bérenger Bramas
- URL: https://gitlab.inria.fr/bramas/apac

6.10. Dagpar

KEYWORDS: Graph algorithmics - Clustering - Partitioning

SCIENTIFIC DESCRIPTION: This library is a clustering algorithm to create macro-tasks in a DAG of tasks. It extends a clustering/partitioning strategy proposed by Rossignon et al. to speed up the parallel execution of a task-based application. In this package, we provide two additional heuristics to this algorithm, which have been validated on a large graph set. The objective of clustering the nodes of task graphs is to increase the granularity of the tasks and thus obtain faster execution by mitigating the overhead from the management of the dependencies. An important asset of this approach is that working at the graph level allows us to create a generic method independent of the application and of what is done at the user level, but also independent of the task-based runtime system that could be used underneath.

FUNCTIONAL DESCRIPTION: Acyclic Dag Partitioning.

- Participants: Bérenger Bramas and Alain Ketterlin
- Contact: Bérenger Bramas
- URL: https://gitlab.inria.fr/bramas/dagpar

6.11. LetItBench

Lenient to Errors, Transformations, Irregularities and Turbulence Benchmarks

KEYWORDS: Approximate computing - Benchmarking

FUNCTIONAL DESCRIPTION: LetItBench is a benchmark set to help evaluating works on approximate compilation techniques. We propose a set of meaningful applications with an iterative kernel, that is not too complex for automatic analysis and can be analyzed by polyhedral tools. The benchmark set called LetItBench (Lenient to Errors, Transformations, Irregularities and Turbulence Benchmarks) is composed of standalone applications written in C, and a benchmark runner based on CMake. The benchmark set includes fluid simulation, FDTD, heat equations, game of life or K-means clustering. It spans various kind of applications that are resilient to approximation.

- Contact: Cédric Bastoul
- URL: https://github.com/Syllo/LetItBench

6.12. ACR

Adaptive Code Refinement

KEYWORDS: Approximate computing - Optimizing compiler

FUNCTIONAL DESCRIPTION: ACR is to approximate programming what OpenMP is to parallel programming. It is an API including a set of language extensions to provide the compiler with pertinent information about how to approximate a code block, a high-level compiler to automatically generate the approximated code, and a runtime library to exploit the approximation information at runtime according to the dataset properties. ACR is designed to provide approximate computing to non experts. The programmer may write a trivial code without approximation, provide approximation information thanks to pragmas, and let the compiler generate an optimized code based on approximation.

- Contact: Cédric Bastoul
- URL: https://github.com/Syllo/acr

6.13. APOLLO

Automatic speculative POLyhedral Loop Optimizer

KEYWORD: Automatic parallelization

FUNCTIONAL DESCRIPTION: APOLLO is dedicated to automatic, dynamic and speculative parallelization of loop nests that cannot be handled efficiently at compile-time. It is composed of a static part consisting of specific passes in the LLVM compiler suite, plus a modified Clang frontend, and a dynamic part consisting of a runtime system. It can apply on-the-fly any kind of polyhedral transformations, including tiling, and can handle nonlinear loops, as while-loops referencing memory through pointers and indirections.

- Participants: Aravind Sukumaran-Rajam, Juan Manuel Martinez Caamaño, Manuel Selva and Philippe Clauss
- Contact: Philippe Clauss
- URL: http://apollo.gforge.inria.fr

7. New Results

7.1. The Polyhedral Model Beyond Loops

Participants: Salwa Kobeissi, Philippe Clauss.

There may be a huge gap between the statements outlined by programmers in a program source code and instructions that are actually performed by a given processor architecture when running the executable code. This gap is due to the way the input code has been interpreted, translated and transformed by the compiler and the final processor hardware. Thus, there is an opportunity for efficient optimization strategies, that are dedicated to specific control structures and memory access patterns, to be applied as soon as the actual runtime behavior has been discovered, even if they could not have been applied on the original source code.

We develop this idea by identifying code excerpts that behave as polyhedral-compliant loops at runtime, while not having been outlined at all as loops in the original source code. In particular, we are interested in recursive functions whose runtime behavior can be modeled as polyhedral loops. Therefore, the scope of this study exclusively includes recursive functions whose control flow and memory accesses exhibit an affine behavior, which means that there exists a semantically equivalent affine loop nest, candidate for polyhedral optimizations. Accordingly, our approach is based on analyzing early executions of a recursive program using a Nested Loop Recognition (NLR) algorithm [3], performing the affine loop modeling of the original program runtime behavior, which is then used to generate an equivalent iterative program, finally optimized using the polyhedral compiler Polly. We present some preliminary results showing that this approach brings recursion optimization techniques into a higher level in addition to widening the scope of the polyhedral model to include originally non-loop programs.

This work is the topic of Salwa Kobeissi's PhD. A first paper has been published at the 9th International Workshop on Polyhedral Compilation Techniques [22].

7.2. New release of Apollo

Participants: Muthena Abdul-Wahab, Philippe Clauss.

Apollo has been updated to use LLVM/Clang version 6.0.1. The unmodified sources are now included, as tar-files, in the APOLLO distribution.

Regarding the build system:

- All components of APOLLO are now installed into the installation directory. Once installed, APOLLO does not need the build directory to be kept.
- The RPATH on APOLLO libraries has been set to the installation directory. This allows APOLLO to be run without having to set up library paths.
- APOLLO_BUILD_JOBS has been introduced to specify the maximum number of build jobs to use. The replaces NB_JOBS which is still supported but deprecated.
- The sources for external dependencies are now included in the APOLLO distribution. They are no longer downloaded during a build.
- A new build target 'check' has been added to run the testsuite. This is supported by Makefiles ('make check') and Ninja ('ninja check').
- The build type (Debug/Release) for LLVM/Clang is now the same as the rest of APOLLO. New build variable APOLLO_LLVM_BUILD_TYPE can be used to specify a separate build type for LLVM/Clang.

Regarding bug fixes:

- Valid code using floating point types (float or double) could make APOLLO stop with an message about unsupported scalars. This has been fixed by removing the Loop Invariant Code Motion (LICM) pass in such cases, preventing floating-point scalars to be generated.
- Code containing try-catch blocks could make APOLLO crash. This has been fixed.
- Dynamic loop bounds were no more instrumented and interpolated. This has been fixed.

7.3. Uniform Random Sampling in Polyhedra

Participant: Philippe Clauss.

We propose a method for generating uniform samples among a domain of integer points defined by a polyhedron in a multi-dimensional space. The method extends to domains defined by parametric polyhedra, in which a subset of the variables are symbolic. We motivate this work by a list of applications for the method in computer science. The proposed method relies on polyhedral ranking functions, as well as a recent inversion method for them, named *trahrhe* expressions. This work has been accomplished in collaboration with Benoît Meister from Reservoir Labs, New York, USA, and has been published at the 10th International Workshop on Polyhedral Compilation Techniques, January 2020.

7.4. Runtime Multi-Versioning and Specialization

Participant: Philippe Clauss.

We have developped an extension of APOLLO that implements code multi-versioning and specialization to optimize and parallelize loop kernels that are invoked many times with varying parameters. These parameters may influence the code structure, the touched memory locations, the workload, and the runtime performance. They may also impact the validity of the parallelizing and optimizing polyhedral transformations that are applied on-the-fly.

For a target loop kernel and its associated parameters, a different optimizing and parallelizing transformation is evaluated at each invocation, among a finite set of transformations (multi-versioning and specialization). The best performing transformed code version is stored and indexed using its associated parameters. When every optimizing transformation has been evaluated, the best performing code version regarding the current parameters, which has been stored, is relaunched at next invocations (memoization).

This work has been accomplished in collaboration with Raquel Lazcano and Eduardo Juarez of the Universidad Politécnica de Madrid, Spain, and has been published at the ACM SIGPLAN 2020 International Conference on Compiler Construction (CC 2020).

7.5. AutoParallel: Automatic parallelization and distributed execution of affine loop nests in Python

Participant: Philippe Clauss.

The last improvements in programming languages and models have focused on simplicity and abstraction; leading Python to the top of the list of the programming languages. However, there is still room for improvement when preventing users from dealing directly with distributed and parallel computing issues. We propose AutoParallel, a Python module to automatically find an appropriate task-based parallelisation of affine loop nests to execute them in parallel in a distributed computing infrastructure. This parallelization can also include the building of data blocks to increase tasks' granularity in order to achieve a good execution performance. Moreover, AutoParallel is based on sequential programming and only contains a small annotation in the form of a Python decorator so that anyone with intermediate-level programming skills can scale up an application to hundreds of cores.

This work has been accomplished in collaboration with Cristian Ramon-Cortes, Ramon Amela, Jorge Ejarque and Rosa M. Badia of the Barcelona Supercomputing Center (BSC), Spain. A journal paper is in preparation.

7.6. Combining Locking and Data Management Interfaces

Participants: Jens Gustedt, Daniel Salas.

Handling data consistency in parallel and distributed settings is a challenging task, in particular if we want to allow for an easy to handle asynchronism between tasks. Our publication [2] shows how to produce deadlock-free iterative programs that implement strong overlapping between communication, IO and computation.

An implementation (ORWL) of our ideas of combining control and data management in C has been undertaken, see Section 6.3. In previous work it has demonstrated its efficiency for a large variety of platforms.

In the framework of the ASNAP project we have used ordered read-write locks (ORWL) as a model to dynamically schedule a pipeline of parallel tasks that realize a parallel control flow of two nested loops; an outer *iteration* loop and an inner *data traversal* loop. Other than dataflow programming, for each individual data object we conserve the same modification order as the sequential algorithm. As a consequence the visible side effects on any object can be guaranteed to be identical to a sequential execution. Thus the set of optimizations that are performed are compatible with C's abstract state machine and compilers could perform them, in principle, automatically and unobserved. See [16] for first results.

In the context of the Prim'Eau project (see 9.1.2) we use ORWL to integrate parallelism into an already existing `Fortran` application that computes floods in the region that is subject to the study. A first step of such a parallelization has been started by using ORWL on a process level. Our final goal will be to extend it to the thread level and to use the application structure for automatic placement on compute nodes. A first step to this goal has been a specific decomposition of geological data, see [21].

Within the framework of the thesis of Daniel Salas we have successfully applied ORWL to process large histopathology images. We are now able to treat such images distributed on several machines or shared in an accelerator (Xeon Phi) transparently for the user. This year, Daniel has successfully defended his thesis, see [7].

7.7. Granularity Control for Parallel Programs

Participant: Arthur Charguéraud.

Arthur Charguéraud studied the development of techniques for controlling granularity in parallel programs. Granularity control is an essential problem because creating too many tasks may induce overwhelming overheads, while creating too few tasks may harm the ability to process tasks in parallel. Granularity control turns out to be especially challenging for nested parallel programs, i.e., programs in which parallel constructs such as fork-join or parallel-loops can be nested arbitrarily.

The proposed approach combines the use of asymptotic complexity functions provided by the programmer, with runtime measurements to estimate the constant factors that apply. Exploiting these two sources of information makes it possible to predict with reasonable accuracy the execution time of tasks. Such predictions may be used to guide the generation of tasks, by sequentializing computations of sufficiently small size. An analysis is developed, establishing that task creation overheads are indeed bounded to a small fraction of the total runtime. These results extend prior work by the same authors [52], extending them with a carefully-designed algorithm for ensuring convergence of the estimation of the constant factors deduced from the measures, even in the face of noise and cache effects, which are taken into account in the analysis. The approach is demonstrated on a range of benchmarks taken from the state-of-the-art PBBS benchmark suite. These results have been accepted for publication at PPoPP'19 [14].

7.8. Program Verification and Formal Languages

Participant: Arthur Charguéraud.

- Armaël Guéneau, a PhD student advised by A. Charguéraud and F. Pottier (Cambium), has developed a formal proof of the functional correctness and the asymptotic complexity of a state-of-the-art incremental cycle detection algorithm due to Bender, Fineman, Gilbert, and Tarjan. This work moreover proposes a simple change that allows the algorithm to be regarded as genuinely online. The verification proof is carried out by exploiting Separation Logic with Time Credits, in the CFML tool, to simultaneously verify the correctness and the worst-case amortized asymptotic complexity of the modified algorithm. This work was published at ITP'19 [17]. It leverages previous work on the extension of the CFML verification tool to allow the specification of the asymptotic complexity of higher-order, imperative programs [55], and shows that this framework scales up to larger, more complex programs.
- Arthur Charguéraud, together with Jean-Christophe Filliâtre and Cláudio Lourenço (CNRS, Inria and Université Paris Saclay), and Mário Pereira (NOVA LINCS & DI, Universidade Nova de Lisboa), developed a behavioral specification language for OCaml, called GOSPEL. It is designed to enable modular verification of data structures and algorithms. Compared with writing specifications directly in Separation Logic, it provides a high-level syntax that greatly improves conciseness and makes it accessible to programmers with no familiarity with Separation Logic. GOSPEL is applied to the development of a formally verified library of general-purpose OCaml data structures. This work was published at the World Congress on Formal Methods (FM) 2019 [15].

7.9. Improvement of Schnaps on multi-GPU nodes using the LAHeteroprio Scheduler

Participant: Bérenger Bramas.

The TONUS team has developed Schnaps, a discontinuous finite element solver with OpenCL and StarPU. The team members have been facing challenges in the scalability of their application when using more than one GPU. This has been the starting point of a collaboration in which Bérenger Bramas has participated in the development of Schnaps and plugged its StarPU scheduler called LAHeteroprio [9]. The improvements obtained were significant and included in a paper [50] (currently under revision).

The potential of LAHeteroprio is now demonstrated. However, setting up this scheduler remains a complicated task. Therefore, we plan to work on its automatic configuration, which will require us to perform on the fly analysis of the graph of tasks.

7.10. Improving Parallel Executions by Increasing Task Granularity in Task-based Runtime Systems using Acyclic DAG Clustering

Participants: Bérenger Bramas, Alain Ketterlin.

Bérenger Bramas and Alain Ketterlin collaborate with the TONUS team in the development of a parallel solver for the resolution of conservative hyperbolic upwind kinetic of unstructured tokamaks [49]. In their methods, they must solve the transport equation on an unstructured mesh, which can be seen as having a wave propagating from neighbor-to-neighbor. The resulting computation can be represented using a direct acyclic graph (DAG) of operations, where each operation is a tiny task. Therefore, Bérenger Bramas and Alain Ketterlin contributed mainly on two aspects. First, they have proposed a highly optimized lock-free parallel implementation of the solution based on atomic instructions. Second, they have improved an existing algorithm from the literature to cluster a DAG of tasks with the aim of increasing the granularity of the tasks and to reduce the overhead of the parallelization consequently. This new approach has been accepted in a dedicated paper (accepted but not yet published).

7.11. FMM Kernel for the Integral Equation Formulation of the N-body Dielectric Spheres Problem

Participant: Bérenger Bramas.

Bérenger Bramas worked with Benjamin Stamm and Muhammad Hassan (RWTH) to create a kernel for the fast multipole method (FMM). The kernel relies on the previously developed kernel with spherical harmonics and accelerated by rotations. It has been extended to accept spherical harmonics (with orders different from the ones used in the kernel) instead of points as input. The kernel allowed us to accelerate the computation and was used for a complexity analysis that has been submitted [54].

7.12. Automatic Task-Based Parallelization using Source to Source Transformations

Participants: Bérenger Bramas, Garip Kusolgu.

Bérenger Bramas and Garip Kusolgu worked on a new approach to parallelize automatically any application written in an object-oriented language. The main idea is to parallelize a code as an HPC expert would do it using the task-based method. With this aim, they created a new source-to-source compiler on top of CLang-LLVM called APAC. APAC is able to insert tasks in a source-code by evaluating data accesses and thus generating the correct dependencies. An important and challenging part of the work consists in managing the granularity, which requires to work both statically on the code but also by delegating decisions at runtime.

7.13. Large Scale Particle Fusion Algorithm for Tracing Systems in Fluid Mechanics Applications

Participant: Bérenger Bramas.

Bérenger Bramas worked with Michael Wilczek and Cristian Lalescu (Max Planck Institute for Dynamics and Self-Organization) in designing a new method to merge particles in a large scale application (*i.e.,* designed to run on thousands of computing nodes). In this context, the particles are originally used in a tracing system to extract information from a vector field in fluid mechanics. However, the physicists are now interested having the particles interacting and even fusioning. Due to the constraints of large scale computing, the system tries to reduce the number and amount of communications. This development has been done in the TurTLE application (not publicly available) and is currently under evaluation.

7.14. Pipelined Multithreaded Code Generation

Participants: Cédric Bastoul, Vincent Loechner, Harenome Ranaivoarivony-Razanajato.

State-of-the-art automatic polyhedral parallelizers extract and express parallelism as isolated parallel loops. For example, the Pluto high-level compiler generates and annotates loops with `#pragma omp parallel for` directives. In this work, we took advantage of pipelined multithreading, a parallelization strategy that can address a wider class of codes, currently not handled by automatic parallelizers. Pipelined multithreading requires interlacing iterations of some loops in a controlled way that enables the parallel execution of these iterations.

This work has been accepted for presentation at the International Workshop on Polyhedral Compilation Techniques (IMPACT 2020), in conjunction with HiPEAC ’20 (Jan. 2020, Bologna, Italy).

7.15. Raster Image Processing (RIP) Optimization

Participants: Cédric Bastoul, Paul Godard, Vincent Loechner.

In the context of our collaboration with the Caldera company, we are interested in original challenges for the computer systems in charge of driving very wide printer farms and very fast digital presses.

We explored new approaches inspired by the high performance computing field to speedup the graphics processing (RIP) necessary to digital printing. To achieve this goal, we developed a distributed system which provides the adequate flexibility and performance by exploiting and optimizing both processing and synchronization techniques. Our architecture meets the specific constraints on generating streams for printing purpose. We performed an evaluation of our solution and provided experimental evidence of its great performance and viability. This work has been presented at the 2019 IEEE International Parallel and Distributed Processing Symposium Workshop (IPDPSW): PDSEC ’19, in May 2019, Rio de Janeiro.

The second topic we worked on during this collaboration is an out-of-core and out-of-place rectangular matrix transposition and rotation algorithm. An originality of our processing algorithm is to rely on an optimized use of the page cache mechanism. It is parallel, optimized by several levels of tiling and independent of any disk block size. We evaluated our approach on four common storage configurations: HDD, hybrid HDD-SSD, SSD and software RAID 0 of several SSDs. We showed that it brings significant performance improvement over a hand-tuned optimized reference implementation developed by the Caldera company and we confront it against the roofline speed of a straight file copy. This work is under submission in the IEEE Transaction on Computers.

Paul Godard has defended his PhD thesis on Dec. 16th, 2019.

7.16. Static Versus Dynamic Memory Allocation

Participant: Vincent Loechner.

Vincent Loechner and Toufik Baroudi (PhD student, Univ. Batna, Algeria) compared the performance of linear algebra kernels using different array allocation modes: as static declared arrays or as dynamically allocated arrays of pointers. They studied the possible reasons of the difference in performance of parallelized or sequential linear algebra kernels on two different architectures: an AMD (Magny-Cours) and an Intel Xeon (Haswell-EP). Static or dynamic memory allocation has an impact on performance in many cases. Both the processor architecture and the compiler can provoke significant and sometimes surprising variations in the number of cache misses and vectorization opportunities taken by the compiler.

This work has been accepted for presentation at the International Workshop on Polyhedral Compilation Techniques (IMPACT 2020), in conjunction with HiPEAC ’20 (Jan. 2020, Bologna, Italy).

7.17. Automatic Adaptive Approximation for Stencil Computations

Participants: Maxime Schmitt, Cédric Bastoul.

This work has been done in collaboration with Philippe Helluy (TONUS).

Approximate computing is necessary to meet deadlines in some compute-intensive applications like simulation. Building them requires a high level of expertise from the application designers as well as a significant development effort. Some application programming interfaces greatly facilitate their conception but they still heavily rely on the developer’s domain-specific knowledge and require many modifications to successfully generate an approximate version of the program. In this work we designed new techniques to semi-automatically discover relevant approximate computing parameters. We believe that superior compiler-user interaction is the key to improved productivity. After pinpointing the region of interest to optimize, the developer is guided by the compiler in making the best implementation choices. Static analysis and runtime monitoring are used to infer approximation parameter values for the application. We evaluated these techniques on multiple application kernels that support approximation and show that with the help of our method, we achieve similar performance as non-assisted, hand-tuned version while requiring minimal intervention from the user.

These techiques and the underlying compiler infrastructure are a significant output of collaboration with the Inria Nancy - Grand Est team TONUS, specialized on applied mathematics (contact: Philippe Helluy), to bring models and techniques from this field to compilers. A paper presenting these extensions has been accepted to the CC international conference [18].

Maxime Schmitt has defended his PhD thesis on Sep. 30th, 2019 [8].

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

8.1.1. Caldera

Participants: Cédric Bastoul, Vincent Loechner.

Duration : 2016 - 2019

Caldera (www.caldera.com) is a company specialized in software development for wide image processing. The goal of this collaboration is the development of a parallel and scalable image processing pipeline for industrial printing. The project started in September 2016 and it includes the industrial thesis (CIFRE) of Paul Godard, defended in Dec. 2019.

9. Partnerships and Cooperations

9.1. Regional Initiatives

9.1.1. ADT SPETABARU-H

Participants: Bérenger Bramas, Vincent Loechner, Paul Cardosi.

Duration: 2019 - 2021

The SPETABARU task-based runtime system is now being developed in CAMUS. This tool is the first runtime system build on the tasks and dependencies paradigm that supports speculative execution. It is at the same time a robust runtime system that could be used for high-performance applications, and the central component to perform research in parallelization, speculation and scheduling.

The SPETABARU-H project started in November 2019 for 2 years aims in improving SPETABARU on several aspects:

- Implement a generic speculative execution model based on the team's research;
- Implement the mechanisms to make SPETABARU supporting GPUs (and heterogeneous computing nodes in general);
- Split the management of the workers and the management of the graph of tasks to allow multiple independent graphs to be used on a single node;
- Use SPETABARU in the Complexes++ application, which is a bio-physic software for protein simulation;
- Maintain and update the code to keep it modern and up to date.

9.1.2. Idex Prim'Eau

Participant: Jens Gustedt [contact].

In the framework of the Prim'Eau project of the University of Strasbourg, we study surface runoff for hydrological periods of several days. We use an efficient domain decomposition method that we apply to a real world example of Mutterbach (Moselle) with geological and flood data from the years 1920, 1940 and 2017. As the time and memory usage for these computations is important, we aim to parallelize them.

9.2. National Initiatives

9.2.1. ANR AJACS

Participant: Arthur Charguéraud.

The AJACS research project is funded by the programme “Société de l’information et de la communication” of the ANR, from October 2014, until March 2019 http://ajacs.inria.fr/.

The goal of the AJACS project is to provide strong security and privacy guarantees on the client side for web application scripts implemented in JavaScript, the most widely used language for the Web. The proposal is to prove correct analyses for JavaScript programs, in particular information flow analyses that guarantee no secret information is leaked to malicious parties. The definition of sub-languages of JavaScript, with certified compilation techniques targeting them, will allow us to derive more precise analyses. Another aspect of the proposal is the design and certification of security and privacy enforcement mechanisms for web applications, including the APIs used to program real-world applications. Arthur Charguéraud focuses on the description of a formal semantics for JavaScript, and the development of tools for interactively executing programs step-by-step according to the formal semantics.

Partners: team Celtique (Inria Rennes - Bretagne Atlantique), team Prosecco (Inria Paris), team Indes (Inria Sophia Antipolis - Méditerranée), and Imperial College (London).

9.2.2. ANR Vocal

Participant: Arthur Charguéraud.

The Vocal research project is funded by the programme “Société de l’information et de la communication” of the ANR, from October 2015 until October 2020 https://vocal.lri.fr/.

The goal of the Vocal project is to develop the first formally verified library of efficient general-purpose data structures and algorithms. It targets the OCaml programming language, which allows for fairly efficient code and offers a simple programming model that eases reasoning about programs. The library will be readily available to implementers of safety-critical OCaml programs, such as Coq, Astrée, or Frama-C. It will provide the essential building blocks needed to significantly decrease the cost of developing safe software. The project intends to combine the strengths of three verification tools, namely Coq, Why3, and CFML. It will use Coq to obtain a common mathematical foundation for program specifications, as well as to verify purely functional components. It will use Why3 to verify a broad range of imperative programs with a high degree of proof automation. Finally, it will use CFML for formal reasoning about effectful higher-order functions and data structures making use of pointers and sharing.

Partners: team Gallium (Inria Paris), team DCS (Verimag), TrustInSoft, and OCamlPro.

9.3. European Initiatives

9.3.1. Collaborations with Major European Organizations

Benjamin Stamm and Muhammad Hassan: Université d’Aix-la-Chapelle RWTH, MATHCCES (Germany). An integral equation formulation of the N-body dielectricspheres problem.

Michael Wilczek and Cristian Lalescu: Max Planck Institute for Dynamics and Self-Organization (Germany). Pseudospectral direct numerical simulations (DNS) of the incompressible Navier-Stokes equations.

Juergen Koefinger: Max Planck Institute of Biophysics, Theoretical Biophysics (Germany). Monte-Carlo simulation for coarse grained protein models.

Pavel Kus: Czech Academy of Sciences, Institute of Mathematics (Tchequia). Direct solver for several matrices at a time.

9.4. International Initiatives

9.4.1. Informal International Partners

The CAMUS team has collaborated with the following entities in 2019:

- Reservoir Labs, New York, NY, USA (See subsection 7.3)
- University of Batna, Algeria (See subsection 7.16)
- Universidad Politécnica de Madrid, Spain (See subsection 7.4)
- Barcelona Supercomputing Center, Barcelona, Spain (See subsection 7.5)

9.5. International Research Visitors

9.5.1. Visits of International Scientists

9.5.1.1. Internships

Toufik Baroudi is a PhD student under the supervision of Rachid Seghir at the University of Batna (Algeria). He is co-advised by Vincent Loechner, and has been visiting our team as an intern for one year from Nov. 2018 to Nov. 2019, founded by the Algerian *Programme National Exceptionnel (PNE)*. His PhD defense is planned at the beginning of 2020.

Raquel Lazcano is a PhD student under the supervision of Eduardo Juárez Martínez at the University of Madrid. She is also co-advised by Philippe Clauss and has been visiting our team as an intern for three months, from February to April 2019. Her PhD defense is planned at the beginning of 2020.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events: Organisation

10.1.1.1. Member of the Organizing Committees

Philippe Clauss organized the Special Session on Compiler Architecture, Design and Optimization (CADO) of the 17th International Conference on High Performance Computing & Simulation (HPCS 2019), July 2019, Dublin, Ireland.

Philippe Clauss will organize the 10th edition of the International Workshop on Polyhedral Compilation Techniques, held in conjunction with HiPEAC 2020, January 22, 2020, Bologna, Italy.

Cédric Bastoul co-organized HIP3ES 2019 (International Workshop on High Performance Energy Efficient Embedded Systems), in conjunction with the international conference HiPEAC 2019.

Arthur Charguéraud co-organized the summer school École des Jeunes Chercheurs en Programmation (EJCP), June 2019, Strasbourg, France.

10.1.2. Scientific Events: Selection

10.1.2.1. Member of the Conference Program Committees

Vincent Loechner has been member of the program committees of HIP3ES 2019, PDP 2020, IMPACT 2020.

Philippe Clauss has been part of the program committees of: CC 2020 (ACM SIGPLAN International Conference on Compiler Construction); ICPP 2020 (49th International Conference on Parallel Processing); IPDRM 2019 (Third Annual Workshop on Emerging Parallel and Distributed Runtime Systems and Middleware, held in conjunction with the International Conference for High Performance Computing, Networking, Storage and Analysis, SC 19).

Arthur Charguéraud has been member of the program committees of ITP 2019, POPL 2020, OOPSLA 2019.

Cédric Bastoul has been part of the program committee of HiPC 2019 (IEEE International Conference on High Performance Computing, Data and Analytics), HIP3ES 2019 (International Workshop on High Performance Energy Efficient Embedded Systems), IMPACT 2019 (International Workshop on Polyhedral Compilation Techniques), CADO 2019 (Special Session on Compiler Architecture, Design and Optimization of the 17th International Conference on High Performance Computing & Simulation - HPCS 2019).

10.1.2.2. Reviewer

Bérenger Bramas has been a reviewer for COMPAS 2019 and PDP 2020.
Arthur Charguéraud has been a reviewer for FOSSACS 2020 and ESOP 2020.

10.1.3. Journal

10.1.3.1. Member of the Editorial Boards

Since October 2001, J. Gustedt is the Editor-in-Chief of the journal *Discrete Mathematics and Theoretical Computer Science* (DMTCS).

10.1.3.2. Reviewer - Reviewing Activities

Bérenger Bramas has been a reviewer for the following journals: Journal of Parallel Computing (Elsevier), Journal of Parallel and Distributed Computing (Elsevier), Journal of Computer Science and Technology (Springer), Parallel Processing Letters (World Scientific), Software: Practice and Experience (Wiley).
Philippe Clauss has been a reviewer for the Journal of Software: Practice and Experience (Wiley).

10.1.4. Invited Talks

Cédric Bastoul delivered the invited talk "Loop Optimization: A Matter of Art and Science" at the Huawei Symposium on Foundations of Software 2019.

10.1.5. Scientific Expertise

10.1.5.1. Standardization

Since Nov. 2014, Jens Gustedt has been a member of the ISO working group SC22-WG14 for the standardization of the C programming language and serves as a co-editor of the standards document, see [46], [47], [40], [33]. He participates actively in the clarification report processing, the planning of future versions of the standard and in a subgroup that discusses the improvement of the C memory model, see [45], [35], [48].

He was one of the main forces behind the elaboration of C17, the new version of the C standard that has been published by ISO in 2018 [51] and contributes to the future standard "C2x" in various ways. In particular he proposed the removal of the so-called K&R definitions [27], the reform of sign representation [25], [26], maximum width integers [44], keywords [31], [41], [36], [36], null pointer constants [34], timing interfaces [37], [30], [30], atomicity and synchronization [42], [32], [39], and function error conventions [28]. Most of these are either integrated in the latest draft or have been adopted subject to reformulations and adaptations.

10.1.5.2. Expertise

Philippe Clauss has been a reviewer for a promotion case to Full Professor in a US University.
Cédric Bastoul has been an expert for the French research ministry and the French finance ministry for the research tax credit programme.

10.1.6. Research Administration

Cédric Bastoul, Philippe Clauss and Vincent Loechner are members of the *Comité d'Experts (section 27, informatique)* of the Université de Strasbourg, providing their scientific and teaching expertise to the university and to the academy. In particular, this committee is involved in the recruitment of researchers and teachers in computer science. Philippe Clauss has been the Vice President of the committee since April 2019.
Jens Gustedt is the head of the ICPS team for the ICube lab, and in that function a member of the board of directors of the lab. He is also a member of the local recruitment committee for PhD students and postdocs of Inria Center Nancy — Grand Est.
Philippe Clauss and Cédric Bastoul are members of the *Collegium Sciences* of the University of Strasbourg, which is a group of representative scientists providing advice regarding the funding of projects.

Philippe Clauss is a member of the *Bureau du Comité des Projets* of the Inria Center Nancy — Grand Est. This group of scientists provides scientific expertise to the Director of the Center.

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Master: Bérenger Bramas, Compilation and Performance, 39h, M2, Université de Strasbourg, France

Master: Bérenger Bramas, Compilation, 30h, M1, Université de Strasbourg, France

Licence: Vincent Loechner, responsable pédagogique de la licence professionnelle ASSR-ARS, L3, Université de Strasbourg, France

Licence: Vincent Loechner, algorithmique et programmation, 168h, L1, Université de Strasbourg, France

Licence: Vincent Loechner, administration système et internet, 45h, L3, Université de Strasbourg, France

Licence: Vincent Loechner, programmation parallèle, 23h, L3, Université de Strasbourg, France

Master: Vincent Loechner, programmation temps réel, 10h, M2, Université de Strasbourg, France

Master: Vincent Loechner, calcul parallèle, 20h, 3ième année école d'ingénieur (TPS), Université de Strasbourg, France

Licence: Philippe Clauss, Computer architecture, 18h, L2, Université de Strasbourg, France

Licence: Philippe Clauss, Bases of computer architecture, 22h, L1, Université de Strasbourg, France

Master: Philippe Clauss, Compilation, 84h, M1, Université de Strasbourg, France

Master: Philippe Clauss, Real-time programming and system, 37h, M1, Université de Strasbourg, France

Master: Philippe Clauss, Code optimization and transformation, 31h, M1, Université de Strasbourg, France

Licence (Math-Info): Alain Ketterlin, Algorithmique et programmation, L1, 96h, Université de Strasbourg, France

Licence (Math-Info): Alain Ketterlin, Architecture des systèmes d'exploitation, L3, 38h, Université de Strasbourg, France

Licence (Math-Info): Alain Ketterlin, Programmation système, L2, 40h, Université de Strasbourg, France

Master (Informatique): Alain Ketterlin, Preuves assistées par ordinateur, 18h, Université de Strasbourg, France

Licence: Éric Violard, Modèles de Calcul, 29h, L1, Université de Strasbourg, France

Licence: Éric Violard, Programmation fonctionnelle, 162h, L1, Université de Strasbourg, France

Licence: Éric Violard, Bases de l'architecture informatique, 62h, L1, Université de Strasbourg, France

Licence: Éric Violard, Architecture des ordinateurs, 45h, L2, Université de Strasbourg, France

Licence: Éric Violard, Systèmes concurrents, 9h, L3, Université de Strasbourg, France

Licence: Cédric Bastoul, Computer architecture, 78h, L1, Université de Strasbourg, France, and 25h, L1, UFAZ Azerbaijani-French University, Azerbaijan

Licence: Cédric Bastoul, Parallel programming, 20h, L3, Université de Strasbourg, France, and 25h, L3, UFAZ Azerbaijani-French University, Azerbaijan

Master: Cédric Bastoul, Compiler Design, 48h, M1, Université de Strasbourg, France

Master: Cédric Bastoul, Project Management, 16h, M1, Université de Strasbourg, France

Master: Cédric Bastoul, Introduction to Research, 3h, L2+M1, Université de Strasbourg, France

10.2.2. Supervision

PhD: Armaël Géneau, *Formal verification of complexity analyses*, co-advised by Arthur Charguéraud and François Pottier, defended on December 16th, 2019.

PhD: Paul Godard, *Parallélisation et passage à l'échelle durable d'une chaîne de traitement graphique pour l'impression professionnelle*, Université de Strasbourg, Dec. 16, 2019. Cédric Bastoul and Vincent Loechner.

PhD: Maxime Schmitt, *Génération automatique de codes adaptatifs*, Université de Strasbourg, Sept. 30, 2019. Cédric Bastoul and Philippe Helluy.

PhD: Daniel Salas, *Parallélisation hybride d'une application de détection de noyaux cellulaires*, Université de Strasbourg, Sept. 10, 2019. Jens Gustedt.

PhD in progress: Harenome Ranaivoarivony-Razanajato, *Hierarchical Parallelization and Optimization*, Oct. 2016, Cédric Bastoul and Vincent Loechner.

PhD in progress: Salwa Kobeissi, *Dynamic parallelization of recursive functions by transformation into loops*, since Sept. 2017, Philippe Clauss.

10.2.3. Juries

Philippe Clauss participated in the following PhD committees in 2019:

Date	**Candidate**	**Place**	**Role**
Jan. 28	Hugo Brunie	Université de Bordeaux	Reviewer
Oct. 25	Ksander EJJAAOUANI	Université de Strasbourg	President
Dec. 9	Arif Ali ANAPPARAKKAL	Université de Rennes	Examiner
Dec. 19	Hang YU	Université Grenoble Alpes	Reviewer

Cédric Bastoul participated in the following PhD committees in 2019:

Date	**Candidate**	**Place**	**Role**
Mar. 29	Pierre Huchant	Université de Bordeaux	Reviewer
Jun. 21	Chandan Reddy	École Normale Supérieure	Reviewer

10.3. Popularization

- A. Charguéraud is a co-organizer of the *Concours Castor informatique*. The purpose of the Concours Castor in to introduce pupils (from *CM1* to *Terminale*) to computer sciences. More than 700,000 teenagers played with the interactive exercises in November 2019. More information on: http://castor-informatique.fr/.

10.3.1. Articles and contents

- Jens Gustedt authored the book *Modern C* [24], which since the first publication of an online draft in 2016 has become one of the major references for the C programming language.
- Jens Gustedt is blogging about efficient programming, in particular about the C programming language. He also is an active member of the stackoverflow community, a technical Q&A site for programming and related subjects.

10.3.2. Education

- Cédric Bastoul participated in the training of high school teachers involved in the forthcoming optional Computer Science course for high school students. Specifically, he produced lectures and materials to teach Computer Architecture to high school students.

10.3.3. Interventions

- Vincent Loechner has been organizing a hub for the Google Hashcode programming contest (online qualification round) at Université de Strasbourg in Feb. 2019. More than 30 students and colleagues were hosted in the university classrooms to participate to this event.
- Cédric Bastoul delivered a presentation on program optimization at "Journée des licences" ("Bachelor Day") in June 2019.

10.3.4. Internal action

- Bérenger Bramas, Jens Gustedt and other members of the scientific computing group (*axe transverse calcul scientifique*) organized two software corners at the ICube laboratory. A software corner is a meeting where researchers exchange about programming best practices, existing and upcoming tools, and their own experiences.

11. Bibliography

Major publications by the team in recent years

[1] P. Clauss, E. Altintas, M. Kuhn.*Automatic Collapsing of Non-Rectangular Loops*, in "Parallel and Distributed Processing Symposium (IPDPS), 2017", Orlando, United States, IEEE International, May 2017, p. 778 - 787 [*DOI :* 10.1109/IPDPS.2017.34], https://hal.inria.fr/hal-01581081

[2] P.-N. Clauss, J. Gustedt.*Iterative Computations with Ordered Read-Write Locks*, in "Journal of Parallel and Distributed Computing", 2010, vol. 70, n^o^ 5, p. 496–504 [*DOI :* 10.1016/j.jpdc.2009.09.002], https://hal.inria.fr/inria-00330024

[3] A. Ketterlin, P. Clauss.*Prediction and trace compression of data access addresses through nested loop recognition*, in "6th annual IEEE/ACM international symposium on Code generation and optimization", Boston, USA, ACM, April 2008, p. 94-103, http://dx.doi.org/10.1145/1356058.1356071

[4] A. Ketterlin, P. Clauss.*Profiling Data-Dependence to Assist Parallelization: Framework, Scope, and Optimization*, in "MICRO-45, The 45th Annual IEEE/ACM International Symposium on Microarchitecture", Vancouver, Canada, December 2012, https://hal.inria.fr/hal-00780782

[5] J. M. Martinez Caamano, M. Selva, P. Clauss, A. Baloian, W. Wolff.*Full runtime polyhedral optimizing loop transformations with the generation, instantiation, and scheduling of code-bones*, in "Concurrency and Computation: Practice and Experience", June 2017, vol. 29, n^o^ 15 [*DOI :* 10.1002/cpe.4192], https://hal.inria.fr/hal-01581093

[6] A. Sukumaran-Rajam, P. Clauss.*The Polyhedral Model of Nonlinear Loops*, in "ACM Transactions on Architecture and Code Optimization", January 2016, vol. 12, n^o^ 4 [*DOI :* 10.1145/2838734], https://hal.inria.fr/hal-01244464

Publications of the year

Doctoral Dissertations and Habilitation Theses

[7] D. Salas.*Hybrid parallellization of a cell nuclei detection application*, Université de Strasbourg, September 2019, https://tel.archives-ouvertes.fr/tel-02384725

[8] M. SCHMITT.*Automatic Generation of Adaptive Codes*, Université de Strasbourg, September 2019, https://hal.inria.fr/tel-02327764

Articles in International Peer-Reviewed Journal

[9] B. BRAMAS.*Impact study of data locality on task-based applications through the Heteroprio scheduler*, in "PeerJ Computer Science", May 2019 [*DOI :* 10.7717/PEERJ-CS.190], https://hal.inria.fr/hal-02120736

[10] B. BRAMAS.*Increasing the degree of parallelism using speculative execution in task-based runtime systems*, in "PeerJ Computer Science", 2019, vol. 5, e183 [*DOI :* 10.7717/PEERJ-CS.183], https://hal.inria.fr/hal-02070576

[11] B. BRAMAS, A. KETTERLIN.*Improving parallel executions by increasing task granularity in task-based runtime systems using acyclic DAG clustering*, in "PeerJ Computer Science", January 2020 [*DOI :* 10.7717/PEERJ-CS.247], https://hal.inria.fr/hal-02436826

[12] A. CHARGUÉRAUD, F. POTTIER.*Verifying the Correctness and Amortized Complexity of a Union-Find Implementation in Separation Logic with Time Credits*, in "Journal of Automated Reasoning", March 2019, vol. 62, n^{o} 3, p. 331–365 [*DOI :* 10.1007/S10817-017-9431-7], https://hal.inria.fr/hal-01652785

Invited Conferences

[13] B. BRAMAS.*SPETABARU: A Task-based Runtime System with Speculative Execution Capability*, in "SIAM CSE 2019 - SIAM Conference on Computational Science and Engineering", Spokane, United States, February 2019, https://hal.inria.fr/hal-02050190

International Conferences with Proceedings

[14] U. A. ACAR, V. AKSENOV, A. CHARGUÉRAUD, M. RAINEY.*Provably and Practically Efficient Granularity Control*, in "PPoPP 2019 - Principles and Practice of Parallel Programming", Washington DC, United States, February 2019 [*DOI :* 10.1145/3293883.3295725], https://hal.inria.fr/hal-01973285

[15] A. CHARGUÉRAUD, J.-C. FILLIÂTRE, C. LOURENÇO, M. PEREIRA.*GOSPEL -Providing OCaml with a Formal Specification Language*, in "FM 2019 - 23rd International Symposium on Formal Methods", Porto, Portugal, October 2019, https://hal.inria.fr/hal-02157484

[16] J. GUSTEDT, M. MOGÉ.*Memory access classification for vertical task parallelism*, in "PDP 2019 - 27th Euromicro International Conference on Parallel, Distributed and Network-Based Processing", Pavia, Italy, IEEE, February 2019, https://hal.inria.fr/hal-02046105

[17] A. GUÉNEAU, J.-H. JOURDAN, A. CHARGUÉRAUD, F. POTTIER.*Formal Proof and Analysis of an Incremental Cycle Detection Algorithm : (extended version)*, in "Interactive Theorem Proving", Portland, United States, J. HARRISON, J. O'LEARY, A. TOLMACH (editors), Schloss Dagstuhl–Leibniz-Zentrum fuer Informatik, September 2019, n^{o} 141, https://hal.inria.fr/hal-02167236

[18] M. SCHMITT, P. HELLUY, C. BASTOUL.*Automatic adaptive approximation for stencil computations*, in "CC 2019 - 28th International Conference on Compiler Construction", Washington, United States, ACM Press, February 2019, p. 170-181 [*DOI :* 10.1145/3302516.3307348], https://hal.inria.fr/hal-02072737

Conferences without Proceedings

[19] P. GODARD.*Échanges non bloquants de données ordonnées entre producteurs multiples et consommateur unique*, in "COMPAS'2019", Anglet, France, June 2019, https://hal.archives-ouvertes.fr/hal-02381769

[20] P. GODARD, V. LOECHNER, C. BASTOUL, F. SOULIER, G. MULLER.*A Flexible and Distributed Runtime System for High-Throughput Constrained Data Streams Generation*, in "IPDPSW 2019 - IEEE International Symposium on Parallel and Distributed Processing, Workshops and Phd Forum", Rio de Janeiro, Brazil, IEEE, May 2019, p. 718-728 [*DOI :* 10.1109/IPDPSW.2019.00120], https://hal.archives-ouvertes.fr/hal-02381750

[21] S. HARIRI, S. WEILL, J. GUSTEDT, I. CHARPENTIER.*Pairing GIS and distributed hydrological models using Matlab 2*, in "CAJG - 2nd Conference of the Arabian Journal of Geosiences", Sousse, Tunisia, November 2019, https://hal.archives-ouvertes.fr/hal-02333260

[22] S. KOBEISSI, P. CLAUSS.*The Polyhedral Model Beyond Loops Recursion Optimization and Parallelization Through Polyhedral Modeling*, in "IMPACT 2019 - 9th International Workshop on Polyhedral Compilation Techniques, In conjunction with HiPEAC 2019", Valencia, Spain, January 2019, https://hal.inria.fr/hal-02059558

[23] B. MEISTER, P. CLAUSS.*Uniform Random Sampling in Polyhedra*, in "10th International Workshop on Polyhedral Compilation Techniques", Bologna, Italy, January 2020, https://hal.inria.fr/hal-02425752

Scientific Books (or Scientific Book chapters)

[24] J. GUSTEDT.*Modern C*, Manning, November 2019, https://hal.inria.fr/hal-02383654

Research Reports

[25] J.-F. BASTIEN, J. GUSTEDT.*Moving to two's complement sign representation*, ISO JCT1/SC22/WG14, January 2019, n^{o} N2330, https://hal.inria.fr/hal-02046444

[26] J.-F. BASTIEN, J. GUSTEDT.*Two's complement sign representation for C2x*, ISO JCT1/SC22/WG14, August 2019, N2412, https://hal.inria.fr/hal-02311453

[27] L. G. BJØNNES, J. GUSTEDT.*Remove support for function definitions with identifier lists*, ISO JCT1/SC22/WG14, September 2019, n^{o} N2432, https://hal.inria.fr/hal-02311466

[28] N. DOUGLAS, J. GUSTEDT.*Function failure annotation*, ISO JCT1/SC22/WG14, September 2019, n^{o} N2429, https://hal.inria.fr/hal-02311462

[29] J. GUSTEDT.*Add an interface to query resolution of time bases : Proposal for C2x*, ISO JTC1/SC22/WG14, November 2019, n^{o} N2459, https://hal.inria.fr/hal-02378605

[30] J. GUSTEDT.*Add new optional time bases v3 Proposal for C2x*, ISO JCT1/SC22/WG14, November 2019, n^{o} N2460, https://hal.inria.fr/hal-02378645

[31] J. GUSTEDT.*Align spelling of keywords with C++ and make them feature tests proposal for C2x*, ISO JCT1/SC22/WG14, April 2019, n^{o} n2368, https://hal.inria.fr/hal-02089925

[32] J. GUSTEDT.*Clean up atomics, non-normative changes : proposal for integration to C2x*, ISO JTC1/SC22/WG14, June 2019, n^{o} N2389, https://hal.inria.fr/hal-02167823

[33] J. GUSTEDT.*Contain the floating point naming explosion*, ISO JCT1/SC22/WG14, September 2019, n^{o} N2426, https://hal.inria.fr/hal-02311460

[34] J. GUSTEDT.*Introduce the nullptr constant*, ISO JTC1/SC22/WG14, June 2019, n^{o} N2394, https://hal.inria.fr/hal-02167929

[35] J. GUSTEDT.*Introduce the term storage instance*, ISO JTC1/SC22/WG14, June 2019, n^{o} N2388, A previous version of this document was N2328, https://hal.inria.fr/hal-02046329

[36] J. GUSTEDT.*Make false and true first-class language features : proposal for C2x*, ISO JTC1/SC22/WG14, November 2019, n^{o} N2458, https://hal.inria.fr/hal-02167916

[37] J. GUSTEDT.*Modernize time.h functions*, ISO JCT1/SC22/WG14, September 2019, n^{o} N2417, https://hal.inria.fr/hal-02311454

[38] J. GUSTEDT.*Out-of-band bit for exceptional return and errno replacement*, ISO JCT1/SC22/WG14, April 2019, n^{o} N2361, https://hal.inria.fr/hal-02089873

[39] J. GUSTEDT.*Remove ATOMIC VAR INIT*, ISO JTC1/SC22/WG14, June 2019, n^{o} N2390, https://hal.inria.fr/hal-02167838

[40] J. GUSTEDT.*Remove conditional "WANT" macros from numbered clauses proposal for C2x*, ISO JTC1/SC22/WG14, April 2019, n^{o} N2359, https://hal.inria.fr/hal-02089861

[41] J. GUSTEDT.*Revise spelling of keywords : proposal for C2x*, ISO JTC1/SC22/WG14, June 2019, n^{o} N2457, https://hal.inria.fr/hal-02167870

[42] J. GUSTEDT.*Synchronization at thread and execution termination : proposal for integration to C2x*, ISO JTC1/SC22/WG14, September 2019, n^{o} N2461, https://hal.inria.fr/hal-02167850

[43] J. GUSTEDT.*Unify string representation functions*, ISO JCT1/SC22/WG14, April 2019, https://hal.inria.fr/hal-02089868

[44] J. GUSTEDT.*intmax_t, a way out*, ISO JCT1/SC22/WG14, September 2019, n^{o} N2425, https://hal.inria.fr/hal-02311457

[45] J. GUSTEDT, P. SEWELL, K. MEMARIAN, V. B. F. GOMES, M. UECKER.*Moving to a provenance-aware memory object model for C: proposal for C2x*, ISO JCT1/SC22/WG14, April 2019, n^{o} N2362, https://hal.inria.fr/hal-02089889

[46] L. JONES, J. GUSTEDT.*ISO/IEC 9899 editor report March 2019*, ISO JCT1/SC22/WG14, March 2019, n^{o} N2348, https://hal.inria.fr/hal-02089676

[47] L. JONES, J. GUSTEDT.*ISO/IEC 9899 editor report November 2019*, ISO JCT1/SC22/WG14, November 2019, n^{o} N2456, https://hal.inria.fr/hal-02378784

[48] P. SEWELL, K. MEMARIAN, V. B. F. GOMES, J. GUSTEDT, M. UECKER.*C provenance semantics: examples*, ISO JCT1/SC22/WG14, April 2019, n° N2363, https://hal.inria.fr/hal-02089907

Other Publications

[49] M. BOILEAU, B. BRAMAS, E. FRANCK, P. HELLUY, L. NAVORET.*Parallel lattice-boltzmann transport solver in complex geometry*, December 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-02404082

[50] B. BRAMAS, P. HELLUY, L. MENDOZA, B. WEBER.*Optimization of a discontinuous finite element solver with OpenCL and StarPU*, July 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-01942863

References in notes

[51] JTC1/SC22/WG14 (editor). *Programming languages - C*, ISO, 2018, n° ISO/IEC 9899

[52] U. A. ACAR, A. CHARGUÉRAUD, M. RAINEY.*Oracle-Guided Scheduling for Controlling Granularity in Implicitly Parallel Languages*, in "Journal of Functional Programming", November 2016, vol. 26 [*DOI :* 10.1017/S0956796816000101], https://hal.inria.fr/hal-01409069

[53] C. BASTOUL.*Code Generation in the Polyhedral Model Is Easier Than You Think*, in "PACT'13 IEEE International Conference on Parallel Architecture and Compilation Techniques", Juan-les-Pins, France, 2004, p. 7–16, https://hal.archives-ouvertes.fr/ccsd-00017260

[54] B. BRAMAS, M. HASSAN, B. STAMM.*An Integral Equation Formulation of the N-body Dielectric Spheres Problem. Part II: Complexity Analysis*, 2019

[55] A. GUÉNEAU, A. CHARGUÉRAUD, F. POTTIER.*A Fistful of Dollars: Formalizing Asymptotic Complexity Claims via Deductive Program Verification*, in "ESOP 2018 - 27th European Symposium on Programming", Thessaloniki, Greece, A. AHMED (editor), LNCS - Lecture Notes in Computer Science, Springer, April 2018, vol. 10801, Held as Part of the European Joint Conferences on Theory and Practice of Software, ETAPS 2018 [*DOI :* 10.1007/978-3-319-89884-1_19], https://hal.inria.fr/hal-01926485

[56] M. HALL, D. PADUA, K. PINGALI.*Compiler research: the next 50 years*, in "Commun. ACM", 2009, vol. 52, n° 2, p. 60–67, http://doi.acm.org/10.1145/1461928.1461946

[57] A. HOBOR, A. W. APPEL, F. Z. NARDELLI.*Oracle Semantics for Concurrent Separation Logic*, in "ESOP", 2008, p. 353-367

Project-Team CAPSID

Computational Algorithms for Protein Structures and Interactions

IN COLLABORATION WITH: Laboratoire lorrain de recherche en informatique et ses applications (LORIA)

IN PARTNERSHIP WITH:
CNRS

Université de Lorraine

RESEARCH CENTER
Nancy - Grand Est

THEME
Computational Biology

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Project-Team CAPSID

Creation of the Team: 2015 January 01, updated into Project-Team: 2015 July 01

The CAPSID team has lost its leader Dave Ritchie who passed away on September 15, 2019. Marie-Dominique Devignes is the new leader of the CAPSID team.

Keywords:

Computer Science and Digital Science:

A3.1.1. - Modeling, representation
A3.1.9. - Database
A3.1.10. - Heterogeneous data
A3.1.11. - Structured data
A3.2.1. - Knowledge bases
A3.2.2. - Knowledge extraction, cleaning
A3.2.4. - Semantic Web
A3.2.5. - Ontologies
A3.2.6. - Linked data
A3.3.2. - Data mining
A3.5.1. - Analysis of large graphs
A6.1.4. - Multiscale modeling
A6.2.7. - High performance computing
A6.3.3. - Data processing
A6.5.5. - Chemistry
A8.2. - Optimization
A9.1. - Knowledge
A9.2. - Machine learning

Other Research Topics and Application Domains:

B1.1.1. - Structural biology
B1.1.2. - Molecular and cellular biology
B1.1.7. - Bioinformatics
B2.2.1. - Cardiovascular and respiratory diseases
B2.2.4. - Infectious diseases, Virology
B2.4.1. - Pharmaco kinetics and dynamics

1. Team, Visitors, External Collaborators

Research Scientists

Marie-Dominique Devignes [Team leader, CNRS, Researcher, HDR]
Isaure Chauvot de Beauchêne [CNRS, Researcher]
Bernard Maigret [CNRS, Emeritus]
David Ritchie [Inria, Senior Researcher, until Sep 2019, HDR]

Faculty Members

Sabeur Aridhi [Université de Lorraine, Associate Professor]
Malika Smaïl-Tabbone [Université de Lorraine, Associate Professor, HDR]

External Collaborators

Taha Boukhobza [Université de Lorraine]
Sjoerd Jacob de Vries [INSERM]
Vincent Leroux [Univ Denis Diderot, until Jun 2019]

Technical Staff

Emmanuel Bresso [CNRS, Engineer]
Claire Lacomblez [CNRS, Engineer, until Nov 2019]
Philippe Noel [CNRS, Engineer, from Sep 2019]

PhD Students

Wissem Inoubli [Université de Lorraine, ATER, from Oct 2019]
Diego Amaya Ramirez [Inria, PhD Student, from Oct 2019]
Kévin Dalleau [CNRS, PhD Student]
Hrishikesh Dhondge [CNRS, PhD Student, from Oct 2019]
Kamrul Islam [Université de Lorraine, PhD Student, from Oct 2019]
Anna Kravchenko [CNRS, PhD Student, from Oct 2019]
Antoine Moniot [Université de Lorraine, PhD Student]
Gabin Personeni [CNRS, PhD Student, until Mar 2019]
Maria Elisa Ruiz Echartea [Inria, PhD Student]
Bishnu Sarker [Inria, PhD Student]
Athenaïs Vaginay [Université de Lorraine, PhD Student]

Post-Doctoral Fellows

Amina Ahmed Nacer [Université de Lorraine, Post-Doctoral Fellow, from Jul 2019]
Dominique Mias Lucquin [Université de Lorraine, Post-Doctoral Fellow, from May 2019]

Administrative Assistants

Antoinette Courrier [CNRS, Administrative Assistant]
Isabelle Herlich [Inria, Administrative Assistant]

2. Overall Objectives

2.1. Computational Challenges in Structural Biology

Many of the processes within living organisms can be studied and understood in terms of biochemical interactions between large macromolecules such as DNA, RNA, and proteins. To a first approximation, DNA may be considered to encode the blueprint for life, whereas proteins and RNA make up the three-dimensional (3D) molecular machinery. Many biological processes are governed by complex systems of proteins which interact cooperatively to regulate the chemical composition within a cell or to carry out a wide range of biochemical processes such as photosynthesis, metabolism, and cell signalling, for example. It is becoming increasingly feasible to isolate and characterise some of the individual protein components of such systems, but it still remains extremely difficult to achieve detailed models of how these complex systems actually work. Consequently, a new multidisciplinary approach called integrative structural biology has emerged which aims to bring together experimental data from a wide range of sources and resolution scales in order to meet this challenge [69], [56].

Understanding how biological systems work at the level of 3D molecular structures presents fascinating challenges for biologists and computer scientists alike. Despite being made from a small set of simple chemical building blocks, protein molecules have a remarkable ability to self-assemble into complex molecular machines which carry out very specific biological processes. As such, these molecular machines may be considered as complex systems because their properties are much greater than the sum of the properties of their component parts.

The overall objective of the Capsid team is to develop algorithms and software to help study biological systems and phenomena from a structural point of view. In particular, the team aims to develop algorithms which can help to model the structures of large multi-component biomolecular machines and to develop tools and techniques to represent and mine knowledge of the 3D shapes of proteins and protein-protein interactions. Thus, a unifying theme of the team is to tackle the recurring problem of representing and reasoning about large 3D macromolecular shapes. More specifically, our aim is to develop computational techniques to represent, analyse, and compare the shapes and interactions of protein molecules in order to help better understand how their 3D structures relate to their biological function. In summary, the Capsid team is organized according to two research axes whose complementarity constitutes an original contribution to the field of structural bioinformatics:

- Axis 1: New Approaches for Knowledge Discovery in Structural Databases,
- Axis 2: Integrative Multi-Component Assembly and Modeling.

As indicated above, structural biology is largely concerned with determining the 3D atomic structures of proteins, RNA, and DNA molecules, and then using these structures to study their biological properties and interactions. Each of these activities can be extremely time-consuming. Solving the 3D structure of even a single protein using X-ray crystallography or nuclear magnetic resonance (NMR) spectroscopy can often take many months or even years of effort. Even simulating the interaction between two proteins using a detailed atomistic molecular dynamics simulation can consume many thousands of CPU-hours. While most X-ray crystallographers, NMR spectroscopists, and molecular modelers often use conventional sequence and structure alignment tools to help propose initial structural models through the homology principle, they often study only individual structures or interactions at a time. Due to the difficulties outlined above, only relatively few research groups are able to solve the structures of large multi-component systems.

Similarly, most current algorithms for comparing protein structures, and especially those for modeling protein interactions, work only at the pair-wise level. Of course, such calculations may be accelerated considerably by using dynamic programming (DP) or fast Fourier transform (FFT) techniques. However, it remains extremely challenging to scale up these techniques to model multi-component systems. For example, the use of high performance computing (HPC) facilities may be used to accelerate arithmetically intensive shape-matching calculations, but this generally does not help solve the fundamentally combinatorial nature of many multi-component problems. It is therefore necessary to devise heuristic hybrid approaches which can be tailored to exploit various sources of domain knowledge. We therefore set ourselves the following main computational objectives:

- classify and mine protein structures and protein-protein interactions,
- develop multi-component assembly techniques for integrative structural biology.

3. Research Program

3.1. Classifying and Mining Protein Structures and Protein Interactions

3.1.1. Context

The scientific discovery process is very often based on cycles of measurement, classification, and generalisation. It is easy to argue that this is especially true in the biological sciences. The proteins that exist today represent the molecular product of some three billion years of evolution. Therefore, comparing protein sequences and structures is important for understanding their functional and evolutionary relationships [67], [48]. There is now overwhelming evidence that all living organisms and many biological processes share a common ancestry in the tree of life. Historically, much of bioinformatics research has focused on developing mathematical and statistical algorithms to process, analyse, annotate, and compare protein and DNA sequences because such sequences represent the primary form of information in biological systems. However, there is growing evidence that structure-based methods can help to predict networks of protein-protein interactions (PPIs) with greater accuracy than those which do not use structural evidence [52], [70]. Therefore, developing techniques which can mine knowledge of protein structures and their interactions is an important way to enhance our knowledge of biology [39].

3.1.2. Formalising and Exploiting Domain Knowledge

Concerning protein structure classification, we aim to explore novel classification paradigms to circumvent the problems encountered with existing hierarchical classifications of protein folds and domains. In particular it will be interesting to set up fuzzy clustering methods taking advantage of our previous work on gene functional classification [43], but instead using Kpax domain-domain similarity matrices. A non-trivial issue with fuzzy clustering is how to handle similarity rather than mathematical distance matrices, and how to find the optimal number of clusters, especially when using a non-Euclidean similarity measure. We will adapt the algorithms and the calculation of quality indices to the Kpax similarity measure. More fundamentally, it will be necessary to integrate this classification step in the more general process leading from data to knowledge called Knowledge Discovery in Databases (KDD) [46].

Another example where domain knowledge can be useful is during result interpretation: several sources of knowledge have to be used to explicitly characterise each cluster and to help decide its validity. Thus, it will be useful to be able to express data models, patterns, and rules in a common formalism using a defined vocabulary for concepts and relationships. Existing approaches such as the Molecular Interaction (MI) format [49] developed by the Human Genome Organization (HUGO) mostly address the experimental wet lab aspects leading to data production and curation [58]. A different point of view is represented in the Interaction Network Ontology (INO), a community-driven ontology that aims to standardise and integrate data on interaction networks and to support computer-assisted reasoning [71]. However, this ontology does not integrate basic 3D concepts and structural relationships. Therefore, extending such formalisms and symbolic relationships will be beneficial, if not essential, when classifying the 3D shapes of proteins at the domain family level.

Domain family classification is also relevant for studying domain-domain interactions (DDI). Our previous work on Knowledge-Based Docking (KBDOCK, [3], [5] will be updated and extended using newly published DDIs. Methods for inferring new DDIs from existing protein-protein interactions (PPIs) will be developped. Efforts should be made for validating such inferred DDIs so that they can be used to enrich DDI classification and predict new PPIs.

In parallel, we also intend to design algorithms for leveraging information embedded in biological knowledge graphs (also known as complex networks). Knowledge graphs mostly represent PPIs, integrated with various properties attached to proteins, such as pathways, drug binding or relation with diseases. Setting up similarity measures for proteins in a knowledge graph is a difficult challenge. Our objective is to extract useful knowledge from such graphs in order to better understand and highlight the role of multi-component assemblies in various types of cell or organisms. Ultimately, knowledge graphs can be used to model and simulate the functioning of such molecular machinery in the context of the living cell, under physiological or pathological conditions.

3.1.3. Function Annotation in large protein graphs

Knowledge of the functional properties of proteins can shed considerable light on how they might interact. However, huge numbers of protein sequences in public databases such as UniProt/TrEMBL lack any functional annotation, and the functional annotation of such sequences is a highly challenging problem. We are developing graph-based and machine learning techniques to annotate automatically the available unannotated sequences with functional properties such as EC numbers and Gene Ontology (GO) terms (note that these terms are organized hierarchically allowing generalization/specialization reasoning). The idea is to transfer annotations from expert-reviewed sequences present in the UniProt/SwissProt database (about 560 thousands entries) to unreviewed sequences present in the UniProt/TrEMBL database (about 80% of 180 millions entries). For this, we have to learn from the UniProt/SwissProt database how to compute the similarity of proteins sharing identical or similar functional annotations. Various similarity measures can be tested using cross-validation approches in the UniProt/SwissProt database. For instance, we can use primary sequence or domain signature similarities. More complex similarities can be computed with graph-embedding techniques.

This work is in progress with Bishnu Sarker's PhD project and a first approach called GrAPFI (Graph-based Automatic Protein Function Inference) was presented at conferences in 2018 [11], [12].

3.2. Integrative Multi-Component Assembly and Modeling

3.2.1. Context

At the molecular level, each PPI is embodied by a physical 3D protein-protein interface. Therefore, if the 3D structures of a pair of interacting proteins are known, it should in principle be possible for a docking algorithm to use this knowledge to predict the structure of the complex. However, modeling protein flexibility accurately during docking is very computationally expensive. This is due to the very large number of internal degrees of freedom in each protein, associated with twisting motions around covalent bonds. Therefore, it is highly impractical to use detailed force-field or geometric representations in a brute-force docking search. Instead, most protein docking algorithms use fast heuristic methods to perform an initial rigid-body search in order to locate a relatively small number of candidate binding orientations, and these are then refined using a more expensive interaction potential or force-field model, which might also include flexible refinement using molecular dynamics (MD), for example.

3.2.2. Polar Fourier Docking Correlations

In our *Hex* protein docking program [60], the shape of a protein molecule is represented using polar Fourier series expansions of the form

$$\sigma(\underline{x}) = \sum_{nlm} a_{nlm} R_{nl}(r) y_{lm}(\theta, \phi), \tag{1}$$

where $\sigma(\underline{x})$ is a 3D shape-density function, a_{nlm} are the expansion coefficients, $R_{nl}(r)$ are orthonormal Gauss-Laguerre polynomials and $y_{lm}(\theta, \phi)$ are the real spherical harmonics. The electrostatic potential, $\phi(\underline{x})$, and charge density, $\rho(\underline{x})$, of a protein may be represented using similar expansions. Such representations allow the *in vacuo* electrostatic interaction energy between two proteins, A and B, to be calculated as [51]

$$E = \frac{1}{2}\int \phi_A(\underline{x})\rho_B(\underline{x})\mathrm{d}\underline{x} + \frac{1}{2}\int \phi_B(\underline{x})\rho_A(\underline{x})\mathrm{d}\underline{x}. \tag{2}$$

This equation demonstrates using the notion of *overlap* between 3D scalar quantities to give a physics-based scoring function. If the aim is to find the configuration that gives the most favourable interaction energy, then it is necessary to perform a six-dimensional search in the space of available rotational and translational degrees of freedom. By re-writing the polar Fourier expansions using complex spherical harmonics, we showed previously that fast Fourier transform (FFT) techniques may be used to accelerate the search in up to five of the six degrees of freedom [61]. Furthermore, we also showed that such calculations may be accelerated dramatically on modern graphics processor units [10], [7]. Consequently, we are continuing to explore new ways to exploit the polar Fourier approach.

3.2.3. Assembling Symmetrical Protein Complexes

Although protein-protein docking algorithms are improving [62], [53], it still remains challenging to produce a high resolution 3D model of a protein complex using *ab initio* techniques. This is mainly due to the problem of structural flexibility described above. However, with the aid of even just one simple constraint on the docking search space, the quality of docking predictions can improve considerably [10], [61]. In particular, many protein complexes involve symmetric arrangements of one or more sub-units, and the presence of symmetry may be exploited to reduce the search space considerably [38], [59], [66]. For example, using our operator notation (in which $\widehat{R}$ and $\widehat{T}$ represent 3D rotation and translation operators, respectively), we have developed an algorithm which can generate and score candidate docking orientations for monomers that assemble into cyclic (C_n) multimers using 3D integrals of the form

$$E_{AB}(y,\alpha,\beta,\gamma) = \int \left[\widehat{T}(0,y,0)\widehat{R}(\alpha,\beta,\gamma)\phi_A(\underline{x})\right] \times \left[\widehat{R}(0,0,\omega_n)\widehat{T}(0,y,0)\widehat{R}(\alpha,\beta,\gamma)\rho_B(\underline{x})\right] \mathrm{d}\underline{x}, \tag{3}$$

where the identical monomers A and B are initially placed at the origin, and $\omega_n = 2\pi/n$ is the rotation about the principal n-fold symmetry axis. This example shows that complexes with cyclic symmetry have just 4 rigid body degrees of freedom (DOFs), compared to $6(n-1)$ DOFs for non-symmetrical n-mers. We have generalised these ideas in order to model protein complexes that crystallise into any of the naturally occurring point group symmetries (C_n, D_n, T, O, I). This approach was published in 2016 [8], and was subsequently applied to several symmetrical complexes from the "CAPRI" blind docking experiment [45]. Although we currently use shape-based FFT correlations, the symmetry operator technique may equally be used to build and refine candidate solutions using a more accurate coarse-grained (CG) force-field scoring function.

3.2.4. Coarse-Grained Models

Many approaches have been proposed in the literature to take into account protein flexibility during docking. The most thorough methods rely on expensive atomistic simulations using MD. However, much of a MD trajectory is unlikely to be relevant to a docking encounter unless it is constrained to explore a putative protein-protein interface. Consequently, MD is normally only used to refine a small number of candidate rigid body docking poses. A much faster, but more approximate method is to use "coarse-grained" (CG) normal mode analysis (NMA) techniques to reduce the number of flexible degrees of freedom to just one or a handful of the most significant vibrational modes [57], [44], [54], [55]. In our experience, docking ensembles of NMA conformations does not give much improvement over basic FFT-based soft docking [68], and it is very computationally expensive to use side-chain repacking to refine candidate soft docking poses [4].

In the last few years, CG force-field models have become increasingly popular in the MD community because they allow very large biomolecular systems to be simulated using conventional MD programs [37]. Typically, a CG force-field representation replaces the atoms in each amino acid with from 2 to 4 "pseudo-atoms", and it assigns each pseudo-atom a small number of parameters to represent its chemo-physical properties. By directly attacking the quadratic nature of pair-wise energy functions, coarse-graining can speed up MD simulations by up to three orders of magnitude. Nonetheless, such CG models can still produce useful models of very large multi-component assemblies [65]. Furthermore, this kind of CG model effectively integrates out many of the internal DOFs to leave a smoother but still physically realistic energy surface [50]. We are currently developing a CG scoring function for fast protein-protein docking and multi-component assembly. This work is part of the PhD project of Maria-Elisa Ruiz-Echartea [19], [64]. Beyond this PhD project, the CG scoring function will be exploited in all our docing projects, especially for RNA-Protein docking (see below).

3.2.5. Assembling Multi-Component Complexes and Integrative Structure Modeling

We also want to develop related approaches for integrative structure modeling using cryo-electron microscopy (cryo-EM). Thanks to recent developments in cryo-EM instruments and technologies, it is now feasible to capture low resolution images of very large macromolecular machines. However, while such developments offer the intriguing prospect of being able to trap biological systems in unprecedented levels of detail, there will also come with an increasing need to analyse, annotate, and interpret the enormous volumes of data that will soon flow from the latest instruments. In particular, a new challenge that is emerging is how to fit previously solved high resolution protein structures into low resolution cryo-EM density maps. However, the problem here is that large molecular machines will have multiple sub-components, some of which will be unknown, and many of which will fit each part of the map almost equally well. Thus, the general problem of building high resolution 3D models from cryo-EM data is like building a complex 3D jigsaw puzzle in which several pieces may be unknown or missing, and none of which will fit perfectly. We wish to proceed firstly by putting more emphasis on the single-body terms in the scoring function [42], and secondly by using fast CG representations and knowledge-based distance restraints to prune large regions of the search space. This work has made some progress during the PhD project of Maria Elisa Ruiz Echartea but still requires further efforts.

3.2.6. Protein-Nucleic Acids Interactions

As well as playing an essential role in the translation of DNA into proteins, RNA molecules carry out many other essential biological functions in cells, often through their interactions with proteins. A critical challenge in modelling such interactions computationally is that the RNA is often highly flexible, especially in single-stranded (ssRNA) regions of its structure. These flexible regions are often very important because it is through their flexibility that the RNA can adjust its 3D conformation in order to bind to a protein surface. However, conventional protein-protein docking algorithms generally assume that the 3D structures to be docked are rigid, and so are not suitable for modeling protein-RNA interactions. There is therefore much interest in developing protein-RNA docking algorithms which can take RNA flexibility into account. This research topic has been initiated with the recruitement of Isaure Chauvot de Beauchêne in 2016 and is becoming a major activity in the team. A novel flexible docking algorithm is currently under development in the team. It first docks small fragments of ssRNA (typically three nucleotides at a time) onto a protein surface, and then combinatorially reassembles those fragments in order to recover a contiguous ssRNA structure on the protein surface [41], [40].

As the correctness of the initial docking of the fragments settles an upper limit to the correctness of the full model, we are now focusing on improving that step. A key component of our docking tool is the energy function of the protein - fragment interactions, that is used both to drive the sampling (positioning of the fragments) by minimization and to discriminate the correct final positions from decoys (i.e. false positives). We are developing a new knowledge-based energy function that will be learnt by machine-learning methods from public structural data on ssRNA-protein complexes.

In the future, we will improve the combinatorial algorithm used for reassembling the docked fragments using experimental constraints and machine-learning approaches.

4. Application Domains

4.1. Biomedical Knowledge Discovery

Participants: Marie-Dominique Devignes [contact person], Malika Smaïl-Tabbone [contact person], Sabeur Aridhi, David Ritchie, Gabin Personeni, Seyed Ziaeddin Alborzi, Kevin Dalleau, Bishnu Sarker, Emmanuel Bresso, Claire Lacomblez, Floriane Odje, Athénaïs Vaginay.

Our main application for Axis 1 : "New Approaches for Knowledge Discovery in Structural Databases", concerns biomedical knowledge discovery. We intend to develop KDD approaches on preclinical (experimental) or clinical datasets integrated with knowledge graphs with a focus on discovering which PPIs or molecular machines play an essentiel role in the onset of a disease and/or for personalized medicine.

As a first step we have been involved since 2015 in the ANR RHU “FIGHT-HF” (Fight Heart Failure) project, which is coordinated by the CIC-P (Centre d’Investigation Clinique Plurithématique) at the CHRU Nancy and INSERM U1116. In this project, the molecular mechanisms that underly heart failure (HF) are re-visited at the cellular and tissue levels in order to adapt treatments to patients’ needs in a more personalized way. The Capsid team is in charge of a workpackage dedicated to network science. A platform has been constructed with the help of a company called Edgeleap (Utrecht, NL) in which biological molecular data and ontologies, available from public sources, are represented in a single integrated complex network also known as knowledge graph. We are developing querying and analysis facilities to help biologists and clinicians interpreting their cohort results in the light of existing interactions and knowledge. We are also currently analyzing pre-clinical data produced at the INSERM unit on the comparison of aging process in obese versus lean rats. Using our expertise in receptor-ligand docking, we are investigating possible cross-talks between mineralocorticoid and other nuclear receptors.

Another application is carried out in the context of a UL-funded interdisciplinary project in collaboration with the CRAN laboratory. It concerns the study of the role of estrogen receptors in the development of gliobastoma tumors. The available data is high-dimensional but involves rather small numbers of samples. The challenge is to identify relevant sets of genes which are differentially expressed in various phenoptyped groups (w.r.t. gender, age, tumor grade). The objectives are to infer pathways involving these genes and to propose candidate models of tumor development which will be experimentally tested thanks to an ex-vivo experimental system available at the CRAN.

Finally, simulating biological networks will be important to understand biological systems and test new hypotheses. One major challenge is the identification of perturbations responsible for the transformation of a healthy system to a pathological one and the discovery of therapeutic targets to reverse this transformation. Control theory, which consists in finding interventions on a system in order to prevent it to go in undesirable states or to force it to converge towards a desired state, is of great interest for this challenge. It can be formulated as "How to force a broken system (pathological) to act as it should do (normal state)?". Many formalisms are used to model biological processes, such as Differential Equations (DE), Boolean Networks (BN), cellular automata. In her PhD thesis, Athenaïs Vaginay investigates ways to find a BN fitting both the knowledge about topology and state transitions "inferred" from experimental data. This step is known as "boolean function synthesis". Our aim is to design automated methods for building biological networks and define operators to intervene on them[29]. Our approaches will be driven by knowledge and keep close connection with experimental data.

4.2. Prokaryotic Type IV Secretion Systems

Participants: Marie-Dominique Devignes [contact person], Isaure Chauvot de Beauchêne [contact person], Bernard Maigret, David Ritchie, Philippe Noel, Antoine Moniot, Dominique Mias-Lucquin.

Concerning Axis 2 : "Integrative Multi-Component Assembly and Modeling", our first application domain is related to prokaryotic type IV secretion systems.

Prokaryotic type IV secretion systems constitute a fascinating example of a family of nanomachines capable of translocating DNA and protein molecules through the cell membrane from one cell to another [36]. The complete system involves at least 12 proteins. The structure of the core channel involving three of these proteins has recently been determined by cryo-EM experiments for Gram-negative bacteria [47], [63]. However, the detailed nature of the interactions between the other components and the core channel remains to be found. Therefore, these secretion systems represent a family of complex biological systems that call for integrated modeling approaches to fully understand their machinery.
In the framework of the Lorraine Université d'Excellence (LUE-FEDER) "CITRAM" project we are pursuing our collaboration with Nathalie Leblond of the Genome Dynamics and Microbial Adaptation (DynAMic) laboratory (UMR 1128, Université de Lorraine, INRA) on the mechanism of horizontal transfer by integrative conjugative elements (ICEs) and integrative mobilisable elements (IMEs) in prokaryotic genomes. These elements use Type IV secretion systems for transferring DNA horizontally from one cell to another. We have discovered more than 200 new ICEs/IMEs by systematic exploration of 72 Streptococcus genomes and characterized a new class of relaxases [21]. We have modeled the dimer of this relaxase protein by homology with a known structure. For this, we have created a new pipeline to model symmetrical dimers of multi-domains proteins. As one activity of the relaxase is to cut the DNA for its transfer, we are also currently studying the DNA-protein interactions that are involved in this very first step of horizontal transfer (see next section).

4.3. Protein - Nucleic Acids Interactions

Participants: Isaure Chauvot de Beauchêne [contact person], David Ritchie, Dominique Mias-Lucquin, Antoine Moniot, Honey Jain, Anna Kravchenko, Hrishikesh Dhondge, Malika Smaïl-Tabbone, Marie-Dominique Devignes.

The second application domain of Axis 2 concerns protein-nucleic acids interactions. We need to assess and optimize our new algorithms on concrete protein-nucleic acids complexes in close collaboration with external partners coming from the experimental field of structural biology. To facilitate such collaborations, we will have to create automated and re-usable protein-nucleic acid docking pipelines.

This is the case for our PEPS collaboration "InterANRIL" with the IMoPA lab (CNRS-Université de Lorraine). We are currently working with biologists to apply our fragment-based docking approach to model complexes of the long non-coding RNA (lncRNA) ANRIL with proteins and DNA. In order to extend this approach to partially structured RNA molecules, we have built an automated pipeline to create (i) libraries of RNA fragments with arbitrary characteristics such as secondary structure, and (ii) testing benchmarks for applying these libraries to docking assays.

In the framework of our LUE-FEDER CITRAM project (see above), we adapted this approach and this pipeline to single-strand DNA docking in order to model the complex formed by a bacterial relaxase and its target DNA.

In the future, we will tackle a defined group of RNA-binding proteins containing RNA-Recognition Motif (RRM) domains. We will study existing and predicted complexes between various types of RRMs and various RNA sequences with computational methods in order to calculate CG force-field energy and to help design new synthetic proteins with targeted RNA specificity. This is the goal of the ITN RNAct project and it will require the construction of a dedicated database equipped with querying and analysis facilities, including machine-learning approaches, as well as many interactions within the ITN RNAct consortium.

5. Highlights of the Year

5.1. Highlights of the Year

Malika Smaïl-Tabbone was invited with Bastien Rance to coordinate the selection of the best contributions from 2018 literature on Bioinformatics and Translational Informatics for the 2019 IMIA YearBook of Medical Informatics [20].

Bishnu Sarker (PhD student) obtained a DrEAM fellowship from Lorraine Université d'Excellence for a 3-month internship at the MILA (Machine Learning Laboratory of the University of Montreal and University of Quebec) in Montreal.

6. New Software and Platforms

6.1. lib3Dmol

Library in Rust for manipulating 3D representations of molecules

KEYWORDS: 3D modeling - Proteins - Molecules - Rust

FUNCTIONAL DESCRIPTION: The lib3Dmol library can be called by programs written in Rust for 3D modelling of biomolecules and their interactions.

RELEASE FUNCTIONAL DESCRIPTION: The 0.2.0 version can be used with any type of biomolécule.

- Contact: Philippe Noel
- URL: http://mbi.loria.fr

6.2. QRMSDmap

Parallelized computation of RMSD map of molecular structures after 3D alignment based on the quaternion method.

KEYWORDS: Molecules - RMSD - Rust - Bioinformatics

FUNCTIONAL DESCRIPTION: This program allows fast computing of 3D alignments and 3D distances on a large number of biomolecular structures.

RELEASE FUNCTIONAL DESCRIPTION: This 2.3.2 version improves CPU parallelization and decreases memory consumption.

- Contact: Philippe Noel
- URL: http://mbi.loria.fr

6.3. EROS-DOCK

Exhaustive Rotational Search using Branch-and-Bound algorithm for rigid docking

KEYWORDS: 3D modeling - Proteins - Docking

FUNCTIONAL DESCRIPTION: EROS-DOCK is a protein-protein docking program for Linux. It takes in input the 3D structures of two proteins in PDB format, and gives as output a list of transformation matrices describing the most probable relative positions of the two proteins in nature, together with a score (approximation of their binding energy for that position). On a modern workstation, docking times is in the order of few hours for a blind global search. The user can also provide nowledge of particular contact points at the surface of each protein, which accelerates the pruning of the solutions space. The underlying algorithm uses a pi-ball representation of the rotational 3D space, to accelerate the search for close-fitting orientations of the two molecules by a branch-and-bound technique.

- Contact: Isaure Chauvot de Beauchêne
- URL: https://erosdock.loria.fr

6.4. NAFRAGDB

Databases of nucleic acids fragments bound to proteins

KEYWORDS: Structural Biology - Nucleic Acids - Data base

FUNCTIONAL DESCRIPTION: NAfragDB is a python-based software for (i) the automated parsing, correction and annotation of all protein - nucleic acid structures in the public Protein Data Bank, (ii) the creation of libraries of non-redundant RNA/DNA structural fragments, (iii) the selection of sets of structures by customized queries, and (iv) the computation of statistics on sets of RNA/DNA - protein structures.

- Contact: Isaure Chauvot de Beauchêne

6.5. RNA-PDBComplete

Completing RNA structures in PDB files

KEYWORDS: Nucleic Acids - Structural Biology

FUNCTIONAL DESCRIPTION: PDBcomplete is a software and a webserver for the completion of missing atoms in an RNA structure provided in PDB format. PDBcomplete is capable of taking into account the presence of other molecules in the overall PDB structure to avoid atoms collisions. It uses as template an in-house library of mono-nucleotide libraries created with the NAfragDB tool.

- Contact: Isaure Chauvot de Beauchêne
- URL: https://pdbcomplete.loria.fr/

6.6. MBI platform for structural bioinformatics

Initiated during the previous CPER projects Intelligence Logicielle (1999-2005) and MISN: Modelisation, Interactions et Systèmes Numériques (2006-2013), the MBI platform (MBI = Modelling Biomolecules and their Interactions) is today part of the SMEC platform coordinated by MD Devignes and M Smaïl-Tabbone (SMEC: Simulation, Modélisation et Extraction de Connaissances), in the frame of the ongoing CPER projet ITM2P (Innovations Technologiques et Modélisation pour la Médecine Personnalisée ; 2015-2020). The MBI platform is composed of several HPC and storage servers that are shared between users mostly for structural bioinformatics usages. The MBI platform is part of the bioinformatic platform network of the French Institute of Bioinformatics (IFB ; http://www.france-bioinformatique.fr.

- Participants: Marie-Dominique Devignes [contact person], Isaure Chauvot de Beauchêne, Sjoerd de Vries, Antoine Moniot, Emmanuel Bresso, Philippe Noel, Patrice Ringot.
- URL: https://mbi.loria.fr

7. New Results

7.1. Axis 1 : New Approaches for Knowledge Discovery in Structural Databases

7.1.1. Biomedical Knowledge Discovery

Our collaboration with clinicians at the CHRU Nancy in the framework of the RHU FIGHT-HF program and of the Contrat d'Interface has lead to two publications demonstrating the added value of database and knowledge graph exploitation when analyzing observational or prospective cohorts. In a retrospective observational study, we have identified and characterized patient subgroups presenting stable or unstable positivity to anti-phospholipid antobodies assays [15]. In the European FibroTarget cohort study, we have contributed to the characterization of at-risk phenotypic groups using proteomic biomarkers [16].

Another application is carried out in collaboration with the Orpailleur Team and concerns the PraktikPharma ANR project. We aim at building explanations for severe drug side effects (such as drug-induced liver injury or severe cutaneous adverse reaction) from pharmacogenomics RDF graph (PGXlod). We obtained a podium abstract at the MedInfo 2019 conference for providing molecular characterization for unexplained adverse drug reactions using pharmacogenomics RDF graph (PGXlod) [30].

7.1.2. Stochastic Decision Trees for Similarity Computation

In the frame of Kévin Dalleau's PhD thesis, we have designed a method to compute similarities on unlabeled data using stochastic decision trees [31], [27]. The main idea of Unsupervised Extremely Randomized Trees (UET) is to randomly and iteratively split the data until a stopping criterion is met. Pairwise similarity values are computed based on the co-occurrence of samples in the leaves of each generated tree. We evaluate our method on synthetic and real-world datasets by comparing the mean similarities between samples with the same label and the mean similarities between samples with distinct labels. Empirical studies show that the method effectively gives distinct similarity values between samples belonging to distinct clusters, and gives indiscernible values when there is no cluster structure. We also assessed some interesting properties such as invariance under monotone transformations of variables and robustness to correlated variables and noise. Our experiments show that the algorithm outperforms existing methods in some cases, and can reduce the amount of preprocessing needed with many real-world datasets. We extended the approach to the computation of pairwise similarity for graph nodes. The experimental results are competitive with state of the art methods. We are currently working on merging the two similarity methods (on attribute-value objects and on graph nodes) to attributed graphs where the nodes are described by attributes.

We plan to study the application of this pairwise similarity computation to quantify protein structural similarities. Two interesting problems will concern the representation of the protein structure and how to tackle extra constraints such as invariance under rotational and translational transformations.

7.1.3. Protein Annotation and Machine Learning

We have been involved in the 3rd international CAFA Challenge ("Critical Assessment of Functional Annotation") through our work on (i) domain functional annotation (Zia Alborzi's PhD thesis) and (ii) label propagation in graphs (Bishnu Sarker's PhD thesis). We were therefore contributors of the general report published this year [23].

As part of his PhD work, Bishnu Sarker developed and tested on UniProt/SwissProt a new method for functional annotation of proteins using domain embedding-based sequence classification [25].

Multiple Instance Learning (MIL) is a machine learning strategy that can be applied to sets of sequences describing organisms displaying a given property. The purpose here is to be able to classify a new organism with respect to this property based on its sequences and their similarity to the sequences of classified organisms. New MIL algorithms have been described and tested in the framework of a collaboration [26], [24]. Another collaborative work has lead to the development of a distributed algorithm for large-scale graph clustering [34].

7.2. Axis 2 : Integrative Multi-Component Assembly and Modeling

7.2.1. EROS-DOCK algorithm and its extensions

We have adapted our EROS-DOCK protein-protein docking software [35], [19] to account for experimental knowledge on the protein-protein interface to be modeled. Indeed, structural biology experiments can identify pairs of amino-acids from each protein in a protein-protein interface that are likely to be in close contact. This additional restraint is used to pre-prune the 3D rotational space of one protein toward another, by eliminating cones of rotations that cannot fulfill the distance between the two points at the protein surfaces. Using a single restraint permits to decrease the average execution time by at least 90 percent.

We also developed a new version of EROS-DOCK for multi-body docking (modeling assemblies of more than 2 proteins), using a combinatorial approach. We assembled trimers by docking in a first stage all possible combinations of pairs of proteins involved in the multi-body complex. Possible trimer solutions are assembled by fixing one protein, the "root-protein" (protein A, say) at the origin and by placing the other two around it using the transformations,T[AB] and T[AC], from the corresponding pairwise solution lists returned by EROS-DOCK. If the three transformations together form a near-native (biologically relevant) trimer structure, then it is natural to suppose that T[BC] should be found in the list of B-C pairwise solutions.

Both extensions of the EROS-DOCK algorithm reported last year and published early this year [19] have been presented by Maria-Elisa Ruiz Echartea at the 2019 CAPRI meeting in april 2019 (http://www.capri-docking.org/events/) and at the MASIM meeting in november 2019 [28]. These results are part of her PhD Thesis that was defended on december 18, 2019 (the thesis will soon be available on HAL). A paper describing EROS-DOCK adaptation to multi-body docking in under revision in *Proteins*.

7.2.2. Protein docking

The regular participation of the Capsid team to the CAPRI challenge is acknowledged through its contribution to the review published this year on CAPRI round 46 [17].

We also contributed to an evaluation of docking software performance in protein-glycosaminoglycan systems [22].

7.2.3. 3D modeling and virtual screening

We have built a 3D model by homology of a new class of relaxase involved in the horizontal transfer of DNA in a group of bacteria called Firmicutes [21].

We also built a 3D model of a chemosensory GPCR as a potential target to control a parasite in plants [13].

Virtual screening was applied on various targets in a re-purposing strategy and led to the discovery of small molecules active against invasive fungal disease [14], [18].

8. Partnerships and Cooperations

8.1. Regional Initiatives

8.1.1. CPER – IT2MP

Participants: Marie-Dominique Devignes [contact person], Malika Smaïl-Tabbone, David Ritchie.

Project title: *Innovations Technologiques, Modélisation et Médecine Personnalisée*; PI: Faiez Zannad, Université de Lorraine (Inserm-CHU-UL). Value: 14.4 M€ ("SMEC" platform – Simulation, Modélisation, Extraction de Connaissances – coordinated by Capsid and Orpailleur teams for Inria Nancy – Grand Est, with IECL and CHRU Nancy: 860 k€, approx); Duration: 2015–2020. Description: The IT2MP project encompasses four interdisciplinary platforms that support several scientific pôles of the university whose research involves human health. The SMEC platform supports research projects ranging from molecular modeling and dynamical simulation to biological data mining and patient cohort studies.

8.1.2. LUE-FEDER – CITRAM

Participants: Marie-Dominique Devignes [contact person], Isaure Chauvot de Beauchêne, Bernard Maigret, Philippe Noel, Dominique Mias-Lucquin, Antoine Moniot, David Ritchie.

Project title: *Conception d'Inhibiteurs du Transfert de Résistances aux agents Anti-Microbiens: bio-ingénierie assistée par des approches virtuelles et numériques, et appliquée à une relaxase d'élément conjugatif intégratif*; PI: N. Leblond, Université de Lorraine (DynAMic, UMR 1128); Other partners: Chris Chipot, CNRS (LPCT, UMR 7565); Value: 200 k€ (Capsid: 80 k€); Duration: 2017–2018. Description: This project follows on from the 2016 PEPS project "MODEL-ICE". The aim is to investigate protein-protein interactions required for initiating the transfer of an ICE (Integrated Conjugative Element) from one bacterial cell to another one, and to develop small-molecule inhibitors of these interactions.

8.1.3. IMPACT GeenAge

Participant: Marie-Dominique Devignes [contact person].

The IMPACT project GeenAge (Lorraine Université d'Excellence) is composed of four axes dedicated to research in high-throughput molecular biology. The Capsid team is involved in a transversal axis for numerical sciences. In the frame of this project, Marie-Dominique Devignes co-supervises with Amedeo Napoli a post-doc hired by the Orpailleur team. She is also responsible with Thierry Bastogne (CRAN) and Anne Gegout-Petit (IECL) for creating a Center of Competencies in Artificial Intelligence and Health.

8.2. National Initiatives

8.2.1. FEDER – SB-Server

Participants: Marie-Dominique Devignes [contact person], Bernard Maigret, Isaure Chauvot de Beauchêne, Sabeur Aridhi, David Ritchie.

Project title: *Structural bioinformatics server*; PI: David Ritchie, Capsid (Inria Nancy – Grand Est); Value: 24 k€; Duration: 2015–2020. Description: This funding provides a small high performance computing server for structural bioinformatics research at the Inria Nancy – Grand Est centre.

8.2.2. ANR

8.2.2.1. FIGHT-HF

Participants: Marie-Dominique Devignes [contact person], Malika Smaïl-Tabbone [contact person], Emmanuel Bresso, Bernard Maigret, Sabeur Aridhi, Kévin Dalleau, Claire Lacomblez, Gabin Personeni, Philippe Noel, David Ritchie.

Project title: *Combattre l'insuffisance cardiaque : Projet de Recherche Hospitalo-Universitaire FIGHT-HF*; PI: Patrick Rossignol, Université de Lorraine (FHU-Cartage); Value: 9 m€ (Capsid and Orpailleur: 450 k€, approx); Duration: 2015–2020. Description: This "Investissements d'Avenir" project aims to discover novel mechanisms for heart failure and to propose decision support for precision medicine. The project has been granted € 9M, and involves many participants from Nancy University Hospital's Federation "CARTAGE". Marie-Dominique Devignes and Malika Smaïl-Tabbone are coordinating a work-package dedicated to network-based science, decision support and drug discovery for this project.

8.2.2.2. IFB

Participants: Marie-Dominique Devignes [contact person], Sabeur Aridhi, Isaure Chauvot de Beauchêne, David Ritchie.

Project title: *Institut Français de Bioinformatique*; PI: Claudine Médigue and Jacques van Helden (CNRS UMS 3601); Value: 20 M€ (Capsid: 126 k€); Duration: 2014–2021. Description: The Capsid team is a research node of the IFB (Institut Français de Bioinformatique), the French national network of bioinformatics platforms (http://www.france-bioinformatique.fr). The principal aim is to make bioinformatics skills and resources more accessible to French biology laboratories. Marie-Dominique Devignes is coordinating with Alban Gaignard the Interoperability task in the Integrative Bioinformatics Workpackage.

8.3. European Initiatives

8.3.1. FP7 & H2020 Projects

8.3.1.1. H2020 ITN RNAct

Participants: Isaure Chauvot de Beauchêne [contact person], Marie-Dominique Devignes, Malika Smaïl-Tabbone, Hrishikesh Dhondge, Anna Kravchenko, David Ritchie.

Program: H2020 Innovative Training Network

Project acronym:RNAct

Project title: Enabling proteins with RNA recognition motifs for synthetic biology and bio-analytics

Duration: octobre 2018 - octobre 2022

Coordinator: Wim Vranken (Vrije University Bruxelles, Belgium)

Other partners: Loria, CNRS (France), Helmholtz Center Munich (Germany), Conseio Superior de Investigaciones Cientificas, Instituto de Biologia Molecular y Celular de Plantas (Spain), Ridgeview instruments AB (Sweden), Giotto Biotech Srl (Italy), Dynamic Biosensors GmbH (Germany).

Abstract: This project aims at designing new proteins with "RNA recognition motifs (RRM)" that target a specific RNA, for exploitation in synthetic biology and bio-analytics. It combines approaches from sequence-based and structure-based computational biology with experimental biophysics, molecular biology and systemic biology. Our scientific participation regards the creation and usage of a large database on RRMs for KDD, and the development of RNA-protein docking methods.

URL: http://rnact.eu

8.3.2. Informal European Partners

EBI: European Bioinformatics Institute, Maria Martin team (UK). We are working with the EBI team to validate and improve our graph-based approaches for protein function annotation.

ELIXIR: 3D-bioinfo Community. We participated in the creation of the new ELIXIR 3D-bioinfo community. ELIXIR Communities enable the participation of communities of practice in different areas of the life sciences in the activities of ELIXIR. The goal is to underpin the evolution of data, tools, interoperability, compute and training infrastructures for European life science informatics (see https://www.elixir-europe.org/use-cases). ELIXIR supports its formally recognised Communities by providing funding for workshops and short collaborative projects associated with the Community. More specifically, Isaure Chauvot de Beauchene is member of the sub-section "Tools to describe, analyze, annotate, and predict nucleic acid structures" of this community.

ELIXIR: Interoperability Platform Marie-Dominique Devignes is collaborating with the ELIXIR Interoperability Platform aa a member of the IFB (the ELIXIR French Node: ELIXIR FR). She co-ordinates and reviews projects in the field of FAIR data, Data Management Plans and Recommended Interoperability Resources (RIR).

8.4. International Initiatives

8.4.1. TempoGraphs

Project: Analyzing big data with temporal graphs and machine learning. Application to urban traffic analysis and protein function annotation.

Participants: Sabeur Aridhi (PI), Marie-Dominique Devignes, Malika Smaïl-Tabbone, Bishnu Sarker, Wissem Inoubli, Dave Ritchie.

Partners: LORIA/Inria NGE, Federal University of Ceará (UFC).

Value: 20 k€.

Duration: 2017–2020.

Description: This project aims to investigate and propose solutions for both urban traffic-related problems and protein annotation problems. In the case of urban traffic analysis, problems such as traffic speed prediction, travel time prediction, traffic congestion identification and nearest neighbors identification will be tackled. In the case of protein annotation problem, protein graphs and/or protein–protein interaction (PPI) networks will be modeled using dynamic time-dependent graph representations.

8.4.2. Inria Associate Teams Not Involved in an Inria International Labs

Project: FlexMol. Algorithms for Multiscale Macromolecular Flexibility:

Participants: Maria-Elisa Ruiz-Echartea, Dave Ritchie, Isaure Chauvot de Beauchêne.

Partners: Nano-D, ChaconLab team, Rocasolano Institute of Physical Chemistry (IQFR-CSIC), Madrid, Spain, as non-beneficiary associated lab.

Description: Developing representations of molecular flexibility at different scales, for the 3D modeling of multi-molecular assemblies.

8.4.3. Informal International Partners

Project: Characterization, expression and molecular modeling ofTRR1 and ALS3 proteins of Candida spp., as a strategy to obtain new drugs with action on yeasts involved in nosocomial infections. Participant: Bernard Maigret. Partner: State University of Maringá, Brasil. Publication: [14], [18].

Project: Fusarium graminearum target selection. Participant: Bernard Maigret. Partner: Embrapa Recursos Geneticos e Biotecnologia, Brasil. Publication: [13].

Project:The thermal shock HSP90 protein as a target for new drugs against paracoccidioidomicose. Participant: Bernard Maigret. Partner: Brasília University, Brasil.

Project:Protein-protein interactions for the development of new drugs. Participant: Bernard Maigret. Partner: Federal University of Goias, Brasil.

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. Scientific Events: Organisation

- Sabeur Aridhi co-chaired the third international workshop on Advances in managing and mining large evolving graphs (LEG - https://leg-ecmlpkdd19.loria.fr/) held in conjunction with the European Conference on Machine Learning and Principles and Practice of Knowledge Discovery in Databases (ECML-PKDD 2019).
- Isaure Chauvot de Beauchêne and Marie-Dominique Devignes organised the first international Workshop (5 days) of the H2020-ITN project RNAct, "RRMs, RNA and RNAct" (http://rnact.eu/Workshop1/)
- Isaure Chauvot de Beauchêne organised the 3rd meeting (regional, 1 day, 25 pers.) of the Glyco-EST group. GlycoEst is an informal working group which was recently created to develop an interdisciplinary regional network of glyco-scientists.
- Isaure Chauvot de Beauchêne organised a lecture and practical course at the AlgoSB WinterSchool 14-21 january 2019 on *Predicting RNA-Protein Interactions*.

9.1.2. Scientific Events: Selection

- Members of the following Conference Program Committees : Joint ICML 2019 Workshop on Computational Biology, IWBBIO 2019, ACM-BCB 2019, BIBM 2019, SWAT4HCLS 2019, EGC 2019.

9.1.3. Journal

- Editorial board of Intelligent Data Analysis (Sabeur Aridhi), Scientific reports (David Ritchie).
- Reviewer for Nucl. Acids Research (Marie-Dominique Devignes).
- Contribution to the IMIA Yearbook of Medical Informatics, 2019 (Malika Smaïl-Tabbone, [20])

9.1.4. Leadership within the Scientific Community

- Isaure Chauvot de Beauchêne is co-founder of the 3D Bioinfo ELIXIR Community.
- Marie-Dominique Devignes and Malika Smaïl-Tabbone have been invited to participate in the INI-CRCT network which is the subnetwork of the F-CRIN project (French Clinical Research Investigation Network) dedicated to cardio-renal diseases. Their contribution is related to their expertise in machine learning and network science.

9.1.5. Scientific Expertise

- Marie-Dominique Devignes reviewed a grant application for FWO (Flanders Research Organization).
- Malika Smaïl-Tabbone and Marie-Dominique Devignes both reviewed grant applications for the ANR.

9.1.6. Research Administration

- Sabeur Aridhi is a member of the Inria Nancy Grand-Est CDT: Commission du Développement Technologique.
- Marie-Dominique Devignes was a member of the ComiPers at Inria Nancy Grand-Est: Commission for the evaluation of CORDI post-doc and CORDI-S doctoral application.
- Malika Smaïl-Tabbone is a member of the IES commission for the elaboration of the policy concerning Scientific Information and Edition Scientifique at Inria Nancy Grand-Est and at the LORIA.
- Dave Ritchie was a member of the CMI at the LORIA: Commission de Mention Informatique of the Université de Lorraine's IAEM doctoral school.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Sabeur Aridhi and Malika Smaïl-Tabbone are enseignants-chercheurs with a full service. Sabeur Aridhi is responsible for the major in IAMD (Ingénierie et Applications des Masses de Données) at TELECOM Nancy (Université de Lorraine),

Marie-Dominique Devignes teaches about 34h at Telecom Nancy (1A) and 10h in the Cursus Master Ingenieur at the Université de Lorraine.

Isaure Chauvot de Beauchêne teaches about 10h in the Cursus Master Ingenieur at the Université de Lorraine.

9.2.2. Supervision

- PhD: Maria Elisa Ruiz Echartea, *Multi-component protein assembly using distance constraints*. Université de Lorraine. Defense date : 18/12/2019 (Manuscript under revision, soon in HAL). David Ritchie, Isaure Chauvot de Beauchêne.
- PhD in progress: Kévin Dalleau, *Complex graph analysis for classification: application to disease nosography,* 01/12/2016, Malika Smaïl-Tabbone, Miguel Couceiro.
- PhD in progress: Bishnu Sarker, *Developing distributed graph-based approaches for large-scale protein function annotation and knowledge discovery,* 01/11/2017, David Ritchie, Sabeur Aridhi.

- PhD in progress: Antoine Moniot, *Modeling protein / nucleic acid complexes by combinatorial structural fragment assembly,* 01/11/2018, David Ritchie, Isaure Chauvot de Beauchêne.
- PhD in progress: Athénaïs Vaginay, *Model selection and analysis for biological networks: use of domain knowledge and application to networks disturbed in diseases,* 01/11/2018, Taha Boukhobza, Malika Smaïl-Tabbone.
- PhD in progress: Anna Kravchenko, *Fragment-based modeling of protein-RNA complexes for protein design,* 01/10/2019, Malika Smaïl-Tabbone, Isaure Chauvot de Beauchêne.
- PhD in progress: Hrishikesh Dhondge, *A new knowledge base for modeling and design of RNA-binding proteins,* 01/10/2019, Marie-Dominique Devignes, Isaure Chauvot de Beauchêne.
- PhD in progress: Diego Amaya Ramirez, *HLA genetic system and organ transplantation: understanding the basics of immunogenicity to improve donor / receptor compatibility when assigning grafts to recipients,* 01/10/2019, Marie-Dominique Devignes, Jean-Luc Taupin.
- PhD in progress: Kamrul Islam, *Distributed link prediction in large complex graphs: application to biomolecule interactions,* 01/11/2019, Malika Smail-Tabbone, Sabeur Aridhi.

9.2.3. Juries

- Sabeur Aridhi was a member (examinator) of the PhD committee of Manel Zoghlami, Universiy of Clermont Auvergne, *Multiple instance learning approaches for ionizing-radiation-resistance prediction,* 20/12/2019.
- Sabeur Aridhi was a member (reviewer) of the PhD committee of Zekarias Tilahun Kefato, Universiy of Trento, *Network and Cascade Representation Learning Algorithms based on Information Diffusion Events,* 29/04/2019.
- Sabeur Aridhi was a member (reviewer) of the PhD committee of Nasrullah Sheikh, Universiy of Trento, *Network Representation Learning with Attributes and Heterogeneity,* 16/07/2019.
- Marie-Dominique Devignes was a member (reviewer) of the PhD committee of Manel Zoghlami, Universiy of Clermont Auvergne, *Multiple instance learning approaches for ionizing-radiation-resistance prediction,* 20/12/2019.

9.3. Popularization

9.3.1. Interventions

- Dominique Mias-Lucquin was co-organizer of the "Pint of Science" event, 21-22 may, 2019 (24 countries involved ; http://pintofscience.com).

10. Bibliography

Major publications by the team in recent years

[1] S. Z. Alborzi, M.-D. Devignes, D. W. Ritchie.*ECDomainMiner: discovering hidden associations between enzyme commission numbers and Pfam domains*, in "BMC Bioinformatics", December 2017, vol. 18, n^{o} 1, 107 [*DOI :* 10.1186/s12859-017-1519-x], https://hal.inria.fr/hal-01466842

[2] S. Z. Alborzi, D. Ritchie, M.-D. Devignes.*Computational Discovery of Direct Associations between GO terms and Protein Domains*, in "BMC Bioinformatics", November 2018, vol. 19, n^{o} Suppl 14, 413 [*DOI :* 10.1186/s12859-018-2380-2], https://hal.inria.fr/hal-01777508

[3] A. W. Ghoorah, M.-D. Devignes, M. Smaïl-Tabbone, D. Ritchie.*Spatial clustering of protein binding sites for template based protein docking*, in "Bioinformatics", August 2011, vol. 27, n^{o} 20, p. 2820-2827 [*DOI :* 10.1093/bioinformatics/btr493], https://hal.inria.fr/inria-00617921

[4] A. W. Ghoorah, M.-D. Devignes, M. Smaïl-Tabbone, D. Ritchie.*Protein Docking Using Case-Based Reasoning*, in "Proteins", October 2013, vol. 81, n^{o} 12, p. 2150-2158 [*DOI :* 10.1002/prot.24433], https://hal.inria.fr/hal-00880341

[5] A. W. Ghoorah, M.-D. Devignes, M. Smaïl-Tabbone, D. Ritchie.*KBDOCK 2013: A spatial classification of 3D protein domain family interactions*, in "Nucleic Acids Research", January 2014, vol. 42, n^{o} D1, p. 389-395, https://hal.inria.fr/hal-00920612

[6] T. V. Hoang, X. Cavin, D. Ritchie.*gEMfitter: A highly parallel FFT-based 3D density fitting tool with GPU texture memory acceleration*, in "Journal of Structural Biology", September 2013 [*DOI :* 10.1016/j.jsb.2013.09.010], https://hal.inria.fr/hal-00866871

[7] G. Macindoe, L. Mavridis, V. Venkatraman, M.-D. Devignes, D. Ritchie.*HexServer: an FFT-based protein docking server powered by graphics processors*, in "Nucleic Acids Research", May 2010, vol. 38, p. W445-W449 [*DOI :* 10.1093/nar/gkq311], https://hal.inria.fr/inria-00522712

[8] D. W. Ritchie, S. Grudinin.*Spherical polar Fourier assembly of protein complexes with arbitrary point group symmetry*, in "Journal of Applied Crystallography", February 2016, vol. 49, n^{o} 1, p. 158-167 [*DOI :* 10.1107/S1600576715022931], https://hal.inria.fr/hal-01261402

[9] D. Ritchie.*Calculating and scoring high quality multiple flexible protein structure alignments*, in "Bioinformatics", May 2016, vol. 32, n^{o} 17, p. 2650-2658 [*DOI :* 10.1093/bioinformatics/btw300], https://hal.inria.fr/hal-01371083

[10] D. W. Ritchie, V. Venkatraman.*Ultra-fast FFT protein docking on graphics processors*, in "Bioinformatics", August 2010, vol. 26, n^{o} 19, p. 2398-2405 [*DOI :* 10.1093/bioinformatics/btq444], https://hal.inria.fr/inria-00537988

[11] B. Sarker, D. Ritchie, S. Aridhi.*GrAPFI: Graph Based Inference for Automatic Protein Function Annotation*, September 2018, ECCB 2018 - 17th European Conference on Computational Biology, Poster, https://hal.inria.fr/hal-01876907

[12] B. Sarker, D. W. Ritchie, S. Aridhi.*Exploiting Complex Protein Domain Networks for Protein Function Annotation*, in "Complex Networks 2018 - 7th International Conference on Complex Networks and Their Applications", Cambridge, United Kingdom, December 2018, https://hal.inria.fr/hal-01920595

Publications of the year

Articles in International Peer-Reviewed Journal

[13] E. Bresso, D. Fernandez, D. X. Amora, P. Noel, A.-S. Petitot, M.-E. Lisei De Sa, E. V. S. Albuquerque, E. Danchin, B. Maigret, N. F. Martins.*A Chemosensory GPCR as a Potential Target to Control the Root-Knot Nematode Meloidogyne incognita Parasitism in Plants*, in "Molecules", 2019, vol. 24, n^{o} 20, 3798 [*DOI :* 10.3390/molecules24203798], https://hal.archives-ouvertes.fr/hal-02324816

[14] I. R. G. Capoci, D. R. Faria, K. M. Sakita, F. A. V. Rodrigues-Vendramini, P. d. S. Bonfim-Mendonça, T. C. A. Becker, E. S. Kioshima, T. I. E. Svidzinski, B. Maigret.*Repurposing approach identifies new treatment options for invasive fungal disease*, in "Bioorganic Chemistry", March 2019, vol. 84, p. 87-97 [*DOI :* 10.1016/j.bioorg.2018.11.019], https://hal.inria.fr/hal-02151642

[15] J. Devignes, M. Smaïl-Tabbone, A. Hervé, G. Cagninacci, M.-D. Devignes, T. Lecompte, S. Zuily, D. Wahl.*Extended persistence of antiphospholipid antibodies beyond the twelve-week time interval: Association with baseline antiphospholipid antibodies titres*, in "International Journal of Laboratory Hematology", September 2019, vol. 41, n° 6, p. 726-730 [*DOI :* 10.1111/ijlh.13094], https://hal.inria.fr/hal-02395258

[16] J. P. Ferreira, A. Pizard, J.-L. Machu, E. Bresso, H.-P. Brunner-LaRocca, N. Girerd, L. Céline, A. González, J. Díez, S. Heymans, M.-D. Devignes.*Plasma protein biomarkers and their association with mutually exclusive cardiovascular phenotypes: the FIBROTARGETS case–control analyses*, in "Clinical Research in Cardiology", April 2019, vol. 1 [*DOI :* 10.1007/s00392-019-01480-4], https://hal.inria.fr/hal-02138814

[17] M. Lensink, G. Brysbaert, N. Nadzirin, S. Velankar, R. A. Chaleil, T. Gerguri, P. Bates, E. Laine, A. Carbone, S. Grudinin, R. Kong, R. Liu, X. Xu, H. Shi, S. Chang, M. Eisenstein, A. Karczynska, C. Czaplewski, E. Lubecka, A. Lipska, P. Krupa, M. Mozolewska, Ł. Golon, S. Samsonov, A. Liwo, S. Crivelli, G. Pagès, M. Karasikov, M. Kadukova, Y. Yan, S. Huang, M. Rosell, L. A. Rodríguez-Lumbreras, M. Romero-Durana, L. Díaz-Bueno, J. Fernandez-Recio, C. Christoffer, G. Terashi, W. Shin, T. Aderinwale, S. Raghavendra Maddhuri Venkata Subram, D. Kihara, D. Kozakov, S. Vajda, K. Porter, D. Padhorny, I. Desta, D. Beglov, M. Ignatov, S. Kotelnikov, I. Moal, D. Ritchie, I. Chauvot de Beauchêne, B. Maigret, M.-E. Ruiz-Echartea, D. Barradas-Bautista, Z. Cao, L. Cavallo, R. Oliva, Y. Cao, Y. Shen, M. Baek, T. Park, H. Woo, C. Seok, M. Braitbard, L. Bitton, D. Scheidman-Duhovny, J. Dapkūnas, K. Olechnovič, Č. Venclovas, P. J. Kundrotas, S. Belkin, D. Chakravarty, V. Badal, I. A. Vakser, T. Vreven, S. Vangaveti, T. M. Borrman, Z. Weng, J. D. Guest, R. Gowthaman, B. G. Pierce, X. Xu, R. Duan, L. Qiu, J. Hou, B. Ryan Merideth, Z. Ma, J. Cheng, X. Zou, P. Koukos, J. Roel-Touris, F. Ambrosetti, C. Geng, J. Schaarschmidt, M. Trellet, A. S. Melquiond, L. Xue, B. Jiménez-García, C. Noort, R. Honorato, A. M. Bonvin, S. J. Wodak.*Blind prediction of homo- and hetero- protein complexes: The CASP13-CAPRI experiment*, in "Proteins - Structure, Function and Bioinformatics", October 2019, vol. 87, n° 12, p. 1200-1221 [*DOI :* 10.1002/prot.25838], https://hal.inria.fr/hal-02320974

[18] F. A. V. Rodrigues-Vendramini, D. R. Faria, G. S. Arita, I. R. G. Capoci, K. M. Sakita, S. M. Caparroz-Assef, T. C. A. Becker, P. de Souza Bonfim-Mendonça, M. S. Felipe, T. I. E. Svidzinski, B. Maigret, E. S. Kioshima, P. Small.*Antifungal activity of two oxadiazole compounds for the paracoccidioidomycosis treatment*, in "PLoS Neglected Tropical Diseases", June 2019, vol. 13, n° 6, e0007441 [*DOI :* 10.1371/journal.pntd.0007441], https://hal.inria.fr/hal-02151638

[19] M. E. Ruiz Echartea, I. Chauvot de Beauchêne, D. Ritchie.*EROS-DOCK: Protein-Protein Docking Using Exhaustive Branch-and-Bound Rotational Search*, in "Bioinformatics", 2019, forthcoming [*DOI :* 10.1093/bioinformatics/btz434], https://hal.archives-ouvertes.fr/hal-02269812

[20] M. Smaïl-Tabbone, M. Smaïl-Tabbone, B. Rance.*Contributions from the 2018 Literature on Bioinformatics and Translational Informatics*, in "IMIA Yearbook of Medical Informatics", August 2019, vol. 28, n° 01, p. 190-193 [*DOI :* 10.1055/s-0039-1677945], https://hal.inria.fr/hal-02413623

[21] N. Soler, E. Robert, I. Chauvot de Beauchêne, P. Monteiro, V. Libante, B. Maigret, J. Staub, D. W. Ritchie, G. Guédon, S. Payot, M.-D. Devignes, N. N. Leblond-Bourget.*Characterization of a relaxase belonging to the MOBT family, a widespread family in Firmicutes mediating the transfer of ICEs*, in "Mobile DNA", December 2019, vol. 10, n° 1 [*DOI :* 10.1186/s13100-019-0160-9], https://hal.inria.fr/hal-02138843

[22] U. UCIECHOWSKA-KACZMARZYK, I. CHAUVOT DE BEAUCHÊNE, S. SAMSONOV.*Docking software performance in protein-glycosaminoglycan systems*, in "Journal of Molecular Graphics and Modelling", April 2019, vol. 90, p. 42-50 [*DOI :* 10.1016/J.JMGM.2019.04.001], https://hal.archives-ouvertes.fr/hal-02391852

[23] N. ZHOU, Y. JIANG, T. BERGQUIST, A. LEE, B. KACSOH, A. CROCKER, K. LEWIS, G. GEORGHIOU, H. NGUYEN, M. N. HAMID, L. DAVIS, T. DOGAN, V. ATALAY, A. RIFAIOGLU, A. DALKIRAN, R. CETIN ATALAY, C. ZHANG, R. HURTO, P. FREDDOLINO, Y. ZHANG, P. BHAT, F. SUPEK, J. FERNANDEZ, B. GEMOVIC, V. PEROVIC, R. DAVIDOVIĆ, N. SUMONJA, N. VELJKOVIC, E. ASGARI, M. R. MOFRAD, G. PROFITI, C. SAVOJARDO, P. L. MARTELLI, R. CASADIO, F. BOECKER, H. SCHOOF, I. KAHANDA, N. THURLBY, A. C. MCHARDY, A. RENAUX, R. SAIDI, J. GOUGH, A. FREITAS, M. ANTCZAK, F. FABRIS, M. WASS, J. HOU, J. CHENG, Z. WANG, A. ROMERO, A. PACCANARO, H. YANG, T. GOLDBERG, C. ZHAO, L. HOLM, P. TÖRÖNEN, A. J. MEDLAR, E. ZOSA, I. BORUKHOV, I. NOVIKOV, A. WILKINS, O. LICHTARGE, P.-H. CHI, W.-C. TSENG, M. LINIAL, P. ROSE, C. DESSIMOZ, V. VIDULIN, S. DZEROSKI, I. SILLITOE, S. DAS, J. G. LEES, D. JONES, C. WAN, D. COZZETTO, R. FA, M. TORRES, A. WARWICK VESZTROCY, J. M. RODRIGUEZ, M. TRESS, M. FRASCA, M. NOTARO, G. GROSSI, A. PETRINI, M. RE, G. VALENTINI, M. MESITI, D. S. ROCHE, J. REEB, D. RITCHIE, S. ARIDHI, S. Z. ALBORZI, M.-D. DEVIGNES, D. C. E. KOO, R. BONNEAU, V. GLIGORIJEVIĆ, M. BAROT, H. FANG, S. TOPPO, E. LAVEZZO, M. FALDA, M. BERSELLI, S. C. TOSATTO, M. CARRARO, D. PIOVESAN, H. UR REHMAN, Q. MAO, S. ZHANG, S. VUCETIC, G. BLACK, D. JO, E. SUH, J. DAYTON, D. LARSEN, A. OMDAHL, L. MCGUFFIN, D. BRACKENRIDGE, P. BABBITT, J. YUNES, P. FONTANA, F. ZHANG, S. ZHU, R. YOU, Z. ZHANG, S. DAI, S. YAO, W. TIAN, R. CAO, C. CHANDLER, M. AMEZOLA, D. JOHNSON, J.-M. CHANG, W.-H. LIAO, Y.-W. LIU, S. PASCARELLI, Y. FRANK, R. HOEHNDORF, M. KULMANOV, I. BOUDELLIOUA, G. POLITANO, S. DI CARLO, A. BENSO, K. HAKALA, F. GINTER, F. MEHRYARY, S. KAEWPHAN, J. BJÖRNE, H. MOEN, M. E. TOLVANEN, T. SALAKOSKI, D. KIHARA, A. JAIN, T. ŠMUC, A. M. ALTENHOFF, A. BEN-HUR, B. ROST, S. BRENNER, C. ORENGO, C. JEFFERY, G. BOSCO, D. HOGAN, M. MARTIN, C. O'DONOVAN, S. MOONEY, C. GREENE, P. RADIVOJAC, I. FRIEDBERG.*The CAFA challenge reports improved protein function prediction and new functional annotations for hundreds of genes through experimental screens*, in "Genome Biology", December 2019, vol. 20, n° 1 [*DOI :* 10.1186/S13059-019-1835-8], https://hal.inria.fr/hal-02393202

[24] M. ZOGHLAMI, S. ARIDHI, M. MADDOURI, E. MEPHU NGUIFO.*Multiple instance learning for sequence data with across bag dependencies*, in "International journal of machine learning and cybernetics", 2019, https://arxiv.org/abs/1602.00163 , forthcoming [*DOI :* 10.1007/S13042-019-01021-5], https://hal.inria.fr/hal-02393742

International Conferences with Proceedings

[25] B. SARKER, D. W. RITCHIE, S. ARIDHI.*Functional Annotation of Proteins using Domain Embedding based Sequence Classification*, in "KDIR 2019 - 11th International Conference on Knowledge Discovery and Information Retrieval", Vienna, Austria, September 2019, https://hal.inria.fr/hal-02283430

[26] M. ZOGHLAMI, S. ARIDHI, M. MADDOURI, E. M. NGUIFO.*A Structure Based Multiple Instance Learning Approach for Bacterial Ionizing Radiation Resistance Prediction*, in "KES 2019 - 23rd International Conference on Knowledge-Based and Intelligent Information & Engineering Systems", Budapest, Hungary, September 2019, https://hal.inria.fr/hal-02307048

National Conferences with Proceeding

[27] K. DALLEAU, M. COUCEIRO, M. SMAÏL-TABBONE.*Les forêts d'arbres extrêmement aléatoires : utilisation dans un cadre non supervisé*, in "EGC 2019 - 19ème Conférence Francophone sur l'Extraction et Gestion des

connaissances", Metz, France, Hermann-Éditions, January 2019, vol. RNTI E-35, p. 395-400, https://hal.inria.fr/hal-02099532

Conferences without Proceedings

[28] M.-E. RUIZ-ECHARTEA, I. CHAUVOT DE BEAUCHÊNE, D. RITCHIE.*EROS-DOCK for Pairwise and Multi-body Protein-Protein Docking*, in "Journée MASIM2019 (Méthodes Algorithmiques pour les Structures et Interactions Macromoléculaires)", Paris, France, November 2019, https://hal.archives-ouvertes.fr/hal-02391973

[29] A. VAGINAY, M. SMAÏL-TABBONE, T. BOUKHOBZA.*Towards an automatic conversion from SBML core to SBML qual*, in "Journées Ouvertes Biologie, Informatique et Mathématiques, JOBIM 2019", Nantes, France, July 2019, Présentation Poster, https://hal.archives-ouvertes.fr/hal-02407443

Other Publications

[30] F.-É. CALVIER, P. MONNIN, M. BOLAND, P. JARNOT, E. BRESSO, M. SMAÏL-TABBONE, A. COULET, C. BOUSQUET.*Providing Molecular Characterization for Unexplained Adverse Drug Reactions : Podium Abstract*, July 2019, Podium Abstract at MedInfo 2019, Lyon, France, https://hal.inria.fr/hal-02196134

[31] K. DALLEAU, M. COUCEIRO, M. SMAÏL-TABBONE.*Clustering graphs using random trees*, September 2019, working paper or preprint, https://hal.inria.fr/hal-02282207

[32] K. DALLEAU, M. COUCEIRO, M. SMAÏL-TABBONE.*Computing Vertex-Vertex Dissimilarities Using Random Trees: Application to Clustering in Graphs*, November 2019, working paper or preprint, https://hal.inria.fr/hal-02427563

[33] K. DALLEAU, M. COUCEIRO, M. SMAÏL-TABBONE.*Unsupervised Extra Trees: a stochastic approach to compute similarities in heterogeneous data*, January 2019, working paper or preprint, https://hal.inria.fr/hal-01982232

[34] W. INOUBLI, S. ARIDHI, H. MEZNI, M. MONDHER, E. M. NGUIFO.*A Distributed Algorithm for Large-Scale Graph Clustering*, August 2019, working paper or preprint, https://hal.inria.fr/hal-02190913

[35] M.-E. RUIZ-ECHARTEA, I. CHAUVOT DE BEAUCHÊNE, D. RITCHIE.*EROS: A Protein Docking Algorithm Using a Quaternion pi- Ball Representation for Exhaustive and Accelerated Exploration of 3D Rotational Space*, April 2019, GGMM (groupe de graphisme et modélisation moléculaire), Poster, https://hal.archives-ouvertes.fr/hal-02392106

References in notes

[36] C. E. ALVAREZ-MARTINEZ, P. J. CHRISTIE.*Biological diversity of prokaryotic type IV secretion systems*, in "Microbiology and Molecular Biology Reviews", 2011, vol. 73, p. 775–808

[37] M. BAADEN, S. R. MARRINK.*Coarse-grained modelling of protein-protein interactions*, in "Current Opinion in Structural Biology", 2013, vol. 23, p. 878–886

[38] A. BERCHANSKI, M. EISENSTEIN.*Construction of molecular assemblies via docking: modeling of tetramers with D_2 symmetry*, in "Proteins", 2003, vol. 53, p. 817–829

[39] P. BORK, L. J. JENSEN, C. VON MERING, A. K. RAMANI, I. LEE, E. M. MARCOTTE.*Protein interaction networks from yeast to human*, in "Current Opinion in Structural Biology", 2004, vol. 14, p. 292–299

[40] I. J. CHAUVOT DE BEAUCHENE, S. J. DE VRIES, M. J. ZACHARIAS.*Fragment-based modeling of protein-bound ssRNA*, September 2016, ECCB 2016: The 15th European Conference on Computational Biology, Poster, https://hal.archives-ouvertes.fr/hal-01573352

[41] I. CHAUVOT DE BEAUCHÊNE, S. J. DE VRIES, M. ZACHARIAS.*Fragment-based modelling of single stranded RNA bound to RNA recognition motif containing proteins*, in "Nucleic Acids Research", June 2016 [*DOI :* 10.1093/NAR/GKW328], https://hal.archives-ouvertes.fr/hal-01505862

[42] S. J. DE VRIES, I. CHAUVOT DE BEAUCHÊNE, C. E. M. SCHINDLER, M. ZACHARIAS.*Cryo-EM Data Are Superior to Contact and Interface Information in Integrative Modeling*, in "Biophysical Journal", February 2016 [*DOI :* 10.1016/J.BPJ.2015.12.038], https://hal.archives-ouvertes.fr/hal-01505863

[43] M.-D. DEVIGNES, S. BENABDERRAHMANE, M. SMAÏL-TABBONE, A. NAPOLI, O. POCH.*Functional classification of genes using semantic distance and fuzzy clustering approach: Evaluation with reference sets and overlap analysis*, in "international Journal of Computational Biology and Drug Design. Special Issue on: ”Systems Biology Approaches in Biological and Biomedical Research”", 2012, vol. 5, n^{o} 3/4, p. 245-260, https://hal.inria.fr/hal-00734329

[44] S. E. DOBBINS, V. I. LESK, M. J. E. STERNBERG.*Insights into protein flexibility: The relationship between normal modes and conformational change upon protein–protein docking*, in "Proceedings of National Academiy of Sciences", 2008, vol. 105, n^{o} 30, p. 10390–10395

[45] M. EL HOUASLI, B. MAIGRET, M.-D. DEVIGNES, A. W. GHOORAH, S. GRUDININ, D. RITCHIE.*Modeling and minimizing CAPRI round 30 symmetrical protein complexes from CASP-11 structural models*, in "Proteins: Structure, Function, and Genetics", March 2017, vol. 85, n^{o} 3, p. 463–469 [*DOI :* 10.1002/PROT.25182], https://hal.inria.fr/hal-01388654

[46] W. J. FRAWLEY, G. PIATETSKY-SHAPIRO, C. J. MATHEUS.*Knowledge Discovery in Databases: An Overview*, in "AI Magazine", 1992, vol. 13, p. 57–70

[47] R. FRONZES, E. SCHÄFER, L. WANG, H. R. SAIBIL, E. V. ORLOVA, G. WAKSMAN.*Structure of a type IV secretion system core complex*, in "Science", 2011, vol. 323, p. 266–268

[48] R. A. GOLDSTEIN.*The structure of protein evolution and the evolution of proteins structure*, in "Current Opinion in Structural Biology", 2008, vol. 18, p. 170–177

[49] H. HERMJAKOB, L. MONTECCHI-PALAZZI, G. BADER, J. WOJCIK, L. SALWINSKI, A. CEOL, S. MOORE, S. ORCHARD, U. SARKANS, C. VON MERING, B. ROECHERT, S. POUX, E. JUNG, H. MERSCH, P. KERSEY, M. LAPPE, Y. LI, R. ZENG, D. RANA, M. NIKOLSKI, H. HUSI, C. BRUN, K. SHANKER, S. G. N. GRANT, C. SANDER, P. BORK, W. ZHU, A. PANDEY, A. BRAZMA, B. JACQ, M. VIDAL, D. SHERMAN, P. LEGRAIN, G. CESARENI, I. XENARIOS, D. EISENBERG, B. STEIPE, C. HOGUE, R. APWEILER.*The HUPO PSI's Molecular Interaction format – a community standard for the representation of protein interaction data*, in "Nature Biotechnology", 2004, vol. 22, n^{o} 2, p. 177-183

[50] H. I. INGÓLFSSON, C. A. LOPEZ, J. J. UUSITALO, D. H. DE JONG, S. M. GOPAL, X. PERIOLE, S. R. MARRINK.*The power of coarse graining in biomolecular simulations*, in "WIRES Comput. Mol. Sci.", 2013, vol. 4, p. 225–248, http://dx.doi.org/10.1002/wcms.1169

[51] J. D. JACKSON.*Classical Electrodynamics*, Wiley, New York, 1975

[52] P. J. KUNDROTAS, Z. W. ZHU, I. A. VAKSER.*GWIDD: Genome-wide protein docking database*, in "Nucleic Acids Research", 2010, vol. 38, p. D513–D517

[53] M. LENSINK, S. J. WODAK.*Docking and scoring protein interactions: CAPRI 2009*, in "Proteins", 2010, vol. 78, p. 3073–3084

[54] A. MAY, M. ZACHARIAS.*Energy minimization in low-frequency normal modes to efficiently allow for global flexibility during systematic protein-protein docking*, in "Proteins", 2008, vol. 70, p. 794–809

[55] I. H. MOAL, P. A. BATES.*SwarmDock and the Use of Normal Modes in Protein-Protein Docking*, in "International Journal of Molecular Sciences", 2010, vol. 11, n^o 10, p. 3623–3648

[56] C. MORRIS.*Towards a structural biology work bench*, in "Acta Crystallographica", 2013, vol. PD69, p. 681–682

[57] D. MUSTARD, D. RITCHIE.*Docking essential dynamics eigenstructures*, in "Proteins: Structure, Function, and Genetics", 2005, vol. 60, p. 269-274 [*DOI :* 10.1002/PROT.20569], https://hal.inria.fr/inria-00434271

[58] S. ORCHARD, S. KERRIEN, S. ABBANI, B. ARANDA, J. BHATE, S. BIDWELL, A. BRIDGE, L. BRIGANTI, F. S. L. BRINKMAN, G. CESARENI, A. CHATRARYAMONTRI, E. CHAUTARD, C. CHEN, M. DUMOUSSEAU, J. GOLL, R. E. W. HANCOCK, L. I. HANNICK, I. JURISICA, J. KHADAKE, D. J. LYNN, U. MAHADEVAN, L. PERFETTO, A. RAGHUNATH, S. RICARD-BLUM, B. ROECHERT, L. SALWINSKI, V. STÜMPFLEN, M. TYERS, P. UETZ, I. XENARIOS, H. HERMJAKOB.*Protein interaction data curation: the International Molecular Exchange (IMEx) consortium*, in "Nature Methods", 2012, vol. 9, n^o 4, p. 345-350

[59] B. PIERCE, W. TONG, Z. WENG.*M-ZDOCK: A Grid-Based Approach for C_n Symmetric Multimer Docking*, in "Bioinformatics", 2005, vol. 21, n^o 8, p. 1472–1478

[60] D. RITCHIE, G. J. KEMP.*Protein docking using spherical polar Fourier correlations*, in "Proteins: Structure, Function, and Genetics", 2000, vol. 39, p. 178-194, https://hal.inria.fr/inria-00434273

[61] D. RITCHIE, D. KOZAKOV, S. VAJDA.*Accelerating and focusing protein–protein docking correlations using multi-dimensional rotational FFT generating functions*, in "Bioinformatics", June 2008, vol. 24, n^o 17, p. 1865-1873 [*DOI :* 10.1093/BIOINFORMATICS/BTN334], https://hal.inria.fr/inria-00434264

[62] D. RITCHIE.*Recent Progress and Future Directions in Protein-Protein Docking*, in "Current Protein and Peptide Science", February 2008, vol. 9, n^o 1, p. 1-15 [*DOI :* 10.2174/138920308783565741], https://hal.inria.fr/inria-00434268

[63] A. RIVERA-CALZADA, R. FRONZES, C. G. SAVVA, V. CHANDRAN, P. W. LIAN, T. LAEREMANS, E. PARDON, J. STEYAERT, H. REMAUT, G. WAKSMAN, E. V. ORLOVA.*Structure of a bacterial type IV secretion core complex at subnanometre resolution*, in "EMBO Journal", 2013, vol. 32, p. 1195–1204

[64] M. E. RUIZ ECHARTEA, I. CHAUVOT DE BEAUCHÊNE, D. RITCHIE.*Accelerating Protein Docking Calculations using the ATTRACT CoarseGrained Force Field and 3D Rotation Maps*, May 2017, GGMM-2017, Poster, https://hal.inria.fr/hal-01927271

[65] M. G. SAUNDERS, G. A. VOTH.*Coarse-graining of multiprotein assemblies*, in "Current Opinion in Structural Biology", 2012, vol. 22, p. 144–150

[66] D. SCHNEIDMAN-DUHOVNY, Y. INBAR, R. NUSSINOV, H. J. WOLFSON.*Geometry-based flexible and symmetric protein docking*, in "Proteins", 2005, vol. 60, n^{o} 2, p. 224–231

[67] M. L. SIERK, G. J. KLEYWEGT.*Déjà vu all over again: Finding and analyzing protein structure similarities*, in "Structure", 2004, vol. 12, p. 2103–2011

[68] V. VENKATRAMAN, D. RITCHIE.*Flexible protein docking refinement using pose-dependent normal mode analysis*, in "Proteins", June 2012, vol. 80, n^{o} 9, p. 2262-2274 [*DOI :* 10.1002/PROT.24115], https://hal.inria.fr/hal-00756809

[69] A. B. WARD, A. SALI, I. A. WILSON.*Integrative Structural Biology*, in "Biochemistry", 2013, vol. 6122, p. 913–915

[70] Q. C. ZHANG, D. PETREY, L. DENG, L. QIANG, Y. SHI, C. A. THU, B. BISIKIRSKA, C. LEFEBVRE, D. ACCILI, T. HUNTER, T. MANIATIS, A. CALIFANO, B. HONIG.*Structure-based prediction of protein-protein interactions on a genome-wide scale*, in "Nature", 2012, vol. 490, p. 556–560

[71] A. ÖZGUR, Z. XIANG, D. R. RADEV, Y. HE.*Mining of vaccine-associated IFN-γ gene interaction networks using the Vaccine Ontology*, in "Journal of Biomedical Semantics", 2011, vol. 2 (Suppl 2), S8

Project-Team CARAMBA

Cryptology, arithmetic : algebraic methods for better algorithms

IN PARTNERSHIP WITH:
CNRS

Université de Lorraine

RESEARCH CENTER
Nancy - Grand Est

THEME
Algorithmics, Computer Algebra and Cryptology

Table of contents

Project-Team CARAMBA

Creation of the Team: 2016 January 01, updated into Project-Team: 2016 September 01

Keywords:

Computer Science and Digital Science:

A1.1.2. - Hardware accelerators (GPGPU, FPGA, etc.)
A4.3.1. - Public key cryptography
A4.3.2. - Secret key cryptography
A4.8. - Privacy-enhancing technologies
A6.2.7. - High performance computing
A7.1. - Algorithms
A8.4. - Computer Algebra
A8.5. - Number theory
A8.10. - Computer arithmetic

Other Research Topics and Application Domains:

B8.5. - Smart society
B9.5.1. - Computer science
B9.5.2. - Mathematics
B9.10. - Privacy

1. Team, Visitors, External Collaborators

Research Scientists

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Jérémie Detrey [Inria, Researcher]
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Aurore Guillevic [Inria, Researcher]
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Cécile Pierrot [Inria, Researcher]
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Marion Videau [Univ de Lorraine, Associate Professor, until Apr 2019, on leave with Quarkslab since Jan 2015]

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Paul Huynh [CNRS]
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Simon Masson [Thales]
Andrianina Sandra Rasoamiaramanana [Orange]

Post-Doctoral Fellow

Bimal Mandal [Inria]

Visiting Scientist

Santanu Sarkar [IIT Madras, India, Associate Professor, from Dec 2019]

Administrative Assistants

Emmanuelle Deschamps [Inria]

Virginie Priester [CNRS]

2. Overall Objectives

2.1. Overall Objectives

Our research addresses the broad application domain of cryptography and cryptanalysis from the algorithmic perspective. We study all the algorithmic aspects, from the top-level mathematical background down to the optimized high-performance software implementations. Several kinds of mathematical objects are commonly encountered in our research. Some basic ones are truly ubiquitous: integers, finite fields, polynomials, real and complex numbers. We also work with more structured objects such as number fields, algebraic curves, or polynomial systems. In all cases, our work is geared towards making computations with these objects effective and fast.

The two facets of cryptology—cryptography and cryptanalysis—are central to our research. The key challenges are the assessment of the security of proposed cryptographic primitives (both public- and secret-key), as well as the introduction of new cryptographic primitives, or the performance improvement of existing ones.

Our research connects to both symmetric and asymmetric key cryptography. While the basic principles of these domains are rather different—indeed their names indicate different handlings of the key—research in both domains is led by the same objective of finding the best trade-offs between efficiency and security. In addition to this, both require to study design and analysis together as these two aspects nurture each other.

Our research topics can be listed either with broad applications domains in mind (a very coarse-grain view would have us list them under cryptography and cryptanalysis), or more thematically (see Figure 1). Either way, we also identify a set of *tools* that we sometimes develop *per se*, but most often as ingredients towards goals that are set in the context of other themes. Following the “vertical” reading direction in Figure 1, our research topics are as follows.

- Extended NFS family. A common algorithmic framework, called the Number Field Sieve (NFS), addresses both the integer factorization problem as well as the discrete logarithm problem over finite fields. We have numerous algorithmic contributions in this context, and develop software to illustrate them.

  We plan to improve on the existing state of the art in this domain by researching new algorithms, by optimizing the software performance, and by demonstrating the reach of our software with highly visible computations.

- Algebraic curves and their Jacobians. We develop algorithms and software for computing essential properties of algebraic curves for cryptology, eventually enabling their widespread cryptographic use.

  One of the challenges we address here is point counting. In a wider perspective, we also study the link between abelian varieties over finite fields and principally polarized abelian varieties over fields of characteristic zero, together with their endomorphism ring. In particular, we work in the direction of making this link an effective one. We are also investigating various approaches for attacking the discrete logarithm problem in Jacobians of algebraic curves. Questions more recently studied include the development of cryptosystems based on isogenies.

- Symmetric key cryptography. This topic has emerged recently in the team, with the recruiting of Marine Minier and Virginie Lallemand. We are interested in particular in automatic tools for new paradigms of cryptanalysis, going beyond the classical linear and differential cryptanalysis techniques. Newer, more intricate techniques are rather hard to apply and are error-prone. The idea is then to automate the analysis process by developing tools implemented in CP, SAT or MILP. We plan to pay special attention to the recent advances in cryptanalysis and to study recently proposed lightweight ciphers.

  In addition, we also study new designs. The challenge of the lightweight world pushes symmetric cryptography to be ever more efficient while guaranteeing the same level of security as before. It is thus very important to scrutinize each building block of the symmetric key primitives to be convinced of their security.
- Tools. Several mathematical objects are pervasive in our research. We sometimes study them *per se*, but they most often play a key role in the work related to the topics above. In particular, we study computer arithmetic, polynomial systems, linear algebra. In the context of symmetric cryptography, the mathematical objects we deal with are rather different: we are mainly interested in small (4 or 8 bits) non-linear permutations (the so-called S-boxes) and in linear transformations based on coding theory (Maximum Distance Separable (MDS) matrices or quasi-MDS matrices).

  Our goals with all these basic objects include a strong commitment to providing high-quality software that can be used as a dependable building block in our research.

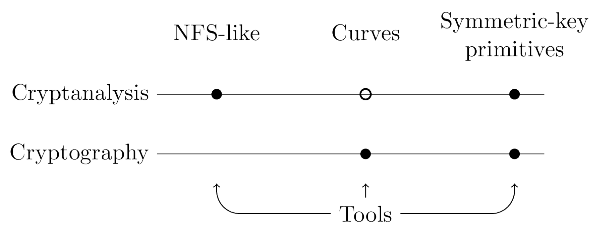

Figure 1. Visual representation of the thematic organization of CARAMBA. Solid dots: major interaction; clear dots: minor interaction.

As a complement to the last point, we consider that the impact of our research on cryptology in general owes a lot to the publication of concrete practical results. We are strongly committed to making our algorithms available as software implementations. We thus have several long-term software development projects that are, and will remain, part of our research activity.

3. Research Program

3.1. The Extended Family of the Number Field Sieve

The Number Field Sieve (NFS) has been the leading algorithm for factoring integers for more than 20 years, and its variants have been used to set records for discrete logarithms in finite fields. It is reasonable to understand NFS as a framework that can be used to solve various sorts of problems. Factoring integers and computing discrete logarithms are the most prominent for the cryptographic observer, but the same framework can also be applied to the computation of class groups.

The state of the art with NFS is built from numerous improvements of its inner steps. In terms of algorithmic improvements, the recent research activity on the NFS family has been rather intense. Several new algorithms have been discovered since 2014, notably for non-prime fields, and their practical reach has been demonstrated by actual experiments.

The algorithmic contributions of the CARAMBA members to NFS would hardly be possible without access to a dependable software implementation. To this end, members of the CARAMBA team have been developing the Cado-NFS software suite since 2007. Cado-NFS is now the most widely visible open-source implementation of NFS, and is a crucial platform for developing prototype implementations for new ideas for the many sub-algorithms of NFS. Cado-NFS is free software (LGPL) and follows an open development model, with publicly accessible development repository and regular software releases. Competing free software implementations exist, such as `msieve`, developed by J. Papadopoulos (whose last commit is from August 2018). In Lausanne, T. Kleinjung develops his own code base, which is unfortunately not public.

The work plan of CARAMBA on the topic of the Number Field Sieve algorithm and its cousins includes the following aspects:

- Pursue the work on NFS, which entails in particular making it ready to tackle larger challenges. Several of the important computational steps of NFS that are currently identified as stumbling blocks will require algorithmic advances and implementation improvements. We will illustrate the importance of this work by computational records.
- Work on the specific aspects of the computation of discrete logarithms in finite fields.
- As a side topic, the application of the broad methodology of NFS to the treatment of "ideal lattices" and their use in cryptographic proposals based on Euclidean lattices is also relevant.

3.2. Algebraic Curves for Cryptology

The challenges associated with algebraic curves in cryptology are diverse, because of the variety of mathematical objects to be considered. These challenges are also connected to each other. On the cryptographic side, efficiency matters. With the standardization of TLS 1.3 in 2018 [34], the curves x25519 and x448 have entered the base specification of standard. These curves were designed by academia and offer an excellent compromise between efficiency and security.

On the cryptanalytic side, the discrete logarithm problem on (Jacobians of) curves has resisted all attempts for many years. Among the currently active topics, the decomposition algorithms raise interesting problems related to polynomial system solving, as do attempts to solve the discrete logarithm problem on curves defined over binary fields. In particular, while it is generally accepted that the so-called Koblitz curves (base field extensions of curves defined over $\mathrm{GF}(2)$) are likely to be a weak class among the various curve choices, no concrete attack supports this claim fully.

The research objectives of CARAMBA on the topic of algebraic curves for cryptology are as follows:

- Work on the practical realization of some of the rich mathematical theory behind algebraic curves. In particular, some of the fundamental mathematical objects have potentially important connections to the broad topic of cryptology: Abel-Jacobi map, Theta functions, computation of isogenies, computation of endomorphisms, complex multiplication.
- Improve the point counting algorithms so as to be able to tackle larger problems. This includes significant work connected to polynomial systems.
- Seek improvements on the computation of discrete logarithms on curves, including by identifying weak instances of this problem.

3.3. Symmetric Cryptography

Since the recruiting of Marine Minier in September 2016 as a Professor at the Université de Lorraine, and of Virginie Lallemand as a CNRS researcher in October 2018, a new research domain has emerged in the CARAMBA team: symmetric key cryptology. Accompanied in this adventure by non-permanent team members, we are tackling problems related to both design and analysis. A large part of our recent researches has been motivated by the Lightweight Cryptography Standardization Process of the NIST [0] that embodies a crucial challenge of the last decade: finding ciphers that are suitable for resource-constrained devices.

On a general note, the working program of CARAMBA in symmetric cryptography is defined as follows:

- Develop automatic tools based on constraint programming to help finding optimum attack parameters. The effort will be focused on the AES standard and on recent lightweight cipher proposals.
- Contribute to the security and performance analysis effort required to sort out the candidates for the NIST Lightweight Cryptography Standardization Process.
- Study how to protect services execution on dedicated platforms using white-box cryptography and software obfuscation methods.

3.4. Computer Arithmetic

Computer arithmetic is part of the common background of all team members, and is naturally ubiquitous in our application domains. However involved the mathematical objects considered may be, dealing with them first requires to master more basic objects: integers, finite fields, polynomials, and real and complex floating-point numbers. Libraries such as GNU MP, GNU MPFR, GNU MPC do an excellent job for these, both for small and large sizes (we rarely, if ever, focus on small-precision floating-point data, which explains our lack of mention of libraries relevant to it).

Most of our involvement in subjects related to computer arithmetic is to be understood in connection to our applications to the Number Field Sieve and to abelian varieties. As such, much of the research work we envision will appear as side-effects of developments in these contexts. On the topic of arithmetic work *per se*:

- We will seek algorithmic and practical improvements to the most basic algorithms. That includes for example the study of advanced algorithms for integer multiplication, and their practical reach.
- We will continue to work on the arithmetic libraries in which we have crucial involvement, such as GNU MPFR, GNU MPC, GF2X, MPFQ, and also GMP-ECM.

3.5. Polynomial Systems

Systems of polynomial equations have been part of the cryptographic landscape for quite some time, with applications to the cryptanalysis of block and stream ciphers, as well as multivariate cryptographic primitives.

Polynomial systems arising from cryptology are usually not generic, in the sense that they have some distinct structural properties, such as symmetries, or bi-linearity for example. During the last decades, several results have shown that identifying and exploiting these structures can lead to dedicated Gröbner basis algorithms that can achieve large speedups compared to generic implementations [29], [28].

Solving polynomial systems is well done by existing software, and duplicating this effort is not relevant. However we develop test-bed open-source software for ideas relevant to the specific polynomial systems that arise in the context of our applications. The TinyGB software is our platform to test new ideas.

We aim to work on the topic of polynomial system solving in connection with our involvement in the aforementioned topics.

- We have high expertise on Elliptic Curve Cryptography in general. On the narrower topic of the Elliptic Curve Discrete Logarithm Problem on small characteristic finite fields, the highly structured polynomial systems that are involved match well our expertise on the topic of polynomial systems. Once a very hot topic in 2015, activity on this precise problem seems to have slowed down. Yet, the conjunction of skills that we have may lead to results in this direction in the future.
- The hiring of Marine Minier is likely to lead the team to study particular polynomial systems in contexts related to symmetric key cryptography.

[0] National Institute of Standard and Technology.

- More centered on polynomial systems *per se*, we will mainly pursue the study of the specificities of the polynomial systems that are strongly linked to our targeted applications, and for which we have significant expertise [29], [28]. We also want to see these recent results provide practical benefits compared to existing software, in particular for systems relevant for cryptanalysis.

4. Application Domains

4.1. Better Awareness and Avoidance of Cryptanalytic Threats

Our study of the Number Field Sieve family of algorithms aims at showing how the threats underlying various supposedly hard problems are real. Our record computations, as well as new algorithms, contribute to having a scientifically accurate assessment of the feasibility limit for these problems, given academic computing resources. The data we provide in this way is a primary ingredient for government agencies whose purpose includes guidance for the choice of appropriate cryptographic primitives. For example the French ANSSI [0], German BSI, or the NIST [0] in the United States base their recommendations on such computational achievements.

The software we make available to achieve these cryptanalytic computations also allows us to give cost estimates for potential attacks to cryptographic systems that are taking the security/efficiency/legacy compatibility trade-offs too lightly. Attacks such as LogJam [26] are understood as being serious concerns thanks to our convincing proof-of-concepts. In the LogJam context, this impact has led to rapid worldwide security advisories and software updates that eventually defeat some potential intelligence threats and improve confidentiality of communications.

4.2. Promotion of Better Cryptography

We also promote the switch to algebraic curves as cryptographic primitives. Those offer nice speed and excellent security, while primitives based on elementary number theory (integer factorization, discrete logarithm in finite fields), which underpin e.g., RSA, are gradually forced to adopt unwieldy key sizes so as to comply with the desired security guarantees of modern cryptography. Our contributions to the ultimate goal of having algebraic curves eventually take over the cryptographic landscape lie in our fast arithmetic contributions, our contributions to the point counting problem, and more generally our expertise on the diverse surrounding mathematical objects, or on the special cases where the discrete logarithm problem is not hard enough and should be avoided.

We also promote cryptographically sound electronic voting, for which we develop the Belenios prototype software (licensed under the AGPL). It depends on research made in collaboration with the PESTO team, and provides stronger guarantees than current state of the art.

4.3. Key Software Tools

The vast majority of our work is eventually realized as software. We can roughly categorize it in two groups. Some of our software covers truly fundamental objects, such as the GNU MPFR, GNU MPC, GF2X, or MPFQ packages. To their respective extent, these software packages are meant to be included or used in broader projects. For this reason, it is important that the license chosen for this software allows proper reuse, and we favor licenses such as the LGPL, which is not restrictive. We can measure the impact of this software by the way it is used in e.g., the GNU Compiler Collection (GCC), in Victor Shoup's Number Theory Library (NTL), or in the Sage computer algebra system. The availability of these software packages in most Linux distributions is also a good measure for the impact of our work.

[0] In [27], the minimal recommended RSA key size is 2048 bits for usage up to 2030. See also Annex B, in particular Section B.1 “Records de calculs cryptographiques”.

[0] The work [31] is one of only two academic works cited by NIST in the initial version (2011) of the report [33].

We also develop more specialized software. Our flagship software package is Cado-NFS [15], and we also develop some others with various levels of maturity, such as GMP-ECM, CMH, or Belenios, aiming at quite diverse targets. Within the lifespan of the CARAMBA project, we expect more software packages of this kind to be developed, specialized towards tasks relevant to our research targets: important mathematical structures attached to genus 2 curves, generation of cryptographically secure curves, or tools for attacking cryptographically hard problems. Such software both illustrates our algorithms, and provides a base on which further research work can be established. Because of the very nature of these specialized software packages as research topics in their own right, needing both to borrow material from other projects, and being possible source of inspiring material for others, it is again important that these be developed in a free and open-source development model.

5. Highlights of the Year

5.1. Highlights of the Year

- On December 2nd, 2019, the factorization of RSA-240 and the computation of a 240-digit discrete logarithm were announced.
- In August 2019, Pierrick Gaudry found a vulnerability in the encryption scheme of the Internet voting system of Moscow.
- Pierrick Gaudry and Cécile Pierrot were invited speakers at the ECC 2019 conference (Bochum, Germany).

5.1.1. Awards

- Simon Abelard received the PhD prize of Université de Lorraine from the doctoral school IAEM (computer science, automatic) [25].

6. New Software and Platforms

6.1. Belenios

Belenios - Verifiable online voting system

KEYWORD: E-voting

FUNCTIONAL DESCRIPTION: Belenios is an open-source online voting system that provides confidentiality and verifiability. End-to-end verifiability relies on the fact that the ballot box is public (voters can check that their ballots have been received) and on the fact that the tally is publicly verifiable (anyone can recount the votes). Confidentiality relies on the encryption of the votes and the distribution of the decryption key.

Belenios builds upon Helios, a voting protocol used in several elections. The main design enhancement of Belenios vs. Helios is that the ballot box can no longer add (fake) ballots, due to the use of credentials. Moreover, Belenios includes a practical threshold decryption system that allows splitting the decryption key among several authorities.

NEWS OF THE YEAR: Since 2015, it has been used by CNRS for remote election among its councils (more than 30 elections every year) and since 2016, it has been used by Inria to elect representatives in the “comités de centre” of each Inria center. In 2018, it has been used to organize about 250 elections (not counting test elections). Belenios is typically used for elections in universities as well as in associations. This goes from laboratory councils (e.g. Irisa, Cran), scientific societies (e.g. SMAI) to various associations (e.g. FFBS - Fédération Française de Baseball et Softball, or SRFA - Société du Rat Francophone et de ses Amateurs).

In 2019, a threshold encryption mode has been added that makes the system more robust to the case where (say) one trustee among three loses her part of the decryption key.

- Participants: Pierrick Gaudry, Stéphane Glondu and Véronique Cortier
- Partners: CNRS - Inria
- Contact: Stéphane Glondu
- URL: http://www.belenios.org/

6.2. CADO-NFS

Crible Algébrique: Distribution, Optimisation - Number Field Sieve

KEYWORDS: Cryptography - Number theory

FUNCTIONAL DESCRIPTION: CADO-NFS is a complete implementation in C/C++ of the Number Field Sieve (NFS) algorithm for factoring integers and computing discrete logarithms in finite fields. It consists in various programs corresponding to all the phases of the algorithm, and a general script that runs them, possibly in parallel over a network of computers.

NEWS OF THE YEAR: The main program for relation collection now supports composite "special-q". The memory footprint of the central step of linear algebra was reduced. Parallelism of many of the Cado-NFS programs was improved considerably (sieving, relation filtering, as well as the central step of linear algebra).

- Participants: Pierrick Gaudry, Emmanuel Thomé and Paul Zimmermann
- Contact: Emmanuel Thomé
- URL: http://cado-nfs.gforge.inria.fr/

6.3. Platforms

6.3.1. Platform: computational resources

Since 2018, the CARAMBA team has been using in particular a computer cluster called `grvingt`, acquired in 2018. This equipment was funded by the CPER «CyberEntreprises» (French Ministry of Research, Région Grand Est, Inria, CNRS) and comprises a 64-node, 2,048-core cluster. This cluster is installed in the Inria facility. Other slightly older hardware (a medium-size cluster called `grcinq` from 2013, funded by ANR, and a special machine funded by the aforementioned CPER grant) is also installed in the same location, to form a coherent platform with about 3,000 cpu cores, 100 TB of storage, and specific machines for RAM-demanding computations. As a whole, this platform provides an excellent support for the computational part of the work done in CARAMBA. This platform is also embedded in the larger Grid'5000/Silecs platform (and accessible as a normal resource within this platform). Technical administration is done by the Grid'5000 staff.

This equipment has played a key role in the record factorization of RSA-240 as well as the computation of discrete logarithms modulo a 240-digit prime, completed in the end of 2019.

7. New Results

7.1. Algebraic Curves for Cryptology

7.1.1. Cocks-Pinch Curves of Embedding Degrees Five to Eight and Optimal Ate Pairing Computation

Participants: Aurore Guillevic, Simon Masson, Emmanuel Thomé.

In [21] we explored a modification of the Cocks-Pinch method to generate pairing-friendly curves resistant to the Special-Tower-NFS algorithm (STNFS). We carefully estimated the cost of the STNFS attack for existing families of curves, and chose curves of embedding degree five to eight. For prime embedding degrees 5 and 7, our curves are naturally immune to the STNFS attack, but their performance level is not high. For composite embedding degrees 6 and 8 for which the TNFS attack applies, we chose the parameters from a family that is general enough to thwart the “special” variant STNFS; we also optimized these parameter choices so that these curves can have a reasonably efficient pairing computation, close with the very best possible curve choices.

7.1.2. A Short-List of Pairing-Friendly Curves Resistant to Special TNFS at the 128-bit Security Level

Participant: Aurore Guillevic.

The preprint [20] applies the refinements of the paper [22] to estimate the cost of the Special Tower NFS algorithm for particular pairing-friendly curves, whose target group is $\mathbb{F}_{p^n}$, and where the characteristic is special, parameterized by a low degree polynomial. We show that with a new variant of the polynomial selection, the estimated cost is reduced, but stays above the theoretical bound of the Special NFS $L_{p^n}(1/3, (32/9)^{1/3})$. This variant does not apply to the Cocks-Pinch curves of [21]. We list nine interesting pairing-friendly curves of embedding degrees between 10 and 16 at the 128-bit security level.

7.1.3. A Practical Attack on ECDSA Implementations Using wNAF Representation

Participants: Gabrielle de Micheli, Cécile Pierrot, Rémi Piau.

ECDSA is a widely deployed public key signature protocol that uses elliptic curves. One way of attacking ECDSA with wNAF implementation for the scalar multiplication is to perform a side-channel analysis to collect information, then use a lattice based method to recover the secret key. In [18], we re-investigate the construction of the lattice used in one of these methods, the Extended Hidden Number Problem (EHNP). We find the secret key with only 3 signatures, thus reaching the theoretical bound never achieved before. Our attack is more efficient than previous attacks, has better probability of success, and is still able to find the secret key with a small amount of erroneous traces, up to 2% of false digits.

7.1.4. Algorithmic Aspects of Elliptic Bases in Finite Field Discrete Logarithm Algorithms

Participant: Cécile Pierrot.

Elliptic bases give an elegant way of representing finite field extensions and were used as a starting point for small characteristic finite field discrete logarithm algorithms. This idea has been proposed by two groups, in order to achieve provable quasi-polynomial time algorithms for computing discrete logarithms in small characteristic finite fields. In [23], together with Antoine Joux, we do not try to achieve a provable algorithm, but instead we investigate the practicality of heuristic algorithms based on elliptic bases.

7.1.5. A Fast Randomized Geometric Algorithm for Computing Riemann-Roch Spaces

Participants: Aude Le Gluher, Pierre-Jean Spaenlehauer [contact].

In [7], we proposed a probabilistic variant of Brill-Noether's algorithm for computing a basis of the Riemann-Roch space $L(D)$ associated to a divisor D on a projective plane curve $\mathcal{C}$ over a sufficiently large perfect field k. Most of the results of this work have been obtained in 2018. In 2019, we have strengthened these results and revised the associated paper. This new version of the paper has been accepted for publication in the journal Mathematics of Computation.

7.1.6. Counting Points on Hyperelliptic Curves

Participants: Pierrick Gaudry, Pierre-Jean Spaenlehauer.

Two works with Simon Abelard [1], [2] following his PhD thesis about improved complexities for counting point algorithms of hyperelliptic curves with or without real multiplication are now formally published as journal articles.

7.1.7. Verifiable Delay Functions from Supersingular Isogenies and Pairings

Participant: Simon Masson.

Together with Luca De Feo, Christophe Petit and Antonio Sanso, we introduce in [11] two verifiable delay functions based on isogenies of supersingular elliptic curves and pairing. We discuss both the advantages and drawbacks of our constructions, we study their security and we demonstrate their practicality with a proof-of-concept implementation. This work appears in the proceedings of ASIACRYPT'2019.

7.1.8. Isogeny Graphs With Maximal Real Multiplication

Participant: Emmanuel Thomé.

Emmanuel Thomé and Sorina Ionica (post-doctoral fellow in the former CARAMEL team in 2012) worked on a new algorithm for computing isogeny graphs for Jacobians of curves having the special property that the intersection of their endomorphism ring with its real subfield is maximal. The resulting algorithm is the first depth-first algorithm for this task. The work [6] was finally published.

7.2. The Number Field Sieve – High-Level Results

7.2.1. A New Ranking Function for Polynomial Selection in the Number Field Sieve

Participant: Paul Zimmermann.

With Nicolas David (ÉNS Paris-Saclay, France), we designed a new ranking function for polynomial selection in the Number Field Sieve. The previous ranking function was only considering the *mean* of the so-called α-value, which measures how small primes divide the norm of the polynomial. The new function also takes into account the *variance* of the corresponding distribution. This partially explains why the previous function did sometimes fail to correctly identify the best polynomials. The new ranking function is implemented in Cado-NFS (branch `dist-alpha`) and is detailed in [3].

7.2.2. On the Alpha Value of Polynomials in the Tower Number Field Sieve Algorithm

Participant: Aurore Guillevic.

With Shashank Singh from IISER Bhopal (former post-doc at CARAMBA in 2017), we generalized the ranking function α for the Tower setting of the Number Field Sieve in [22]. In the relation collection of the NFS algorithm, one tests the smoothness of algebraic norms (computed with resultants). The α function measures the bias of the average valuation at small primes of algebraic norms, compared to the average valuation at random integers of the same size. A negative α means more small divisors than average. We then estimate the total number of relations with a Monte-Carlo simulation, as a generalized Murphy's E function, and finally give a rough estimate of the total cost of TNFS for finite fields $\mathbb{F}_{p^k}$ of popular pairing-friendly curves.

7.2.3. Faster Individual Discrete Logarithms in Finite Fields of Composite Extension Degree

Participant: Aurore Guillevic.

We improved the previous work [30] on speeding-up the first phase of the individual discrete logarithm computation, the initial splitting, a.k.a. the smoothing phase. We extended the algorithm to any non-prime finite field $\mathbb{F}_{p^n}$ where n is composite. We also applied it to the new variant Tower-NFS. The paper was finally published in 2019 [4].

7.3. The Number Field Sieve – Implementation Results

7.3.1. Parallel Structured Gaussian Elimination for the Number Field Sieve

Participant: Paul Zimmermann.

Together with Charles Bouillaguet (University of Lille, France), we completely re-designed the structured Gaussian elimination step of Cado-NFS (called `merge`). The new algorithm is fully parallel, and scales quite well. With 32 cores on modern hardware, the `merge`-step of RSA-512 (factored in 1999) now takes only 20 seconds, and for the hidden SNFS DLP-1024 record (done in 2017) it takes only 140 seconds [16].

7.4. Computer Arithmetic

7.4.1. Breaking Randomized Mixed-Radix Scalar Multiplication Algorithms

Participant: Jérémie Detrey.

Together with Laurent Imbert (LIRMM, France), we designed in [13] an attack against a recently published randomized elliptic-curve scalar multiplication scheme based on covering systems of congruences. We also proposed a more robust algorithm based on a mixed-radix representation of the scalar. However, under strong security hypotheses, this algorithm may still allow a virtual powerful attacker to recover much more information than what was first expected. This led us to the conclusion that randomized algorithms based on the mixed-radix number system should be avoided.

7.5. Symmetric Cryptology

7.5.1. Vectorial Boolean Functions with Very Low Differential-Linear Uniformity Using Maiorana-McFarland Type Construction

Participant: Bimal Mandal.

With Deng Tang and Subhamoy Maitra, we constructed in [14] a new class of balanced vectorial Boolean functions with very low differential-linear uniformity, whose coordinate functions are derived by modifying the Maiorana–McFarland bent functions. Further, we provided a combinatorial count of hardware gates required to implement such circuits.

7.5.2. Analysis of Boolean Functions in a Restricted (Biased) Domain

Participant: Bimal Mandal.

This work with Subhamoy Maitra, Thor Martinsen, Dibyendu Roy and Pantelimon Stanica [8] is a substantially revised and extended version of the paper “Tools in analyzing linear approximation for Boolean functions related to FLIP” that appeared in the proceedings of Indocrypt 2018 [32]. We proposed a technique to study the cryptographic properties of Boolean functions, whose inputs do not follow uniform distribution, and obtain a lower bound for the bias of the nonlinear filter function of FLIP by using biased Walsh–Hadamard transform. Our results provided more accurate calculation of the biases of Boolean function over restricted domain, which help to determine the security parameter of FLIP type ciphers.

7.5.3. Forkcipher: a New Primitive for Authenticated Encryption of Very Short Messages

Participant: Virginie Lallemand.

Together with Elena Andreeva, Antoon Purnal, Reza Reyhanitabar, Arnab Roy and Damian Vizár, we proposed a candidate to the NIST Lightweight competition that we also published at Asiacrypt 2019 [10]. Our proposal is based on the so-called forkcipher construction that was previously presented and investigated by a subset of the authors and which provides authenticated encryption optimized for short messages. Our NIST candidate is called ForkAE, and as required by NIST it is based on well investigated primitives, out of which the Skinny tweakable cipher. ForkAE is one of the 32 candidates that were selected to continue to Round 2 out of 56 valid submissions.

7.5.4. Computing AES Related-Key Differential Characteristics With Constraint Programming

Participant: Marine Minier.

In [5], with David Gérault, Pascal Lafourcade, and Christine Solnon, we improve existing Constraint Programming (CP) approaches for computing optimal related-key differential characteristics: we add new constraints that detect inconsistencies sooner, and we introduce a new decomposition of the problem in two steps. These improvements allow us to compute all optimal related-key differential characteristics for AES-128, AES-192 and AES-256 in a few hours.

7.5.5. Participation in the NIST Lightweight Cryptography Standardization Process

Participants: Marine Minier [contact], Paul Huynh, Virginie Lallemand.

The team is actively taking part in the lightweight cryptography standardization process of the NIST. The two major actions that have been taken are the following:

- Proposition of two candidates, namely Lilliput-AE (Alexandre Adomnicai, Thierry P. Berger, Christophe Clavier, Julien Francq, Paul Huynh, Virginie Lallemand, Kévin LeGouguec, Marine Minier, Léo Reynaud and Gaël Thomas) and ForkAE (Elena Andreeva, Virginie Lallemand, Antoon Purnal, Reza Reyhanitabar, Arnab Roy and Damian Vizár). ForkAE made it to the second round, but unfortunately a weak point has been detected in the design of Lilliput-AE.
- Organization of regular cryptanalysis meetings with other french cryptographers. Since the publication of the 56 proposals, four meetings have been held and some tangible results have already been achieved. As an example, the meeting participants found a practical differential forgery attack against the proposal named *Quartet*. The details have been made public on the NIST mailing list and they made the NIST remove this candidate from consideration.

7.5.6. Cryptanalysis of SKINNY in the Framework of the SKINNY 2018-2019 Cryptanalysis Competition

Participant: Virginie Lallemand.

Together with Patrick Derbez (University of Rennes) and Aleksei Udovenko (University of Luxembourg) we investigated in [12] the security of the SKINNY tweakable block cipher, a lightweight symmetric cipher proposed at Crypto in 2016. Our setting was the one of the SKINNY 2018-2019 Cryptanalysis Competition, that is we looked for attacks that can be run in practical time and that succeed with a data set reduced to the provided set of 2^{20} (plaintext, ciphertext). We solved the challenges (meaning that we experimentally recovered the 128-bit key) for up to 10-round SKINNY-128-128 and 12-round SKINNY-64-128. To this day these are the best results reported in this setting.

7.6. E-voting

7.6.1. Belenios: a Simple Private and Verifiable Electronic Voting System

Participant: Pierrick Gaudry.

In [9], written with Véronique Cortier and Stéphane Glondu, we have summarized the current state of our voting platform Belenios. It was the occasion to put in a single place the description of several sub-parts of the protocol that are otherwise spread in many articles. We also made statistics regarding the use of the platform during the year 2018, and discussed how security features were or were not activated by the users.

7.6.2. A Simple Alternative to Benaloh Challenge for the Cast-as-Intended Property in Helios/Belenios

Participant: Pierrick Gaudry.

In a short note [17] written with Véronique Cortier, Jannik Dreier, and Mathieu Turuani from the PESTO team, we propose a simple technique that can be added to an Helios-like e-voting protocol, so that the voter can check whether their potentially infected computer has not silently changed their vote.

7.6.3. Breaking the Encryption Scheme of the Moscow Internet Voting System

Participant: Pierrick Gaudry.

In [19], written in collaboration with Alexander Golovnev (Harvard), we explain the vulnerabilities we have found in an Internet voting system used for the election for the representatives of the Moscow Duma that took place in September 2019. The weaknesses in the encryption scheme (based on the discrete logarithm problem in finite fields) were found in the source code that was made available in July 2019 as part of a public testing.

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

- Together with the PESTO team, we had a contract with the Docapost company, the purpose of which is to improve their e-voting solution by adding some verifiability properties and switching to elliptic curve cryptography.
- Together with the PESTO team, we have a contract with the Idemia company about e-voting.

8.2. Bilateral Grants with Industry

- A contract with Orange Gardens at Chatillon-Montrouge is dedicated to the supervision of Sandra Rasoamiaramanana's PhD thesis about security in the white box context. The co-supervisor for Orange Gardens is Gilles Macario-rat.
- A contract with Thales (Thales Communication & Security, Gennevilliers, subsidiary of Thales Group) is dedicated to the supervision of Simon Masson's PhD thesis about elliptic curves for bilinear and post-quantum cryptography. The co-supervisor for Thales is Olivier Bernard.

9. Partnerships and Cooperations

9.1. Regional Initiatives

9.1.1. CPER CyberEntreprises

Program: CPER (Contrat de Plan État Région)
Project title: Cyber-Entreprises
Duration: 01/07/2015 - 31/12/2020
Coordinator: Emmanuel Thomé and Marc Jungers (CRAN)
Other partners: Inria, LORIA, CRAN, IÉCL, Centrale Supelec, LCFC.
Abstract: cf web site (in French only).

A high-performance computer cluster was funded by the CPER Cyber-entreprises project (Région Grand-Est, French Ministry of Research and Higher Education, Inria, CNRS). This cluster is also mentioned in 6.3.

9.2. National Initiatives

9.2.1. FUI Industrial Partnership on Lightweight Cryptography

Program: FUI (Fonds Unique Interministériel)
Project acronym: PACLIDO
Project title: Protocoles et Algorithmes Cryptographiques Légers pour l'Internet Des Objets
Duration: 12/2017 - 12/2020
Coordinator: Airbus Cybersecurity
Other partners: Airbus Cybersecurity, LORIA-CNRS, Rtone, Trusted Objects, CEA, Sophia Engineering, Université de Limoges, Saint-Quentin-en-Yvelines.
This contract is dedicated to the definition of new lightweight cryptographic primitives for the IoT. See web site for a full presentation.

9.2.2. ANR Decrypt

The CARAMBA team coordinates this ANR Project (started in January 2019) with the 5 following partners: LORIA, LIRIS (Lyon), LIMOS (Clermont-Ferrand), IRISA (Rennes), TASC (Nantes). This project aims to propose a declarative language dedicated to cryptanalytic problems in symmetric key cryptography using constraint programming (CP) to simplify the representation of attacks, to improve existing attacks and to build new cryptographic primitives that withstand these attacks. We also want to compare the different tools that can be used to solve these problems: SAT and MILP where the constraints are homogeneous and CP where the heterogeneous constraints can allow a more complex treatment.

One of the challenges of this project will be to define global constraints dedicated to the case of symmetric cryptography.

Concerning constraint programming, this project will define new dedicated global constraints, will improve the underlying filtering and solution search algorithms, and will propose dedicated explanations generated automatically. This 4-year project started in January 2019. See web site for more information.

9.3. International Research Visitors

9.3.1. Visits of International Scientists

- Diego Aranha from Aarhus University visited the team one week in May and presented his work on the Brazilian voting machines at the SSL seminar, and his work on fast pairing implementation at the team's seminar. As a result, some of the new secure pairing-friendly curves of [21], [22] are implemented in the C++ library RELIC [0] (free software).
- Santanu Sarkar from IIT Madras, Chennai, India is visiting the team from December 2019 to the end of February 2020.

9.3.1.1. Internships

- Hamid Boukerrou (Université Paris 8, from March 2019 until September 2019). Subject: cryptanalysis of LBlock.
- Félix Breton (ÉNS Paris, from June 2019 until July 2019). Félix Breton has formally proven in Coq the GNU MPFR subtraction routine in the case where all three operands (the two inputs and the result) have the same precision p, and $1 \le p < w$, where w is the machine bit-size. This extends previous work done by Jianyang Pan in 2018 on the addition and multiplication routines.
- Émilien Failly (CPP Nancy, from April 2019 until June 2019). Émilien Failly studied the Multiple Polynomial General Number Field Sieve (MNFS). He compared the use of 2, 3, and 4 polynomials on three test numbers: a 60-digit number, a 70-digit number, and a 96-digit number. In each case, the sieving time was estimated, because Cado-NFS cannot currently fully deal with MNFS polynomials.
- Liwei Liu (Peking University, from June 2019 until September 2019). In the context of the computation of discrete logarithms in finite field extensions of small degree, using the Number Field Sieve, Liwei Liu worked on the individual logarithm step, in order to make it faster and more robust.
- Rémi Piau (ÉNS Rennes, from May 2019 until July 2019). Rémi Piau worked on the implementation in Python of our attack against ECDSA using wNAF representation. He was able to improve it by making it cleaner, and using small tricks to make it faster too.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events: Selection

10.1.1.1. Member of steering committees

Pierrick Gaudry is a member of the steering committee of the Workshop on Elliptic Curve Cryptography (ECC).

Emmanuel Thomé is a member of the steering committee of the Algorithmic Number Theory Symposium (ANTS).

[0] https://github.com/relic-toolkit/relic

10.1.1.2. Member of the Conference Program Committees

- Aurore Guillevic was a member of the Program Committee of Latincrypt 2019 and WCC 2019.
- Virginie Lallemand was a member of the Program Committee of Asiacrypt 2019.
- Cécile Pierrot was a member of the Program Committee of EUROCRYPT 2020 and Journées Codage et Cryptographie 2020.
- Pierre-Jean Spaenlehauer was a member of the Program Committee of ISSAC 2019.
- Emmanuel Thomé is a member of the scientific directorate of the Dagstuhl computer science seminar series.

10.1.2. Journal

10.1.2.1. Member of the Editorial Boards

- Virginie Lallemand is a member of the editorial board of the IACR Transactions on Symmetric Cryptology (ToSC) Journal for 2019/2020. This journal is the open-access journal associated to the International Conference on Fast Software Encryption (FSE). She is also a member of the editorial board for the Special Issue of ToSC on Designs for the NIST Lightweight Standardization Process.

10.1.2.2. Reviewer - Reviewing Activities

Members of the project-team did their share in reviewing submissions to renowned conferences and journals. Actual publications venues are not disclosed for anonymity reasons.

10.1.3. Invited Talks

- Cécile Pierrot and Pierrick Gaudry were invited to give a talk at the Elliptic Curve Cryptography Conference (ECC19), Bochum, Germany.
- Marine Minier was invited to give a talk at the Journées Scientifiques Inria in Lyon, France, June 2019.
- Pierrick Gaudry gave a lecture during the Summer School Mathematical foundations of asymmetric cryptography, Aussois, France.
- Aurore Guillevic and Virginie Lallemand were invited to give a talk at the C2 seminar (formerly CCA seminar), Paris, France.
- Aurore Guillevic was invited to give a talk at the Workshop on Randomness and Arithmetics for Cryptography on Hardware in Roscoff, Brittany, France.

10.1.4. Research Administration

- Jérémie Detrey chaired the *Commission des Utilisateurs des Moyens Informatiques* (CUMI) of the Inria Nancy – Grand Est research center until November 2019.
- Pierrick Gaudry is:
  - vice-head of the *Commission de mention Informatique* of the *École doctorale IAEM* of the University of Lorraine;
  - a member of the *Conseil Scientifique du GdR IM*;
  - member of the visiting committee for the HCERES evaluation of the CRIStAL laboratory (Lille).
- Aurore Guillevic
  - was member of the CoS, poste MCF number 27MCF1087, Université de Clermont Auvergne;
  - was member of the CoS, poste Chargé d'Enseignement (ChE), École Polytechnique (Palaiseau).
- Marine Minier
  - is a member of Collegium of Science et Techniques of Université de Lorraine;

- was a member of the CoS, poste MCF number 27MCF-0781944P-4184, Université de Versailles.

- Pierre-Jean Spaenlehauer is a member of the *commission développement technologique* (CDT) of the Inria Nancy - Grand Est research center.
- Emmanuel Thomé
  - is a member of the management committee for the research project “CPER Cyberentreprises” (co-chair);
  - is a member of the *Comipers* of the Inria Nancy – Grand Est research center, in charge of deciding the attribution of Inria PhD and post-doc grants;
  - is an elected member of the Inria evaluation committee (CE), and a member of the committee “bureau”;
  - is an elected member of the Inria technical committee (CTI).
- Paul Zimmermann is member of the Scientific Committee of the EXPLOR *Mésocentre*, of the “groupe de réflexion” *Calcul, Codage, Information* of the GDR-IM, of the scientific council of the LIRMM laboratory in Montpellier, France.

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Licence: Jérémie Detrey, *Sécurité des applications Web*, 2h eq. TD, LP, Université de Lorraine, IUT Charlemagne, Nancy, France.

Licence: Pierrick Gaudry, *Intégration Web*, 48h eq. TD, IUT 1A, Université de Lorraine, IUT Charlemagne, Nancy, France.

Licence: Aurore Guillevic, *Introduction to algorithms* (CSE103), 32 eq. TD, L1, École Polytechnique, Palaiseau, France.

Licence: Aurore Guillevic, *Les bases de la programmation et de l'algorithmique* (INF411), 40 eq. TD, 2e année, École Polytechnique, Palaiseau, France.

Master: Marine Minier, *Contrôle d'accès*, 40h eq. TD, M2 Informatique, Université de Lorraine, Faculté des sciences et technologies, Vandœuvre-lès-Nancy, France.

Master: Marine Minier, *Intégration Méthodologique*, 36h eq. TD, M2 Informatique, Université de Lorraine, Faculté des sciences et technologies, Vandœuvre-lès-Nancy, France.

Master: Marine Minier, *Introduction à la cryptographie*, 15h eq. TD, M1 Informatique, Université de Lorraine, Faculté des sciences et technologies, Vandœuvre-lès-Nancy, France.

Licence: Marine Minier, *Introduction à la sécurité et à la cryptographie*, 10 hours (lectures) + 10 hours (tutorial sessions) + 10 hours (practical sessions), L3, Université de Lorraine, Faculté des sciences et technologies, Vandœuvre-lès-Nancy, France.

Licence: Marine Minier, *Mathématiques Discrètes*, 80h eq. TD, L2, Université de Lorraine, Faculté des sciences et technologies, Vandœuvre-lès-Nancy, France.

Responsability of the M2 SIRAV *Sécurité Informatique, Réseaux et Architectures Virtuelles*, 30 students: Marine Minier. Université de Lorraine, Faculté des sciences et technologies, Vandœuvre-lès-Nancy, France.

Master: Cécile Pierrot, *Introduction à la cryptographie*, 60h eq. TD, Mastère spécialisé en sécurité, École des Mines de Nancy, France.

Master: Cécile Pierrot, *Introduction à LaTeX*, 6h eq. TD, Master 1, École des Mines de Nancy, France.

Master: Emmanuel Thomé, *Protocoles de sécurité et Vérification* (sub-part dedicated to cryptographic primitives), 8h (lectures) + 6h (tutorial sessions), Télécom Nancy.

10.2.2. Supervision

PhD in progress: Sandra Rasoamiaramanana, *Délivrance de contextes sécurisés par des approches hybrides*, since May 2017, PhD CIFRE Orange Gardens, Marine Minier. Planed to be defended in April 2020.

PhD in progress: Simon Masson, *Algorithmique des courbes destinées aux contextes de la cryptographie bilinéaire et post-quantique*, since Jan. 2018, Emmanuel Thomé and Aurore Guillevic.

PhD in progress: Aude Le Gluher, *Analyse algorithmique fine et simulation du crible algébrique*, since Sep. 2018, Pierre-Jean Spaenlehauer and Emmanuel Thomé.

PhD in progress: Gabrielle De Micheli, *Le logarithme discret dans les corps finis*, since Oct. 2018, Cécile Pierrot and Pierrick Gaudry.

PhD in progress: Paul Huynh, *Analyse et conception de chiffrements authentifiés à bas coût*, since Oct. 2017, Marine Minier.

PhD in progress: Hamid Boukerrou, *Design of New Finite State Dynamical Systems Admitting a Matrix Representation: Application to Cryptography*, since Oct. 2019, Marine Minier and Gilles Millerioux.

10.2.3. Juries

Pierrick Gaudry was

- reviewer of the PhD thesis *Arithmétique rapide pour des corps finis* defended by Robin Larrieu, December 2019, École polytechnique;
- member of the PhD thesis jury *Delaunay triangulations of a family of symmetric hyperbolic surfaces in practice* defended by Iordan Iordanov, March 2019, Université de Lorraine;
- member of the HdR jury *Cryptographie basée sur les corps quadratiques : cryptanalyses, primitives et protocoles* defended by Guilhem Castagnos, November 2019, Université de Bordeaux.

Virginie Lallemand was member of the PhD thesis jury: *Optimization of Core Components of Block Ciphers* defended by Baptiste Lambin on the 22nd of October 2019 at the University of Rennes 1.

Marine Minier:

- reviewer of the PhD thesis: Secure Multi-Party Computation and Privacy defended by Aurélien Dupin, June 2019, ENS Ulm, Paris.
- reviewer of the PhD thesis: Optimization of Core Components of Block Ciphers defended by Baptiste Lambin, October 2019, Université de Rennes, Rennes.
- reviewer of the PhD thesis: Représentations adaptées à l'arithmétique modulaire et à la résolution de systèmes flous defended by Jérémie Marrez, December 2019, Université Paris 6, Paris.
- reviewer of the PhD thesis: Security for the Internet of Things: A bottom-up approach to the secure and standardized Internet of Things defended by Timothy Claeys, December 2019, Université Grenoble Alpes, Grenoble.
- President of the PhD thesis jury: Software Datapaths for Multi-Tenant Packet Processing defended by Paul Chaignon, June 2019, Université de Lorraine, Nancy.
- President of the PhD thesis jury: Usability: low tech, high security, defended by Nicolas Blanchard, June 2019, Université de Paris, Paris.
- President of the PhD thesis jury: Contributions à l'analyse de canaux auxiliaires sans connaissance des clairs et chiffrés, et à la recherche de S-boxs compactes, defended by Léo Reynaud, December 2019, Université de Limoges, Limoges.

Emmanuel Thomé was:

- reviewer for the HDR thesis *Algorithmes et implantations efficaces en algèbre linéaire exacte* defended by Pascal Giorgi, October 2019, Université de Montpellier.
- member of the PhD thesis jury *Vote électronique : définitions et techniques d'analyse* defended by Joseph Lallemand, November 2019, Université de Lorraine;

Paul Zimmermann was reviewer of the PhD thesis *Formalisations d'analyses d'erreurs en analyse numérique et en arithmétique à virgule flottante* defended by Florian Faissole, December 2019, Université Paris-Saclay.

10.3. Popularization

10.3.1. Internal or external Inria responsibilities

Pierrick Gaudry was member of a jury for the Innoviris LAUNCH program, whose goal is to fund start-ups created on the basis of academic work.

10.3.2. Articles and contents

- Cécile Pierrot wrote a blog post for Le Monde Binaire.

10.3.3. Interventions

- Cécile Pierrot gave a talk about women in science at a meeting *Les Filles, osez les sciences !* in Reims, March 2019.
- Cécile Pierrot and Paul Zimmermann took part in La Fête de la Science, Nancy and Bouxurulles, October 2019.
- Cécile Pierrot gave a talk at La Cité des Sciences, Paris, to open the exhibition called *Espions*, November 2019.
- Pierre-Jean Spaenlehauer gave an introductory talk on polynomial systems to visiting students of the ÉNS Paris-Saclay.

11. Bibliography

Publications of the year

Articles in International Peer-Reviewed Journal

[1] S. ABELARD. *Counting points on hyperelliptic curves with explicit real multiplication in arbitrary genus*, in "Journal of Complexity", 2019, forthcoming [*DOI :* 10.1016/J.JCO.2019.101440], https://hal.inria.fr/hal-01905580

[2] S. ABELARD, P. GAUDRY, P.-J. SPAENLEHAUER. *Improved Complexity Bounds for Counting Points on Hyperelliptic Curves*, in "Foundations of Computational Mathematics", 2019, vol. 19, n^{o} 3, p. 591-621, https://arxiv.org/abs/1710.03448 [*DOI :* 10.1007/S10208-018-9392-1], https://hal.inria.fr/hal-01613530

[3] N. DAVID, P. ZIMMERMANN. *A New Ranking Function for Polynomial Selection in the Number Field Sieve*, in "Contemporary mathematics", 2019, forthcoming, https://hal.inria.fr/hal-02151093

[4] A. GUILLEVIC. *Faster individual discrete logarithms in finite fields of composite extension degree*, in "Mathematics of Computation", January 2019, vol. 88, n^{o} 317, p. 1273-1301, https://arxiv.org/abs/1809.06135 [*DOI :* 10.1090/MCOM/3376], https://hal.inria.fr/hal-01341849

[5] D. GÉRAULT, P. LAFOURCADE, M. MINIER, C. SOLNON.*Computing AES related-key differential characteristics with constraint programming*, in "Artificial Intelligence", January 2020, vol. 278, 103183 [*DOI :* 10.1016/J.ARTINT.2019.103183], https://hal.archives-ouvertes.fr/hal-02327893

[6] S. IONICA, E. THOMÉ.*Isogeny graphs with maximal real multiplication*, in "Journal of Number Theory", February 2020, vol. 207, p. 385-422, https://arxiv.org/abs/1407.6672 [*DOI :* 10.1016/J.JNT.2019.06.019], https://hal.archives-ouvertes.fr/hal-00967742

[7] A. LE GLUHER, P.-J. SPAENLEHAUER.*A Fast Randomized Geometric Algorithm for Computing Riemann-Roch Spaces*, in "Mathematics of Computation", 2019, https://arxiv.org/abs/1811.08237 , forthcoming, https://hal.inria.fr/hal-01930573

[8] S. MAITRA, B. MANDAL, T. MARTINSEN, D. ROY, P. STANICA.*Analysis on Boolean function in a restricted (biased) domain*, in "IEEE Transactions on Information Theory", August 2019, p. 1-13 [*DOI :* 10.1109/TIT.2019.2932739], https://hal.inria.fr/hal-02374194

Invited Conferences

[9] V. CORTIER, P. GAUDRY, S. GLONDU.*Belenios: a simple private and verifiable electronic voting system*, in "Foundations of Security, Protocols, and Equational Reasoning", Fredericksburg, Virgina, United States, J. D. GUTTMAN, C. E. LANDWEHR, J. MESEGUER, D. PAVLOVIC (editors), LNCS, Springer, 2019, vol. 11565, p. 214-238 [*DOI :* 10.1007/978-3-030-19052-1_14], https://hal.inria.fr/hal-02066930

International Conferences with Proceedings

[10] E. ANDREEVA, V. LALLEMAND, A. PURNAL, R. REYHANITABAR, A. ROY, D. VIZÁR.*Forkcipher: A New Primitive for Authenticated Encryption of Very Short Messages*, in "ASIACRYPT 2019 - 25th Annual International Conference on the Theory and Application of Cryptology and Information Security", Kobe, Japan, Advances in Cryptology – ASIACRYPT 2019, November 2019, p. 153-182 [*DOI :* 10.1007/978-3-030-34621-8_6], https://hal.inria.fr/hal-02388234

[11] L. DE FEO, S. MASSON, C. PETIT, A. SANSO.*Verifiable Delay Functions from Supersingular Isogenies and Pairings*, in "Advances in Cryptology - ASIACRYPT 2019 - 25th International Conference on the Theory and Application of Cryptology and Information Security", Kobe, Japan, Advances in Cryptology - ASIACRYPT 2019, August 2019, vol. 1, p. 248-277 [*DOI :* 10.1007/978-3-030-34578-5_10], https://hal.inria.fr/hal-02388349

[12] P. DERBEZ, V. LALLEMAND, A. UDOVENKO.*Cryptanalysis of SKINNY in the Framework of the SKINNY 2018-2019 Cryptanalysis Competition*, in "SAC 2019 - Selected Areas in Cryptography", Waterloo, Canada, August 2019, https://hal.inria.fr/hal-02388239

[13] J. DETREY, L. IMBERT.*Breaking randomized mixed-radix scalar multiplication algorithms*, in "LATINCRYPT 2019 - 6th International Conference on Cryptology and Information Security in Latin America", Santiago de Chile, Chile, Lecture Notes in Computer Science, 2019, vol. 11774, p. 24-39 [*DOI :* 10.1007/978-3-030-30530-7_2], https://hal-lirmm.ccsd.cnrs.fr/lirmm-02309203

[14] D. TANG, B. MANDAL, S. MAITRA.*Vectorial Boolean Functions with Very Low Differential-Linear Uniformity Using Maiorana-McFarland Type Construction*, in "Progress in Cryptology – INDOCRYPT 2019", Hyderabad, India, December 2019 [*DOI :* 10.1007/978-3-030-35423-7_17], https://hal.inria.fr/hal-02374286

Software

[15] T. CADO-NFS DEVELOPMENT TEAM.*CADO-NFS, An Implementation of the Number Field Sieve Algorithm*, April 2019, Version : 2.3.0, Software, https://hal.inria.fr/hal-02099620

Other Publications

[16] C. BOUILLAGUET, P. ZIMMERMANN.*Parallel Structured Gaussian Elimination for the Number Field Sieve*, April 2019, working paper or preprint, https://hal.inria.fr/hal-02098114

[17] V. CORTIER, J. DREIER, P. GAUDRY, M. TURUANI.*A simple alternative to Benaloh challenge for the cast-as-intended property in Helios/Belenios*, 2019, working paper or preprint, https://hal.inria.fr/hal-02346420

[18] G. DE MICHELI, R. PIAU, C. PIERROT.*A Tale of Three Signatures: practical attack of ECDSA with wNAF*, December 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-02393302

[19] P. GAUDRY, A. GOLOVNEV.*Breaking the encryption scheme of the Moscow Internet voting system*, November 2019, https://arxiv.org/abs/1908.05127 - This work is a merger of arXiv:1908.09170 and arXiv:1908.05127., https://hal.inria.fr/hal-02266264

[20] A. GUILLEVIC.*A short-list of pairing-friendly curves resistant to Special TNFS at the 128-bit security level*, December 2019, working paper or preprint, https://hal.inria.fr/hal-02396352

[21] A. GUILLEVIC, S. MASSON, E. THOMÉ.*Cocks-Pinch curves of embedding degrees five to eight and optimal ate pairing computation*, October 2019, working paper or preprint, https://hal.inria.fr/hal-02305051

[22] A. GUILLEVIC, S. SINGH.*On the Alpha Value of Polynomials in the Tower Number Field Sieve Algorithm*, August 2019, working paper or preprint, https://hal.inria.fr/hal-02263098

[23] A. JOUX, C. PIERROT.*Algorithmic aspects of elliptic bases in finite field discrete logarithm algorithms*, July 2019, https://arxiv.org/abs/1907.02689 - working paper or preprint, https://hal.sorbonne-universite.fr/hal-02173688

[24] E. MILIO, D. ROBERT.*Modular polynomials on Hilbert surfaces*, June 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-01520262

References in notes

[25] S. ABELARD.*Counting points on hyperelliptic curves in large characteristic : algorithms and complexity*, Université de Lorraine, September 2018, PhD thesis, https://tel.archives-ouvertes.fr/tel-01876314

[26] D. ADRIAN, K. BHARGAVAN, Z. DURUMERIC, P. GAUDRY, M. GREEN, J. ALEX HALDERMAN, N. HENINGER, D. SPRINGALL, E. THOMÉ, L. VALENTA, B. VANDERSLOOT, E. WUSTROW, S. ZANELLA-BÉGUELIN, P. ZIMMERMANN.*Imperfect Forward Secrecy: How Diffie-Hellman fails in practice*, in "CCS'15", ACM, 2015, p. 5–17, http://dl.acm.org/citation.cfm?doid=2810103.2813707

[27] AGENCE NATIONALE DE LA SÉCURITÉ DES SYSTÈMES D'INFORMATION.*Référentiel général de sécurité, annexe B1*, 2014, Version 2.03, http://www.ssi.gouv.fr/uploads/2014/11/RGS_v-2-0_B1.pdf

[28] J.-C. FAUGÈRE, P.-J. SPAENLEHAUER, J. SVARTZ.*Sparse Gröbner bases: the unmixed case*, in "ISSAC 2014", K. NABESHIMA (editor), ACM, 2014, p. 178–185, Proceedings

[29] J.-C. FAUGÈRE, M. SAFEY EL DIN, P.-J. SPAENLEHAUER.*Gröbner Bases of Bihomogeneous Ideals generated by Polynomials of Bidegree* $(1,1)$*: Algorithms and Complexity*, in "J. Symbolic Comput.", 2011, vol. 46, n^{o} 4, p. 406–437

[30] A. GUILLEVIC.*Computing Individual Discrete Logarithms Faster in* $GF(p^n)$ *with the NFS-DL Algorithm*, in "Asiacrypt 2015", Auckland, New Zealand, T. IWATA, J. H. CHEON (editors), Lecture Notes in Computer Science, Springer, November 2015, vol. 9452, p. 149-173 [*DOI :* 10.1007/978-3-662-48797-6_7], https://hal.inria.fr/hal-01157378

[31] T. KLEINJUNG, K. AOKI, J. FRANKE, A. K. LENSTRA, E. THOMÉ, J. BOS, P. GAUDRY, A. KRUPPA, P. L. MONTGOMERY, D. A. OSVIK, H. TE RIELE, A. TIMOFEEV, P. ZIMMERMANN.*Factorization of a 768-bit RSA modulus*, in "CRYPTO 2010", T. RABIN (editor), Lecture Notes in Comput. Sci., Springer–Verlag, 2010, vol. 6223, p. 333–350, Proceedings

[32] S. MAITRA, B. MANDAL, T. MARTINSEN, D. ROY, P. STANICA.*Tools in Analyzing Linear Approximation for Boolean Functions Related to FLIP*, in "Progress in Cryptology - INDOCRYPT 2018 - 19th International Conference on Cryptology in India, New Delhi, India, December 9-12, 2018, Proceedings", D. CHAKRABORTY, T. IWATA (editors), Lecture Notes in Computer Science, Springer, 2018, vol. 11356, p. 282–303, https://doi.org/10.1007/978-3-030-05378-9_16

[33] NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY.*Transitions: Recommendation for Transitioning the Use of Cryptographic Algorithms and Key Lengths*, 2011, First revision, http://dx.doi.org/10.6028/NIST.SP.800-131A

[34] E. RESCORLA.*The Transport Layer Security (TLS) Protocol Version 1.3*, 2018, RFC 8446, https://tools.ietf.org/html/rfc8446

Project-Team COAST

Web Scale Trustworthy Collaborative Service Systems

IN COLLABORATION WITH: Laboratoire lorrain de recherche en informatique et ses applications (LORIA)

IN PARTNERSHIP WITH:
CNRS

Université de Lorraine

RESEARCH CENTER
Nancy - Grand Est

THEME
Distributed Systems and middleware

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Project-Team COAST

Creation of the Team: 2014 July 01, updated into Project-Team: 2015 July 01

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A1.3.5. - Cloud
A1.3.6. - Fog, Edge
A2.5.1. - Software Architecture & Design
A2.6.2. - Middleware
A3.1.3. - Distributed data
A3.1.5. - Control access, privacy
A5.1.1. - Engineering of interactive systems
A5.1.2. - Evaluation of interactive systems

Other Research Topics and Application Domains:

B6.1.1. - Software engineering
B6.3.1. - Web
B6.5. - Information systems
B8.4. - Security and personal assistance
B8.4.1. - Crisis management
B9.1.1. - E-learning, MOOC
B9.6.1. - Psychology
B9.8. - Reproducibility
B9.10. - Privacy

1. Team, Visitors, External Collaborators

Research Scientist

Claudia-Lavinia Ignat [Inria, Researcher]

Faculty Members

François Charoy [Team leader, Univ de Lorraine, Professor, HDR]
Khalid Benali [Univ de Lorraine, Associate Professor, HDR]
Gérôme Canals [Univ de Lorraine, Associate Professor]
Claude Godart [Univ de Lorraine, Professor]
Gérald Oster [Univ de Lorraine, Associate Professor]
Olivier Perrin [Univ de Lorraine, Professor, HDR]
Samir Youcef [Univ de Lorraine, Associate Professor]

Technical Staff

Jean-Philippe Eisenbarth [Univ de Lorraine, Engineer, until Mar 2019]
Cédric Enclos [Inria, Engineer]

PhD Students

Victorien Elvinger [Univ de Lorraine, Researcher, until Aug 2020]
Anis Ahmed Nacer [Inria]
Clélie Amiot [CNRS, from Nov 2019]
Abir Ismaili-Alaoui [Univ de Lorraine]
Quentin Laporte Chabasse [Univ de Lorraine]
Hoai-Le Nguyen [Univ Lorraine]
Hoang Long Nguyen [Univ de Lorraine, until Mar 2019]
Matthieu Nicolas [Univ de Lorraine]
Guillaume Rosinosky [Univ de Lorraine, until Jan 2019]
Béatrice Linot [Univ de Lorraine]

Post-Doctoral Fellows

Mohammed Riyadh Abdmeziem [Univ de Lorraine, Researcher]
Siavash Atarodi [Univ de Lorraine, until Feb 2019]
Chahrazed Labba [Univ de Lorraine, until Feb 2019]
Amina Ahmed Nacer [Univ de Lorraine, Chercheur, until Jul 2019]

Visiting Scientist

Weihai Yu [Artic University Norway, until Sep 2019]

2. Overall Objectives

2.1. Overall Objectives

The advent of the Cloud, smart mobile devices and service-based architecture has opened a field of possibilities as wide as the invention of the Web 25 years ago. Software companies now deliver applications and services using the Web as a platform. From text to video editing, from data analytic to process management, they distribute business applications to users within their web browser or on some mobile appliance [0]. These services are deployed on sophisticated infrastructures that can cope with very demanding loads. The Software as a Service approach (SaaS) highlights their cooperative nature, by enabling the storage of data in cloud infrastructures that can be easily shared among users. Thus, clients consume applications through service API (web services), available on delivery platforms, called stores or markets. This approach of software distribution outstrips the traditional software distribution channels, in both scale and opportunity. Scale has different dimensions: the number of users (communities rather than groups), the size of data produced and managed (billions of documents), the number of services and of organizations (tens of thousands). Opportunity refers to the infinite number of combinations between these services and the many ways to consume and use them. This fast-paced evolution challenges research because the creation of applications from the composition of services must incorporate new content and context based constraints. From a socio-technical perspective, the behaviour of users is evolving constantly as they get acculturated to new services and ways to cooperate. Mere enhancement of current existing solutions to cope with these challenges is insufficient. We conduct a dedicated research effort to tackle the problems arising from the evolution of contemporary technologies and of those we can anticipate. For this purpose, we explore three directions: large scale collaborative data management, data centred service composition and above all, a foundation for the construction of trustworthy collaborative systems. **Large scale collaborative data management** concerns mostly the problem of allowing people to collaborate on shared data, synchronously or not, on a central server or on a peer to peer network. This research has a long history referring back to a paper by Ellis [14]. Users acculturation to online collaboration triggers new challenges. these refer to the number of participants to a collaboration (a crowd), to sharing among different organizations and to the nature of documents that are shared and produced. The problem is to design new algorithms and to evaluate them under different usage conditions and constraints and for different kinds of data. **Data centred service composition** deals with the challenge of creating applications by composing services from different providers. Service composition has been studied for some time now but the technical

[0] See http://blog.programmableweb.com/2011/09/16/open-api-growth-a-visualization/

evolution and the growing availability of public API oblige us to reconsider the problem [13]. Our goal here is, taking into account this evolution, like the advent of the Cloud, the availability at a large scale of public API based on the REST [0] architectural style, to design models, methods and tools to help developers to compose these services in a safe and effective way. Based on the work that we do in the two first topics, our main research direction aims at providing support to build **trustworthy collaborative applications.** We base it on the knowledge that we can gather from the underlying algorithms, the composition of services and the quality of services that we can deduce and monitor. The complexity of the context in which applications are executed does not allow to provide proven guarantees. Our goal is to base our work on a contractual and monitored approach to provide users with confidence in the service they use. Surprisingly, people rely today on services with very little knowledge about the amount of confidence they can put in these services. They are based on composition of other unknown services. Thus, it becomes very difficult to understand the consequences of the failure of a component of the composition. We follow a path that portrays a ruptured continuum, to underscore both the endurance of the common questions along with the challenge of accommodating a new scale. We regard collaborative systems as a combination of supportive services, encompassing safe data management and data sharing. Trustworthy data centred services are an essential support for collaboration at the scale of communities and organizations. We will combine our results and expertise to achieve a new leap forward toward the design of methods and techniques to enable the construction of usable large scale collaborative systems.

3. Research Program

3.1. Introduction

Our scientific foundations are grounded on distributed collaborative systems supported by sophisticated data sharing mechanisms and on service oriented computing with an emphasis on orchestration and on non-functional properties. Distributed collaborative systems enable distributed group work supported by computer technologies. Designing such systems requires an expertise in Distributed Systems and in Computer-supported collaborative Work research area. Besides theoretical and technical aspects of distributed systems, the design of distributed collaborative systems must take into account the human factor to offer solutions suitable for users and groups. The Coast team vision is to move away from a centralized authority based collaboration toward a decentralized collaboration. Users will have full control over their data. They can store them locally and decide with whom to share them. The Coast team investigates the issues related to the management of distributed shared data and coordination between users and groups. Service oriented Computing [16] is an established domain on which the ECOO, Score and now the Coast teams have been contributing for a long time. It refers to the general discipline that studies the development of computer applications on the web. A service is an independent software program with a specific functional context and capabilities published as a service contract (or more traditionally an API). A service composition aggregates a set of services and coordinates their interactions. The scale, the autonomy of services, the heterogeneity and some design principles underlying Service Oriented Computing open new research questions that are at the basis of our research. They span the disciplines of **distributed computing**, **software engineering** and **computer supported collaborative work** (CSCW). Our approach to contribute to the general vision of Service Oriented Computing is to focus on the issue of the efficient and flexible construction of reliable and secure high-level services. We aim to achieve it through the coordination/orchestration/composition of other services provided by distributed organizations or people.

3.2. Consistency Models for Distributed Collaborative Systems

Collaborative systems are distributed systems that allow users to share data. One important issue is to manage consistency of shared data according to concurrent access. Traditional consistency criteria such as serializability, linearizability are not adequate for collaborative systems. Causality, Convergence and Intention

[0] representational state transfer

preservation (CCI) [21] are more suitable for developing middleware for collaborative applications. We develop algorithms for ensuring CCI properties on collaborative distributed systems. Constraints on the algorithms are different according to the kind of distributed system and to the data structure. The distributed system can be centralized, decentralized or peer-to-peer. The type of data can include strings, growable arrays, ordered trees, semantic graphs and multimedia data.

3.3. Optimistic Replication

Replication of data among different nodes of a network promotes reliability, fault tolerance, and availability. When data are mutable, consistency among the different replicas must be ensured. Pessimistic replication is based on the principle of single-copy consistency while optimistic replication allows the replicas to diverge during a short time period. The consistency model for optimistic replication [19] is called eventual consistency, meaning that replicas are guaranteed to converge to the same value when the system is idle. Our research focuses on the two most promising families of optimistic replication algorithms for ensuring CCI:

- operational transformation (OT) algorithms [14]
- algorithms based on commutative replicated data types (CRDT) [18].

Operational transformation algorithms are based on the application of a transformation function when a remote modification is integrated into the local document. Integration algorithms are generic, being parametrised by operational transformation functions which depend on replicated document types. The advantage of these algorithms is their genericity. These algorithms can be applied to any data type and they can merge heterogeneous data in a uniform manner. Commutative replicated data types is a new class of algorithms initiated by WooT [15], the first algorithm designed WithOut Operational Transformations. They ensure consistency of highly dynamic content on peer-to-peer networks. Unlike traditional optimistic replication algorithms, they can ensure consistency without concurrency control. CRDT algorithms rely on natively commutative operations defined on abstract data types such as lists or ordered trees. Thus, they do not require a merge algorithm or an integration procedure.

3.4. Process Orchestration and Management

Process Orchestration and Management is considered as a core discipline behind Service Management and Computing. It includes the analysis, the modelling, the execution, the monitoring and the continuous improvement of enterprise processes and is for us a central domain of studies. Many efforts have been devoted establishing standard business process models founded on well-grounded theories (e.g. Petri Nets) that meet the needs of business analysts, software engineers and software integrator. This led to heated debate in the Business Process Management (BPM) community as the two points of view are very difficult to reconcile. On one side, business people in general require models that are easy to use and understand and that can be quickly adapted to exceptional situations. On the other side, IT people need models with an operational semantic in order to be able transform them into executable artifacts. Part of our work has been an attempt to reconcile these points of view. This resulted in the development of the Bonita BPM system. It resulted also more recently on our work in crisis management where the same people are designing, executing and monitoring the process as it executes. More generally, and at a larger scale, we have been considering the problem of processes spanning the barriers of organizations. This leads to the more general problem of service composition as a way to coordinate inter organizational construction of applications. These applications provide value, based on the composition of lower level services [12].

3.5. Service Composition

Recently, we started a study on service composition for software architects where services are coming from different providers with different plans (capacity, degree of resilience...). The objective is to support the architects to select the most accurate services (wrt. to their requirements, both functional and non-functional) and plans for building their software. We also compute the properties that we enforce for the composition of these services.

4. Application Domains

4.1. Crisis Management

Crisis management research investigates all the dimensions regarding the management of unexpected catastrophic events like floods, earthquake or terrorist attacks. All the phases of a crisis, from preparedness to recovery require collaboration between people from many organizations. This provides opportunities to study inter-organizational collaboration at a large scale and to propose and evaluate mechanisms that ensure secure and safe collaboration. The work of Béatrice Linot provides us with a deep understanding of the factors that encourage collaboration and help to maintain trustworthy collaboration between stakeholders. This work is continued by Clélie Amiot who studies the effects of human chat-bot collaboration in this kind of setting.

4.2. Collaborative Editing

Collaborative editing is a common application of optimistic replication in distributed settings. The goal of collaborative editors, irrespective of the kind of document, is to allow a group of users to update a document concurrently while ensuring that they eventually get all the same copy at the end. Our algorithm allows to implement collaborative editor in a peer to peer way. It avoids the need for a central server ensuring a higher level of privacy among collaborators. In this context, it requires to consider the problem of authentication and authorization of participants[4] and of trust between them[7].

5. Highlights of the Year

5.1. Highlights of the Year

In collaboration with Valerie Shalin (Department of Psychology, Wright State University), we proposed a novel validation methodology for automatic trust assessment of users based on their collaboration behavior. Our validation methodology relies on experimental game theory, namely trust game. In the large scale collaboration context of our team research, results of our experimental design [7] suggest that trust score could enhance or even replace traditional identity mechanisms.

6. New Software and Platforms

6.1. MUTE

Multi-User Text Editor

KEYWORD: Collaborative systems

SCIENTIFIC DESCRIPTION: MUTE is a peer 2 peer collaborative editing platform that is used to evaluate replication algorithms in editing situations regarding their performances and to understand how it affects user experience.

FUNCTIONAL DESCRIPTION: Existing collaborative systems generally rely on a service provider that stores and has control over user data which is a threat for privacy. MUTE (Multi-User Text Editor) is a web-based real-time collaborative editor that overcomes this limitation by using a peer-to-peer architecture relying on WebRTC. Several users may edit in real-time a shared document and their modifications are immediately sent to the other users without transiting through a central server. Our editor offers support for working offline while still being able to reconnect at a later time, which gives it a unique feature. Data synchronisation is achieved by using the LogootSplit algorithm developed by team Coast.

NEWS OF THE YEAR: In 2019 we implemented a new algorithm, dotted logoot-split. We integrated a group key management algorithm to evaluate a secure version of the algorithm in dynamic situation. We also incorporated probes to evaluate collaboration situation.

- Participants: Claudia Ignat, François Charoy, Gérald Oster, Luc André, Matthieu Nicolas and Victorien Elvinger
- Contact: Gérald Oster
- URL: https://github.com/coast-team/mute

7. New Results

7.1. Trustworthy Collaboration

Participants: Claudia-Lavinia Ignat, Hoang Long Nguyen, Olivier Perrin.

In order to test user acceptance of a collaboration model based on automatic trust assessment, we designed an experiment relying on the trust game. In the trust game money exchange is entirely attributable to the existence of trust between users. Our experimental design [7] tested variations of the trust game: with and without showing the partner identity and with and without explicit computation of partner trust values based on the computational trust model we previously proposed. We organized a user study with 30 participants that confirmed that the availability of this trust metric improves user cooperation and that it predicts participants future behavior. We showed that trust score availability has the same effect as an identity to improve cooperation. Our study suggests that trust score could function as an enhancement or even replacement of traditional identity systems and has the advantage of scalability.

In the scope of Hoang Long Nguyen's PhD thesis, we proposed the architecture of ÔBlock, an open ecosystem for quick development of transparent applications based on consortium blockchain.

7.2. Undo in Collaborative Editing

Participants: Victorien Elvinger, Claudia-Lavinia Ignat.

In collaborative editors a selective undo allows a user to undo an earlier operation, regardless of when, where and by which user the operation was generated. In most existing collaborative editors such as GoogleDrive, selective undo is not integrated and users can only undo their own operations but not the ones generated by the other users. There is currently no generally applicable undo support as stated in the manifesto on CRDTs [17]. We presented a generic support of selective undo for CRDTs by proposing an abstraction that captures the semantics of concurrent undo and redo operations through equivalence classes. The abstraction is a natural extension of undo and redo in sequential applications and is straightforward to implement in practice [9].

7.3. Mitigating the Cost of Identifiers in Sequence CRDT

Participants: Matthieu Nicolas, Gérald Oster, Olivier Perrin.

To achieve high availability, large-scale distributed systems have to replicate data and to minimise coordination between nodes. The literature and industry increasingly adopt Conflict-free Replicated Data Types (CRDTs) to design such systems. CRDTs are data types which behave as traditional ones, e.g. the Set or the Sequence. However, compared to traditional data types, they are designed to support natively concurrent modifications. To this end, they embed in their specification a conflict-resolution mechanism.

To resolve conflicts in a deterministic manner, CRDTs usually attach identifiers to elements stored in the data structure. Identifiers have to comply with several constraints such as uniqueness or being densely ordered according to the kind of CRDT. These constraints may prevent the identifiers' size from being bounded. As the number of the updates increases, the size of identifiers grows. This leads to performance issues, since the efficiency of the replicated data structure decreases over time.

To address this issue, we propose a new CRDT for Sequence which embeds a renaming mechanism. It enables nodes to reassign shorter identifiers to elements in an uncoordinated manner. Obtained experiment results demonstrate that this mechanism decreases the overhead of the replicated data structure and eventually limits it.

To validate the proposed renaming mechanism, we performed an experimental evaluation to measure its performances on several aspects: (i) the size of the data structure ; (ii) the integration time of the rename operation ; (iii) the integration time of insert and remove operations. In cases (i) and (iii), we use LogootSplit as the baseline data structure to compare results. The results we obtained are very encouraging, as the integration time is far shorter with the renaming mechanism, even with the time spent to apply the rename operation.

7.4. Social Networks as Collaboration Support

Participants: Quentin Laporte Chabasse, Gérald Oster, François Charoy.

Safe peer to peer collaborative services requires a trusted peer to peer network in order to be effective. We started to investigate how to leverage social networks underlying inter organizational collaboration to support such collaboration. To reach this goal, we need to analyze collaborative graphs. They are a relevant sources of information to understand behavioural tendencies of groups of individuals. Exponential Random Graph Models (ERGMs) are commonly used to analyze such social processes including dependencies between members of the group. Our approach considers a modified version of ERGMs, modeling the problem as an edge labelling one. The main difficulty is inference since the normalizing constant involved in classical Markov Chain Monte Carlo approaches is not available in an analytic closed form.

The main contribution is to use the recent ABC Shadow algorithm [20]. This algorithm is built to sample from posterior distributions while avoiding the previously mentioned drawback. The proposed method is illustrated on real data sets provided by the HAL [0] platform and provides new insights on self-organized collaborations among researchers[11]

7.5. Secure Collaborative Editing

Participants: Mohammed Riyadh Abdmeziem, François Charoy.

Collaborative edition allows a group of entities to simultaneously edit and share the content of a document in real time. To provide the required keying materials, group key management protocols are usually considered in order to secure and encrypt the exchanged data. Indeed, existing fully distributed protocols induce significant overhead. Instead, centralized solutions are preferred for their high efficiency. Nevertheless, these centralized solutions present two main issues. The first issue is related to the broken end-to-end property, considering the central entity has access to the established credentials. The second issue is related to the single point of failure problem. In fact, if the central entity fails, the key establishment process fails too. To address these challenges, we proposed a simple, and yet efficient approach which enhances central-based protocols with both fault tolerance and end-to-end properties. To do so, we considered the group key as composed of two sub-keys. The first sub-key is only known to the members of the group, excluding the central entity, while the second sub-key is distributed and updated by the central entity following membership changes[3], [4]. Our initial assessment shows that the overall complexity of rekeying operations is not negatively impacted. In addition, our approach is backward compatible with existing solutions in the literature.

7.6. Trust and Data Sharing in Crisis Management

Participants: François Charoy, Béatrice Linot.

Sharing information between responders is important during crisis management response. Tools and platforms are eagerly developed for that purpose. They are supposed to support people and help them to build a shared situation awareness. However as the scale of crisis increases and as more and more organizations are involved, people get reluctant to use them to share their data. They prefer to rely on one to one communication tools like

[0] https://hal.inria.fr/

phones or text. This is why we are studying how these collaborative platforms impact the work of responders positively or negatively. We want to know why most of the time they don't want to use them for their original purpose. We studied reports on past incidents and conducted extensive analysis of the use of existing systems (e.g. the French platform CRISORSEC) through interviews, observation and data analysis. Early results show that participant have problems sharing written information for different kind of reason including its persistence, the time taken to produce the message and the lack of knowledge regarding who may access this information. This informs us on the requirement for future collaborative platforms.

7.7. Identification and Selection of Services from Cloud Providers

Participants: Anis Ahmed Nacer, François Charoy, Olivier Perrin.

We continued our work on providing a framework to compare plans for services from cloud providers in order to help architects to select the best composition given the required criteria (both both functional and non-functional requirements) for an application. This year, we have made progress in two directions: the first is how to identify the key elements to be considered when architects want to compare the different plans, and the second one is a methodology to compute the best composition, given partial information provided in service description (based on the WOWA method).

In order to gather the key elements of the comparison that met the architects' requirements and the relationship between these key elements of the comparison, we reviewed the service providers' plans and previous works on benchmarks. Finally, to ensure that the list of key elements of the comparison and their relationship was complete for the service selection process, we conducted an empirical study with the architects.

Regarding the second part, we use the WOWA (Weighted Ordered Weighted Averaging) operator to solve this decision problem. This operator provides an aggregation function that uses both the simultaneous advantage of the OWA method to allow compensation between high and low values and the weighted average method to consider the importance of the suppliers who provide the information. WOWA uses two sets of weights: one corresponds to source significance, and the other corresponds to value significance.

Our evaluations are encouraging, and we are now ready to submit our proposals to conferences.

7.8. Risk Management for the Deployment of a Business Process in a Multi-Cloud Context

Participants: Amina Ahmed Nacer, Claude Godart, Guillaume Rosinosky, Samir Youcef.

The lack of trust in cloud organizations is often seen as braking forces to SaaS developments. This work proposes an approach which supports a trust model and a business process model in order to allow the orchestration of trusted business process components in the cloud.

The contribution is threefold and consists in a method, a model and a framework. The method categorizes techniques to transform an existing business process into a risk-aware process model that takes into account security risks related to cloud environments. These techniques are partially described in the form of constraints to automatically support process transformation. The model formalizes the relations and the responsibilities between the different actors of the cloud. This allows users to identify the different pieces of information required to assess and quantify security risks in cloud environments.

The framework is a comprehensive approach that decomposes a business process into fragments that can automatically be deployed on multiple clouds. The framework also integrates a selection algorithm that combines the security information of cloud offers and of the process with other quality of service criteria to generate an optimized configuration. It is implemented in a tool to assess cloud providers and decompose processes.

Rooted in past years' work, the paper [5] synthesizes our trust-aware deployment method.

7.9. Priority based events management in IoT-BPM architecture

Participants: Khalid Benali, Abir Ismaili-Alaoui.

BPM allows organizations to evolve their performance and achieve their goals, as it helps them to have a clear vision of their business. Several research works have been done in this area and aimed at improving business processes, by focusing on the optimization of business processes issues at build-time and at run-time, from different perspectives: control-flow perspective, data and event data perspective, and scheduling and event management perspective. Business process instances scheduling and event management are considered as a crucial step in the journey of business process improvement. However, this step becomes more challenging especially when the events are triggered by IoT devices. The main objective of our research consists on scheduling business process instances based on the priority of events that trigger these instances, taking into consideration historical data gathered from previous business process instances. We proposed a clustering approach based on the K-Means algorithm that we apply on a set of event sources, as to classify these sources on different clusters using a score calculated for each event source. This score is based on the frequency and the critically of previous events. The main objective of this approach was to create clusters of priorities. These clusters are used to estimate the criticality level of incoming events, and then the priority level of incoming process instances. However, there is always a degree of uncertainty regarding the criticality/priority level of events generated from sources that belong to the same cluster. This issue can be addressed by using fuzzy logic. In fact, the integration of a Fuzzy Inference System (FIS) in our IoT-BPM architecture, helps us to handle uncertainties regarding the criticality level of events, especially when these events are generated by sources that may have the same characteristics [8].

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

8.1.1. Open Group

Participants: Claudia-Lavinia Ignat, François Charoy [contact], Gérald Oster, Olivier Perrin, Anis Ahmed Nacer.

Company: Open Group

Dates: 2017-2020

The objective of the project is to propose and validate a model of service composition for middleware services for software as a service architecture. The composition must take into account middleware service quality attributes and service plan in order to optimise the operational cost while ensuring a level of quality of service.

9. Partnerships and Cooperations

9.1. Regional Initiatives

9.1.1. Region Grand Est TV Paint (2017–2019)

Participants: Claudia-Lavinia Ignat [contact], Gérald Oster, Cédric Enclos.

Partners: TVPaint Development, Inria

Website: https://www.tvpaint.com/

This is a project in collaboration with TVPaint Development financed by Region Grand Est. It is a follow-up of a project in collaboration with TVPaint Development financed by Region Lorraine from 2016 to 2017.

The goal is to contribute to the creation of a collaborative system dedicated to manage the production of animated movies. This system has to manipulate a large amount of data in a safe and secure manner. Based on the previously proposed architecture and prototype, this project intends to design and implement a commercial product. In the framework of this project, we bring our expertise in data management, business process management, distributed systems and collaborative systems.

9.2. National Initiatives

9.2.1. OpenPaas NG (2015–2019)

Participants: Claudia-Lavinia Ignat, François Charoy [contact], Gérald Oster, Olivier Perrin, Jean-Philippe Eisenbarth, Matthieu Nicolas, Mohammed Riyadh Abdmeziem, Victorien Elvinger, Quentin Laporte Chabasse, Hoai-Le Nguyen, Hoang Long Nguyen.

Partners: Linagora, XWiki, Nexedi, Université de Lorraine, LIX.

Website: http://www.open-paas.org/

This project is funded by BpiFrance and involves French industrial leaders in open-source software development (Linagora, Nexedi, XWiki) and academic partners in collaborative work (Coast team) and recommender systems (DaScim team, LIX). The goal of the project is to develop next generation of cloud enabled virtual desktop based on an Enterprise Social Network to provide advanced collaborative and recommendation services. Coast is responsible for the work package dedicated to the design of the peer-to-peer collaborative middleware. In this context, we bring our expertise on data replication for collaborative data in peer-to-peer environments and on trust and access control and identity management in distributed collaborative information systems.

9.3. International Research Visitors

9.3.1. Visits of International Scientists

Weihai Yu, The Arctic University of Norway, did his sabbatical year in the period September 1, 2018 - August 31, 2019 in the Coast team. He worked on the formalisation of undo with CRDTs.

9.3.2. Research Stays Abroad

François Charoy was invited by Heiko Ludwig to spend 3 month (March-May 2019) at IBM Almaden Research Center in San Jose,CA. He worked on P2P Federated Learning. A replication protocol has been designed that is under evaluation thanks to a shared internship. It also led to an ANR submission on the topic with a french company.

François Charoy was invited by Akhil Kumar to spend 6 weeks at Penn State University to collaborate to on a long transaction protocol implementation on a permissioned blockchain. This work is based on previous work done in the Coast project-team. It is also ongoing and has led to the submission of a project to a proposal submission with a local startup.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events: Selection

10.1.1.1. Member of the Conference Program Committees

- Khalid Benali was a PC member of WorldCIST (World Conference on Information Systems and Technologies) 2019, MEDES (11th International Conference on Management of Digital EcoSystems) 2019, ICCCI (11th International Conference on Computational Collective Intelligence) 2019, CEISEE (15th China-Europe International Symposium on Software Engineering Education) 2019, I3E (IFIP Conference on e-Business, e-Services and e-Society) 2019, INFORSID (INFormatique des ORganisations et Systèmes d'Information et de Décision) 2019, ISKO-Maghreb (8th. Edition of the International Symposium on: « Digital Sciences: impacts and challenges on Knowledge Organization. ») 2019, and SysCoBIoTS (4th International Conference on Systems of Collaboration, Big Data, Internet of Things and Security), 2019.
- Claudia-Lavinia Ignat was a PC member of ECSCW (European Conference on Computer-Supported Cooperative Work: The International venue on Practice-centred computing and the Design of cooperation technologies) 2019, CDVE (International Conference on Cooperative Design, Visualization and Engineering) 2019 and 2020, CollabTech (International Conference on Collaboration Technologies and Social Computing) 2019
- Olivier Perrin was a PC member of the conference program committee of ICSOC (International Conference on Services Oriented Computing) 2019, CoopIS (27h International Conference on Cooperative Information Systems) 2019, and IEEE ATC-19 (16th IEEE International Conference on Advanced and Trusted Computing).
- François Charoy was a PC Member of ICEBE (International Conference on Business Engineering) 2019, ICSOC 2019, IEEE International Conference on Business Information Systems, ISCRAM 2019, and of several workshops.
- Claude Godart is a member of the editorial board of IEEE transaction on Service Computing. In 2019, he was a PC member of BPMDS (Business Process Modeling, Development and Support), EDOC (The enterprise computing conference), ICSOC (International Conference on Services Computing), ICWS (IEEE International Conference on Web Services), SCC (IEEE International Conference on Services Computing)and WISE (Web Information Systems Engineering) conferences.

10.1.2. Journal

10.1.2.1. Member of the Editorial Boards

- Claudia-Lavinia Ignat is an Associate editor for the Journal of Computer Supported Cooperative Work (JCSCW) since 2011 and is Member of Editorial Board for the journal track of ECSCW conference since 2019
- François Charoy is a member of the editorial board of Service Oriented Computing and Applications (Springer)

10.1.2.2. Reviewer - Reviewing Activities

- Claudia-Lavinia Ignat reviewed papers for International Journal of Cooperative Information Systems
- Olivier Perrin reviewed papers for Elsevier Information Systems and Spring SoSyM (Software and Systems Modeling) journals.
- Francois Charoy reviewed papers for IEEE IoT, VLDB Journal and Interacting with Computers

10.1.3. Invited Talks

- In November 2019 Claudia-Lavinia Ignat was invited to give a talk at Inria Paris on “Large-scale trustworthy distributed collaborative systems”

10.1.4. Leadership within the Scientific Community

- François Charoy is steering committee member of European Society for Socially Embedded Technologies (EUSSET).
- Claudia-Lavinia Ignat was steering committee member of EUSSET until August 2019

10.1.5. Scientific Expertise

François Charoy was a member of the HCERES committee for the evaluation of the Laboratoire d'Informatique de Grenoble, Université de Grenoble Alpes

10.1.6. Research Administration

- Claudia-Lavinia Ignat is member of the Inria Evaluation Commission. She is a member of the Inria Nancy-Grand Est COMIPERS committee. She was a member of COST-GTRI commission. She is a member of the organisation committee of the Security Seminar at LORIA. Until March 2019 she was in charge of the European affairs and Delegate for International Relations for Inria Nancy-Grand Est. Until August 2019 she was member of Inria CAP Chercheurs commission. In 2019, she was a member of the CRCN recruitment jury at Inria Nancy-Grand Est and at Inria Saclay Ile de France. In 2019, she was a member of the national CRCN Inria recruitment jury and of the CRCN Inria admission jury.
- Gérald Oster is an elected member at AM2I scientist council of University of Lorraine
- Francois Charoy is an elected member of the CNU 27. He is a member of the board as assessor.

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Permanent members of the Coast project-team are leading teachers in their respective institutions. They are responsible of lectures in disciplines like software engineering, database systems, object oriented programming and design, distributed systems, service computing and more advanced topics at all levels and in different of departments in the University. Most PhD Students have also teaching duties in the same institutions. Claudia-Lavinia Ignat teaches the lecture and the exercises on data replication and consistency at master level (M2 SIRAV) at University of Lorraine. As a whole, the Coast team accounts for more than 2500 hours of teaching. Members of the Coast team are also deeply involved in the pedagogical and administrative life of their departments.

- Olivier Perrin is responsible for the MIAGE of Nancy at the IDMC of University of Lorraine.
- Claude Godart is responsible for the Computer Science Department of the Polytech Nancy engineering school .
- Khalid Benali is responsible for the professional master degree speciality “Distributed Information Systems” of MIAGE and of its international branch in Morocco.
- François Charoy is responsible for the Software Engineering specialisation at the TELECOM Nancy Engineering School of University of Lorraine.
- Gérald Oster is responsible for the 3rd (last) year of study at the TELECOM Nancy Engineering School of University of Lorraine.

10.2.2. Supervision

- PhD : Guillaume Rosinoski, Elasticity of business processes execution, January 2019, François Charoy and Samir Youssef [2]
- PhD : Amina Ahmed Nacer, Contributions au déploiement sécurisé de processus métiers dans le cloud, Université de Lorraine et Université A. Mira (Bejaïa, Algérie), February 2019, Claude Godart, Samir Youcef and Abdelkamel Tari. [1]
- PhD : Hoang Long Nguyen, Blockchain based transparency system, December 2019, Claudia-Lavinia Ignat and Olivier Perrin
- PhD in progress: Hoai Le Nguyen, Study of group performance and behaviour in collaborative editing, started in September 2015, Claudia-Lavinia Ignat and François Charoy
- PhD in progress: Victorien Elvinger, Secured Replication for Peer-to-Peer Collaborative Infrastructures, started in October 2015, François Charoy and Gérald Oster
- PhD in progress: Abir Ismaïli-Alaoui, started in September 2016, Khalid Benali and Karim Baïna (Université Mohammed V, Rabat, Morocco)

- PhD in progress: Quentin Laporte-Chabasse, Federation of Organisations over Peer to Peer Collaborative Network, started in October 2016, François Charoy and Gérald Oster
- PhD in progress: Béatrice Linot, Trust in cooperative systems, started in November 2016, Jérome Dinet and François Charoy
- PhD in progress: Anis Ahmed Nacer, Safe Service Composition, started in March 2017, Olivier Perrin and François Charoy
- PhD in progress: Matthieu Nicolas, Optimisation of Replication Algorithms, started in October 2017, Olivier Perrin and Gérald Oster
- PhD in progress: Jean Philippe Eisenbarth, Securing the future blockchain-based security services, started in May 2019, Olivier Perrin and Thibault Cholez.
- PhD in progress: Clélie Amiot, Trust and Human/Chatbot collaboration, started in October 2019, Jérome Dinet and François Charoy

10.2.3. Juries

Coast members were members of the following PhD defence committees:

- Sina Namaki Arraghi, PhD,IMT Mines d'Albi-Carmaux, November 2019 (François Charoy, rapporteur)
- Nicolas Schnepf, PhD, Université de Lorraine, September 2019 (François Charoy, président)
- Suhrid Satyal, PhD, University of New South Wales, June 2019 (François Charoy, rapporteur)

11. Bibliography

Publications of the year

Doctoral Dissertations and Habilitation Theses

[1] A. AHMED NACER.*Contribution to the secure deployment of business processes in the cloud*, Université de Lorraine ; Université A. Mira (Bejaïa, Algérie), February 2019, https://hal.univ-lorraine.fr/tel-02096672

[2] G. ROSINOSKY.*Elasticity of business processes execution*, Université de Lorraine, January 2019, https://hal.univ-lorraine.fr/tel-02096324

Articles in International Peer-Reviewed Journal

[3] M. R. ABDMEZIEM.*Securing IoT-based collaborative applications using a new compressed and distributed MIKEY mode*, in "International Journal of Information and Computer Security", March 2019, vol. x,No.x, https://hal.archives-ouvertes.fr/hal-02378897

[4] M. R. ABDMEZIEM, F. CHAROY.*Securing IoT-based Groups: Efficient, Scalable and Fault-tolerant Key Management Protocol*, in "Ad Hoc & Sensor Wireless Networks", October 2019, https://hal.archives-ouvertes.fr/hal-02378889

[5] A. AHMED NACER, C. GODART, G. ROSINOSKY, A. TARI, S. YOUCEF.*Business process outsourcing to the cloud: Balancing costs with security risks*, in "Computers in Industry", January 2019, vol. 104, p. 59-74 [*DOI :* 10.1016/J.COMPIND.2018.10.003], https://hal.archives-ouvertes.fr/hal-01888396

[6] S. ATARODI, A. M. BERARDI, A.-M. TONIOLO.*Comparing local policy practices to implement ICT-based home care services for aging-in-place in Finland, France, Italy, Spain & Sweden*, in "Gerontechnology", June 2019, vol. 18, n° 2 [*DOI :* 10.4017/GT.2019.18.2.005.00], https://hal.archives-ouvertes.fr/hal-02315164

[7] C.-L. IGNAT, Q.-V. DANG, V. SHALIN.*The Influence of Trust Score on Cooperative Behavior*, in "ACM Transactions on Internet Technology", September 2019, vol. 19, n^{o} 4, p. 1-22, https://arxiv.org/abs/1910.09895 [*DOI :* 10.1145/3329250], https://hal.inria.fr/hal-02307981

International Conferences with Proceedings

[8] A. ISMAILI-ALAOUI, O. KASMI, A. BAÏNA, K. BAÏNA, K. BENALI, M. BELLAFKIH.*Priority-based Event Management using Fuzzy Logic for an IoT-BPM Architecture*, in "The 12th IEEE International Conference on Service Oriented Computing and Applications (SOCA 2019)", Kaohsiung, Taiwan, November 2019, https://hal.inria.fr/hal-02413950

[9] W. YU, V. ELVINGER, C.-L. IGNAT.*A Generic Undo Support for State-Based CRDTs*, in "Proceedings of 23rd International Conference on Principles of Distributed Systems (OPODIS 2019)", Neuchâtel, Switzerland, December 2019 [*DOI :* 10.4230/LIPIcs.OPODIS.2019.2], https://hal.inria.fr/hal-02370231

Conferences without Proceedings

[10] B. LINOT, F. CHAROY, J. DINET, V. SHALIN.*Une perspective computationnelle sur un défi (probable) CRISORSEC*, in "1ère biennale de la sécurité civile: « L'acceptabilité des risques : approches pluridisciplinaires »", Aix-en-Provence, France, Ecole nationale supérieure des officiers de sapeurs-pompiers, 2019, https://hal.univ-lorraine.fr/hal-02280588

Other Publications

[11] Q. LAPORTE-CHABASSE, M. CLAUSEL, R. STOICA, F. CHAROY, G. OSTER.*Morpho-statistical description of networks through graph modelling and Bayesian inference*, December 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-02421787

References in notes

[12] S. BHIRI, O. PERRIN, W. GAALOUL, C. GODART.*An Object-Oriented Metamodel For Inter-Enterprises Cooperative Processes Based on Web Services*, in "Journal of Integrated Design and Process Science", 2004, vol. 8, p. 37–55, http://hal.inria.fr/inria-00099953/en/

[13] F. CASATI.*Promises and Failures of Research in Dynamic Service Composition*, in "Seminal Contributions to Information Systems Engineering", J. BUBENKO, J. KROGSTIE, O. PASTOR, B. PERNICI, C. ROLLAND, A. SØLVBERG (editors), Springer Berlin Heidelberg, 2013, p. 235-239, http://dx.doi.org/10.1007/978-3-642-36926-1_18

[14] C. A. ELLIS, S. J. GIBBS.*Concurrency Control in Groupware Systems*, in "Proceedings of the ACM SIGMOD Conference on the Management of Data - SIGMOD 89", Portland, Oregon, USA, May 1989, p. 399–407, http://doi.acm.org/10.1145/67544.66963

[15] G. OSTER, P. URSO, P. MOLLI, A. IMINE.*Data Consistency for P2P Collaborative Editing*, in "ACM Conference on Computer-Supported Cooperative Work - CSCW 2006", Banff, Alberta, Canada, ACM Press, 11 2006, p. 259 - 268, http://hal.inria.fr/inria-00108523/en/

[16] M. P. PAPAZOGLOU, P. TRAVERSO, S. DUSTDAR, F. LEYMANN.*Service-Oriented Computing: State of the Art and Research Challenges*, in "Computer", 2007, vol. 40, p. 38-45

[17] N. M. PREGUIÇA, C. BAQUERO, M. SHAPIRO.*Conflict-Free Replicated Data Types CRDTs*, in "Encyclopedia of Big Data Technologies", 2019, https://doi.org/10.1007/978-3-319-63962-8_185-1

[18] N. PREGUIÇA, J. M. MARQUÈS, M. SHAPIRO, M. LETIA.*A commutative replicated data type for cooperative editing*, in "29th IEEE International Conference on Distributed Computing Systems (ICDCS 2009)", Montreal, Québec Canada, IEEE Computer Society, 2009, p. 395-403 [*DOI :* 10.1109/ICDCS.2009.20], http://hal.inria.fr/inria-00445975/en/

[19] Y. SAITO, M. SHAPIRO.*Optimistic Replication*, in "Computing Surveys", March 2005, vol. 37, n^{o} 1, p. 42–81, http://doi.acm.org/10.1145/1057977.1057980

[20] R. S. STOICA, A. PHILIPPE, P. GREGORI, J. MATEU.*ABC Shadow algorithm: a tool for statistical analysis of spatial patterns*, in "Statistics and computing", 2017, vol. 27, n^{o} 5, p. 1225–1238

[21] C. SUN, X. JIA, Y. ZHANG, Y. YANG, D. CHEN.*Achieving Convergence, Causality Preservation, and Intention Preservation in Real-Time Cooperative Editing Systems*, in "ACM Transactions on Computer-Human Interaction", March 1998, vol. 5, n^{o} 1, p. 63–108, http://doi.acm.org/10.1145/274444.274447

Project-Team GAMBLE

Geometric Algorithms & Models Beyond the Linear & Euclidean realm

IN COLLABORATION WITH: Laboratoire lorrain de recherche en informatique et ses applications (LORIA)

IN PARTNERSHIP WITH:
Université de Lorraine

RESEARCH CENTER
Nancy - Grand Est

THEME
Algorithmics, Computer Algebra and Cryptology

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Project-Team GAMBLE

Creation of the Team: 2017 January 01, updated into Project-Team: 2017 July 01

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A5.5.1. - Geometrical modeling
A5.10.1. - Design
A7.1. - Algorithms
A8.1. - Discrete mathematics, combinatorics
A8.3. - Geometry, Topology
A8.4. - Computer Algebra

Other Research Topics and Application Domains:
B1.1.1. - Structural biology
B1.2.3. - Computational neurosciences
B2.6. - Biological and medical imaging
B3.3. - Geosciences
B5.5. - Materials
B5.6. - Robotic systems
B5.7. - 3D printing
B6.2.2. - Radio technology

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Guillaume Moroz [Inria, Researcher]
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Galatée Hemery Vaglica [Univ de Lorraine]
Nuwan Herath Mudiyanselage [Inria, from Nov 2019]
George Krait [Inria]
Fernand Kuiebove Pefireko [Inria, until Aug 2019]

Post-Doctoral Fellows
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Ji Won Park [Inria, from Sep 2019]

Visiting Scientists
Georg Osang [IST Austria, PhD candidate, Mar 2019]

Gert Vegter [University of Groningen, Professor, Mar 2019]

Administrative Assistants

Isabelle Blanchard [Inria]

Annick Jacquot [CNRS]

Virginie Priester [CNRS]

2. Overall Objectives

2.1. Overall Objectives

Starting in the eighties, the emerging computational geometry community has put a lot of effort into designing and analyzing algorithms for geometric problems. The most commonly used framework was to study the worst-case theoretical complexity of geometric problems involving linear objects (points, lines, polyhedra...) in Euclidean spaces. This so-called *classical computational geometry* has some known limitations:

- Objects: dealing with objects only defined by linear equations.
- Ambient space: considering only Euclidean spaces.
- Complexity: worst-case complexities often do not capture realistic behaviour.
- Dimension: complexities are often exponential in the dimension.
- Robustness: ignoring degeneracies and rounding errors.

Even if these limitations have already got some attention from the community [44], a quick look at the flagship conference SoCG [0] proceedings shows that these topics still need a big effort.

It should be stressed that, in this document, the notion of certified algorithms is to be understood with respect to robustness issues. In other words, certification does not refer to programs that are proven correct with the help of mechnical proof assistants such as Coq, but to algorithms that are proven correct on paper even in the presence of degeneracies and computer-induced numerical rounding errors.

We address several of the above limitations:

• **Non-linear computational geometry.** Curved objects are ubiquitous in the world we live in. However, despite this ubiquity and decades of research in several communities, curved objects are far from being robustly and efficiently manipulated by geometric algorithms. Our work on, for instance, quadric intersections and certified drawing of plane curves has proven that dramatic improvements can be accomplished when the right mathematics and computer science concepts are put into motion. In this direction, many problems are fundamental and solutions have potential industrial impact in Computer Aided Design and Robotics for instance. Intersecting NURBS (Non-uniform rational basis splines) and meshing singular surfaces in a certified manner are important examples of such problems.

• **Non-Euclidean computational geometry.** Triangulations are central geometric data structures in many areas of science and engineering. Traditionally, their study has been limited to the Euclidean setting. Needs for triangulations in non-Euclidean settings have emerged in many areas dealing with objects whose sizes range from the nuclear to the astrophysical scale, and both in academia and in industry. It has become timely to extend the traditional focus on $\mathbb{R}^d$ of computational geometry and encompass non-Euclidean spaces.

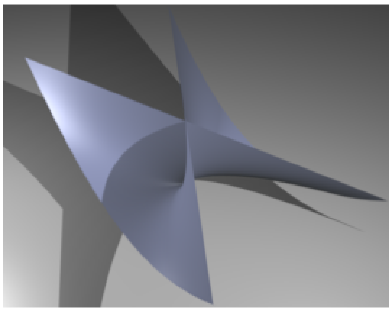
• **Probability in computational geometry.** The design of efficient algorithms is driven by the analysis of their complexity. Traditionally, worst-case input and sometimes uniform distributions are considered and many results in these settings have had a great influence on the domain. Nowadays, it is necessary to be more subtle and to prove new results in between these two extreme settings. For instance, smoothed analysis, which was introduced for the simplex algorithm and which we applied successfully to convex hulls, proves that such promising alternatives exist.

[0] Symposium on Computational Geometry. http://www.computational-geometry.org/.

• **Discrete geometric structures.** Many geometric algorithms work, explicitly or implicitly, over discrete structures such as graphs, hypergraphs, lattices that are induced by the geometric input data. For example, convex hulls or straight-line graph drawing are essentially based on orientation predicates, and therefore operate on the so-called *order type* of the input point set. Order types are a subclass of oriented matroids that remains poorly understood: for instance, we do not even know how to sample this space with reasonable bias. One of our goals is to contribute to the development of these foundations by better understanding these discrete geometric structures.

3. Research Program

3.1. Non-linear computational geometry



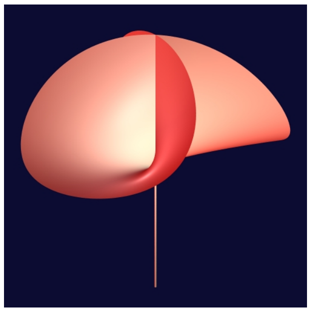


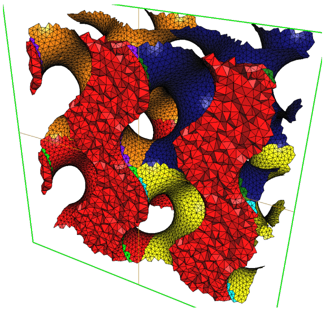
Figure 1. Two views of the Whitney umbrella (on the left, the "stick" of the umbrella, i.e., the negative z-axis, is missing). Right picture from [Wikipedia], left picture from [Lachaud et al.].

As mentioned above, curved objects are ubiquitous in real world problems and in computer science and, despite this fact, there are very few problems on curved objects that admit robust and efficient algorithmic solutions without first discretizing the curved objects into meshes. Meshing curved objects induces a loss of accuracy which is sometimes not an issue but which can also be most problematic depending on the application. In addition, discretization induces a combinatorial explosion which could cause a loss in efficiency compared to a direct solution on the curved objects (as our work on quadrics has demonstrated with flying colors [50], [51], [52], [54], [58]). But it is also crucial to know that even the process of computing meshes that approximate curved objects is far from being resolved. As a matter of fact there is no algorithm capable of computing in practice meshes with certified topology of even rather simple singular 3D surfaces, due to the high constants in the theoretical complexity and the difficulty of handling degenerate cases. Part of the difficulty comes from the unintuitive fact that the structure of an algebraic object can be quite complicated, as depicted in the Whitney umbrella (see Figure 1), surface of equation $x^2 = y^2z$ on which the origin (the "special" point of the surface) is a vertex of the arrangement induced by the surface while the singular locus is simply the whole z-axis. Even in 2D, meshing an algebraic curve with the correct topology, that is in other words producing a correct drawing of the curve (without knowing where the domain of interest is), is a very difficult problem on which we have recently made important contributions [37], [38], [59].

It is thus to be understood that producing practical robust and efficient algorithmic solutions to geometric problems on curved objects is a challenge on all and even the most basic problems. The basicness and fundamentality of two problems we mentioned above on the intersection of 3D quadrics and on the drawing in a topologically certified way of plane algebraic curves show rather well that the domain is still in its infancy. And it should be stressed that these two sets of results were not anecdotal but flagship results produced during the lifetime of the VEGAS team (the team preceding GAMBLE).

There are many problems in this theme that are expected to have high long-term impacts. Intersecting NURBS (Non-uniform rational basis splines) in a certified way is an important problem in computer-aided design and manufacturing. As hinted above, meshing objects in a certified way is important when topology matters. The 2D case, that is essentially drawing plane curves with the correct topology, is a fundamental problem with far-reaching applications in research or R&D. Notice that on such elementary problems it is often difficult to predict the reach of the applications; as an example, we were astonished by the scope of the applications of our software on 3D quadric intersection [0] which was used by researchers in, for instance, photochemistry, computer vision, statistics and mathematics.

3.2. Non-Euclidean computational geometry



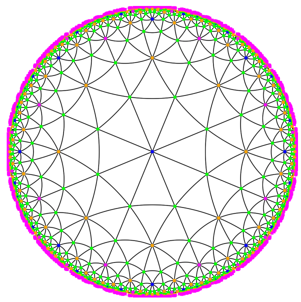


Figure 2. Left: 3D mesh of a gyroid (triply periodic surface) [61]. Right: Simulation of a periodic Delaunay triangulation of the hyperbolic plane [33].

Triangulations, in particular Delaunay triangulations, in the *Euclidean space*$\mathbb{R}^d$ have been extensively studied throughout the 20th century and they are still a very active research topic. Their mathematical properties are now well understood, many algorithms to construct them have been proposed and analyzed (see the book of Aurenhammer *et al.* [32]). Some members of GAMBLE have been contributing to these algorithmic advances (see, e.g. [36], [68], [47], [35]); they have also contributed robust and efficient triangulation packages through the state-of-the-art Computational Geometry Algorithms Library CGAL whose impact extends far beyond computational geometry. Application fields include particle physics, fluid dynamics, shape matching, image processing, geometry processing, computer graphics, computer vision, shape reconstruction, mesh generation, virtual worlds, geophysics, and medical imaging. [0]

It is fair to say that little has been done on non-Euclidean spaces, in spite of the large number of questions raised by application domains. Needs for simulations or modeling in a variety of domains [0] ranging from the infinitely small (nuclear matter, nano-structures, biological data) to the infinitely large (astrophysics) have led us to consider 3D periodic Delaunay triangulations, which can be seen as Delaunay triangulations in the 3D *flat torus*, quotient of $\mathbb{R}^3$ under the action of some group of translations [42]. This work has already yielded a fruitful collaboration with astrophysicists [55], [69] and new collaborations with physicists are emerging. To the best of our knowledge, our CGAL package [41] is the only publicly available software that computes Delaunay triangulations of a 3D flat torus, in the special case where the domain is cubic. This case, although restrictive, is already useful. [0] We have also generalized this algorithm to the case of general d-dimensional

[0] QI: web.

[0] See Projects using CGAL for details.

[0] See CGAL Prospective Workshop on Geometric Computing in Periodic Spaces, Subdivide and Tile: Triangulating spaces for understanding the world, Computational geometry in non-Euclidean spaces, Shape Up 2015 : Exercises in Materials Geometry and Topology

[0] See examples at Projects using CGAL

compact flat manifolds [43]. As far as non-compact manifolds are concerned, past approaches, limited to the two-dimensional case, have stayed theoretical [60].

Interestingly, even for the simple case of triangulations on the *sphere*, the software packages that are currently available are far from offering satisfactory solutions in terms of robustness and efficiency [40].

Moreover, while our solution for computing triangulations in hyperbolic spaces can be considered as ultimate [33], the case of *hyperbolic manifolds* has hardly been explored. Hyperbolic manifolds are quotients of a hyperbolic space by some group of hyperbolic isometries. Their triangulations can be seen as hyperbolic periodic triangulations. Periodic hyperbolic triangulations and meshes appear for instance in geometric modeling [62], neuromathematics [45], or physics [65]. Even the case of the Bolza surface (a surface of genus 2, whose fundamental domain is the regular octagon in the hyperbolic plane) shows mathematical difficulties [34], [57].

3.3. Probability in computational geometry

In most computational geometry papers, algorithms are analyzed in the worst-case setting. This often yields too pessimistic complexities that arise only in pathological situations that are unlikely to occur in practice. On the other hand, probabilistic geometry provides analyses with great precision [63], [64], [39], but using hypotheses with much more randomness than in most realistic situations. We are developing new algorithmic designs improving state-of-the-art performance in random settings that are not overly simplified and that can thus reflect many realistic situations.

Twelve years ago, smooth analysis was introduced by Spielman and Teng analyzing the simplex algorithm by averaging on some noise on the data [67] (and they won the Gödel prize). In essence, this analysis smoothes the complexity around worst-case situations, thus avoiding pathological scenarios but without considering unrealistic randomness. In that sense, this method makes a bridge between full randomness and worst case situations by tuning the noise intensity. The analysis of computational geometry algorithms within this framework is still embryonic. To illustrate the difficulty of the problem, we started working in 2009 on the smooth analysis of the size of the convex hull of a point set, arguably the simplest computational geometry data structure; then, only one very rough result from 2004 existed [46] and we only obtained in 2015 breakthrough results, but still not definitive [49], [48], [53].

Another example of a problem of different flavor concerns Delaunay triangulations, which are rather ubiquitous in computational geometry. When Delaunay triangulations are computed for reconstructing meshes from point clouds coming from 3D scanners, the worst-case scenario is, again, too pessimistic and the full randomness hypothesis is clearly not adapted. Some results exist for “good samplings of generic surfaces” [31] but the big result that everybody wishes for is an analysis for random samples (without the extra assumptions hidden in the “good” sampling) of possibly non-generic surfaces.

Trade-offs between full randomness and worst case may also appear in other forms such as dependent distributions, or random distributions conditioned to be in some special configurations. Simulating these kinds of geometric distributions is currently out of reach for more than a few hundred points [56] although it has practical applications in physics or networks.

3.4. Discrete geometric structures

Our work on discrete geometric structures develops in several directions, each one probing a different type of structure. Although these objects appear unrelated at first sight, they can be tackled by the same set of probabilistic and topological tools.

A first research topic is the study of *Order types*. Order types are combinatorial encodings of finite (planar) point sets, recording for each triple of points the orientation (clockwise or counterclockwise) of the triangle they form. This already determines properties such as convex hulls or half-space depths, and the behaviour of algorithms based on orientation predicates. These properties for all (infinitely many) n-point sets can be studied through the finitely many order types of size n. Yet, this finite space is poorly understood: its estimated size leaves an exponential margin of error, no method is known to sample it without concentrating on a vanishingly small corner, the effect of pattern exclusion or VC dimension-type restrictions are unknown. These are all directions we actively investigate.

A second research topic is the study of *Embedded graphs and simplicial complexes.* Many topological structures can be effectively discretized, for instance combinatorial maps record homotopy classes of embedded graphs and simplicial complexes represent a large class of topological spaces. This raises many structural and algorithmic questions on these discrete structures; for example, given a closed walk in an embedded graph, can we find a cycle of the graph homotopic to that walk? (The complexity status of that problem is unknown.) Going in the other direction, some purely discrete structures can be given an associated topological space that reveals some of their properties (*e.g.* the Nerve theorem for intersection patterns). An open problem is for instance to obtain fractional Helly theorems for set system of bounded topological complexity.

Another research topic is that of *Sparse inclusion-exclusion formulas.* For any family of sets $A_1, A_2, ..., A_n$, by the principle of inclusion-exclusion we have

$$\mathbb{1}_{\bigcup_{i=1}^{n} A_i} = \sum_{I \subseteq \{1,2,...,n\}} (-1)^{|I|+1} \mathbb{1}_{\bigcap_{i \in I} A_i} \tag{4}$$

where $\mathbb{1}_X$ is the indicator function of X. This formula is universal (it applies to any family of sets) but its number of summands grows exponentially with the number n of sets. When the sets are balls, the formula remains true if the summation is restricted to the regular triangulation; we proved that similar simplifications are possible whenever the Venn diagram of the A_i is sparse. There is much room for improvements, both for general set systems and for specific geometric settings. Another interesting problem (the subject of the PhD thesis of Galatée Hemery) is to combine these simplifications with the inclusion-exclusion algorithms developed, for instance, for graph coloring.

4. Application Domains

4.1. Applications of computational geometry

Many domains of science can benefit from the results developed by GAMBLE. Curves and surfaces are ubiquitous in all sciences to understand and interpret raw data as well as experimental results. Still, the non-linear problems we address are rather basic and fundamental, and it is often difficult to predict the impact of solutions in that area. The short-term industrial impact is likely to be small because, on basic problems, industries have used ad hoc solutions for decades and have thus got used to it. The example of our work on quadric intersection is typical: even though we were fully convinced that intersecting 3D quadrics is such an elementary/fundamental problem that it ought to be useful, we were the first to be astonished by the scope of the applications of our software [0] (which was the first and still is the only one —to our knowledge— to compute robustly and efficiently the intersection of 3D quadrics) which has been used by researchers in, for instance, photochemistry, computer vision, statistics, and mathematics. Our work on certified drawing of plane (algebraic) curves falls in the same category. It seems obvious that it is widely useful to be able to draw curves correctly (recall also that part of the problem is to determine where to look in the plane) but it is quite hard to come up with specific examples of fields where this is relevant. A contrario, we know that certified meshing is critical in mechanical-design applications in robotics, which is a non-obvious application field. There, the singularities of a manipulator often have degrees higher than 10 and meshing the singular locus in a certified way is currently out of reach. As a result, researchers in robotics can only build physical prototypes for validating, or not, the approximate solutions given by non-certified numerical algorithms.

[0] QI: web.

The fact that several of our pieces of software for computing non-Euclidean triangulations had already been requested by users long before they become public in CGAL is a good sign for their wide future impact. This will not come as a surprise, since most of the questions that we have been studying followed from discussions with researchers outside computer science and pure mathematics. Such researchers are either users of our algorithms and software, or we meet them in workshops. Let us only mention a few names here. Rien van de Weijgaert [55], [69] (astrophysicist, Groningen, NL) and Michael Schindler [66] (theoretical physicist, ENSPCI, CNRS, France) used our software for 3D periodic weighted triangulations. Stephen Hyde and Vanessa Robins (applied mathematics and physics at Australian National University) used our package for 3D periodic meshing. Olivier Faugeras (neuromathematics, Inria Sophia Antipolis) had come to us and mentioned his needs for good meshes of the Bolza surface [45] before we started to study them. Such contacts are very important both to get feedback about our research and to help us choose problems that are relevant for applications. These problems are at the same time challenging from the mathematical and algorithmic points of view. Note that our research and our software are generic, i.e., we are studying fundamental geometric questions, which do not depend on any specific application. This recipe has made the sucess of the CGAL library.

Probabilistic models for geometric data are widely used to model various situations ranging from cell phone distribution to quantum mechanics. The impact of our work on probabilistic distributions is twofold. On the one hand, our studies of properties of geometric objects built on such distributions will yield a better understanding of the above phenomena and has potential impact in many scientific domains. On the other hand, our work on simulations of probabilistic distributions will be used by other teams, more maths oriented, to study these distributions.

5. Highlights of the Year

5.1. Highlights of the Year

We are happy to report that some of our past work appeared this year in highly visible journals. Our proof that deciding *shellability* of simplicial complexes, a problem that was open for 40 years, was published in the Journal of the ACM [15], and our survey on *combinatorial geometry and topology and their applications* was published in the Bulletin of the AMS [13].

6. New Software and Platforms

6.1. CGAL Package : 2D periodic hyperbolic triangulations

KEYWORDS: Geometry - Delaunay triangulation - Hyperbolic space

FUNCTIONAL DESCRIPTION: This module implements the computation of Delaunay triangulations of the Bolza surface.

NEWS OF THE YEAR: Integration into CGAL 4.14

- Authors: Iordan Iordanov and Monique Teillaud
- Contact: Monique Teillaud
- Publication: Implementing Delaunay Triangulations of the Bolza Surface
- URL: https://doc.cgal.org/latest/Manual/packages.html#PkgPeriodic4HyperbolicTriangulation2

6.2. CGAL Package : 2D hyperbolic triangulations

KEYWORDS: Geometry - Delaunay triangulation - Hyperbolic space

FUNCTIONAL DESCRIPTION: This package implements the construction of Delaunay triangulations in the Poincaré disk model.

NEWS OF THE YEAR: Integration into CGAL 4.14

- Participants: Mikhail Bogdanov, Olivier Devillers, Iordan Iordanov and Monique Teillaud
- Contact: Monique Teillaud
- Publication: Hyperbolic Delaunay Complexes and Voronoi Diagrams Made Practical
- URL: https://doc.cgal.org/latest/Manual/packages.html#PkgHyperbolicTriangulation2

6.3. clenshaw

KEYWORDS: Numerical solver - Visualization - Polynomial equations

FUNCTIONAL DESCRIPTION: Clenshaw is a mixed C and python library that provides computation and plotting functions for the solutions of polynomial equations in the Taylor or the Chebyshev basis. The library is optimized for machine double precision and for numerically well-conditioned polynomials. In particular, it can find the roots of polynomials with random coefficients of degree one million.

- Contact: Guillaume Moroz
- URL: https://gitlab.inria.fr/gmoro/clenshaw

6.4. voxelize

KEYWORDS: Visualization - Curve plotting - Implicit surface - Polynomial equations

FUNCTIONAL DESCRIPTION: Voxelize is a C++ software to visualize the solutions of polynomial equations and inequalities. The software is optimized for high degree curves and surfaces. Internally, polynomials and sets of boxes are stored in the Compressed Sparse Fiber format. The output is either a mesh or a union of boxes written in the standard 3D file format ply.

RELEASE FUNCTIONAL DESCRIPTION: This is the first published version.

- Contact: Guillaume Moroz
- URL: https://gitlab.inria.fr/gmoro/voxelize

7. New Results

7.1. Non-Linear Computational Geometry

Participants: Laurent Dupont, Nuwan Herath Mudiyanselage, George Krait, Sylvain Lazard, Viviane Ledoux, Guillaume Moroz, Marc Pouget.

7.1.1. Clustering Complex Zeros of Triangular Systems of Polynomials

This work, presented at the CASC'19 Conference [23], gives the first algorithm for finding a set of natural ϵ-clusters of complex zeros of a regular triangular system of polynomials within a given polybox in $\mathbb{C}^n$, for any given $\epsilon > 0$. Our algorithm is based on a recent near-optimal algorithm of Becker et al (2016) for clustering the complex roots of a univariate polynomial where the coefficients are represented by number oracles. Our algorithm is based on recursive subdivision. It is local, numeric, certified and handles solutions with multiplicity. Our implementation is compared to well-known homotopy solvers on various triangular systems. Our solver always gives correct answers, is often faster than the homotopy solvers that often give correct answers, and sometimes faster than the ones that give sometimes correct results.

In collaboration with R. Imbach and C. Yap (Courant Institute of Mathematical Sciences, New York University, USA).

7.1.2. Numerical Algorithm for the Topology of Singular Plane Curves

We are interested in computing the topology of plane singular curves. For this, the singular points must be isolated. Numerical methods for isolating singular points are efficient but not certified in general. We are interested in developing certified numerical algorithms for isolating the singularities. In order to do so, we restrict our attention to the special case of plane curves that are projections of smooth curves in higher dimensions. In this setting, we show that the singularities can be encoded by a regular square system whose isolation can be certified by numerical methods. This type of curves appears naturally in robotics applications and scientific visualization. This work was presented at the EuroCG'19 Conference [24].

7.1.3. Reliable Computation of the Singularities of the Projection in $\mathbb{R}^3$ of a Generic Surface of $\mathbb{R}^4$

Computing efficiently the singularities of surfaces embedded in $\mathbb{R}^3$ is a difficult problem, and most state-of-the-art approaches only handle the case of surfaces defined by polynomial equations. Let F and G be C^∞ functions from $\mathbb{R}^4$ to $\mathbb{R}$ and $\mathcal{M} = \{(x, y, z, t) \in \mathbb{R}^4 \mid F(x, y, z, t) = G(x, y, z, t) = 0\}$ be the surface they define. Generically, the surface $\mathcal{M}$ is smooth and its projection Ω in $\mathbb{R}^3$ is singular. After describing the types of singularities that appear generically in Ω, we design a numerically well-posed system that encodes them. This can be used to return a set of boxes that enclose the singularities of Ω as tightly as required. As opposed to state-of-the art approaches, our approach is not restricted to polynomial mappings, and can handle trigonometric or exponential functions for example. This work was presented at the MACIS'19 Conference [19].

In collaboration with Sény Diatta (University Assane Seck of Ziguinchor, Senegal)

7.1.4. Evaluation of Chebyshev polynomials on intervals and application to root finding

In approximation theory, it is standard to approximate functions by polynomials expressed in the Chebyshev basis. Evaluating a polynomial f of degree n given in the Chebyshev basis can be done in $O(n)$ arithmetic operations using the Clenshaw algorithm. Unfortunately, the evaluation of f on an interval I using the Clenshaw algorithm with interval arithmetic returns an interval of width exponential in n. We describe a variant of the Clenshaw algorithm based on ball arithmetic that returns an interval of width quadratic in n for an interval of small enough width. As an application, our variant of the Clenshaw algorithm can be used to design an efficient root finding algorithm. This work was presented at the MACIS'19 Conference [21].

7.1.5. Using Maple to analyse parallel robots

We present the SIROPA Maple Library which has been designed to study serial and parallel manipulators at the conception level. We show how modern algorithms in Computer Algebra can be used to study the workspace, the joint space but also the existence of some physical capabilities w.r.t. to some design parameters left as degree of freedom for the designer of the robot. This work was presented at the Maple Conference 2019 [18].

In collaboration with Philippe Wenger, Damien Chablat (Laboratoire des Sciences du Numérique de Nantes, UMR CNRS 6004) and Fabrice Rouillier (project team OURAGAN *)*

7.2. Non-Euclidean Computational Geometry

Participants: Vincent Despré, Yan Garito, Elies Harington, Benedikt Kolbe, Georg Osang, Monique Teillaud, Gert Vegter.

7.2.1. Flipping Geometric Triangulations on Hyperbolic Surfaces

We consider geometric triangulations of surfaces, i.e., triangulations whose edges can be realized by disjoint locally geodesic segments. We prove that the flip graph of geometric triangulations with fixed vertices of a flat torus or a closed hyperbolic surface is connected. We give upper bounds on the number of edge flips that are necessary to transform any geometric triangulation on such a surface into a Delaunay triangulation [28].

In collaboration with Jean-Marc Schlenker (University of Luxembourg).

7.2.2. Computing the Geometric Intersection Number of Curves

The geometric intersection number of a curve on a surface is the minimal number of self-intersections of any homotopic curve, i.e. of any curve obtained by continuous deformation. Given a curve c represented by a closed walk of length at most ℓ on a combinatorial surface of complexity n we describe simple algorithms to compute the geometric intersection number of c in $O(n+\ell^2)$ time, construct a curve homotopic to c that realizes this geometric intersection number in $O(n+\ell^4)$ time, decide if the geometric intersection number of c is zero, i.e. if c is homotopic to a simple curve, in $O(n+\ell\log(\ell))$ time [14].

In collaboration with Francis Lazarus (University of Grenoble).

7.3. Probabilistic Analysis of Geometric Data Structures and Algorithms

Participants: Olivier Devillers, Charles Duménil, Xavier Goaoc, Fernand Kuiebove Pefireko, Ji Won Park.

7.3.1. Expected Complexity of Routing in Θ6 and Half-Θ6 Graphs

We study online routing algorithms on the Θ6-graph and the half-Θ6-graph (which is equivalent to a variant of the Delaunay triangulation). Given a source vertex s and a target vertex t in the Θ6-graph (resp. half-Θ6-graph), there exists a deterministic online routing algorithm that finds a path from s to t whose length is at most 2 st (resp. 2.89 st) which is optimal in the worst case [Bose et al., SIAM J. on Computing, 44(6)]. We propose alternative, slightly simpler routing algorithms that are optimal in the worst case and for which we provide an analysis of the average routing ratio for the Θ6-graph and half-Θ6-graph defined on a Poisson point process. For the Θ6-graph, our online routing algorithm has an expected routing ratio of 1.161 (when s and t random) and a maximum expected routing ratio of 1.22 (maximum for fixed s and t where all other points are random), much better than the worst-case routing ratio of 2. For the half-Θ6-graph, our memoryless online routing algorithm has an expected routing ratio of 1.43 and a maximum expected routing ratio of 1.58. Our online routing algorithm that uses a constant amount of additional memory has an expected routing ratio of 1.34 and a maximum expected routing ratio of 1.40. The additional memory is only used to remember the coordinates of the starting point of the route. Both of these algorithms have an expected routing ratio that is much better than their worst-case routing ratio of 2.89 [27].

In collaboration with Prosenjit Bose (University Carleton) and JeanLou De Carufel (University of Ottawa)

7.3.2. A Poisson sample of a smooth surface is a good sample

The complexity of the 3D-Delaunay triangulation (tetrahedralization) of n points distributed on a surface ranges from linear to quadratic. When the points are a deterministic good sample of a smooth compact generic surface, the size of the Delaunay triangulation is $O(n\log n)$. Using this result, we prove that when points are Poisson distributed on a surface under the same hypothesis, whose expected number of vertices is λ, the expected size is $O(\lambda\log_2\lambda)$ [22].

7.3.3. On Order Types of Random Point Sets

Let P be a set of n random points chosen uniformly in the unit square. We examine the typical resolution of the order type of P. First, we show that with high probability, P can be rounded to the grid of step $\frac{1}{n^{3+\epsilon}}$ without changing its order type. Second, we study algorithms for determining the order type of a point set in terms of the number of coordinate bits they require to know. We give an algorithm that requires on average $4n\log_2 n+O(n)$ bits to determine the order type of P, and show that any algorithm requires at least $4n\log_2 n-O(n\log\log n)$ bits. Both results extend to more general models of random point sets [29].

In collaboration with Philippe Duchon (Université de Bordeaux) and Marc Glisse (project team DATASHAPE *).*

7.3.4. Randomized incremental construction of Delaunay triangulations of nice point sets

Randomized incremental construction (RIC) is one of the most important paradigms for building geometric data structures. Clarkson and Shor developed a general theory that led to numerous algorithms that are both simple and efficient in theory and in practice. Randomized incremental constructions are most of the time space and time optimal in the worst-case, as exemplified by the construction of convex hulls, Delaunay triangulations and arrangements of line segments. However, the worst-case scenario occurs rarely in practice and we would like to understand how RIC behaves when the input is nice in the sense that the associated output is significantly smaller than in the worst-case. For example, it is known that the Delaunay triangulations of nicely distributed points on polyhedral surfaces in $\mathbb{E}^3$ has linear complexity, as opposed to a worst-case quadratic complexity. The standard analysis does not provide accurate bounds on the complexity of such cases and we aim at establishing such bounds. More precisely, we will show that, in the case of nicely distributed points on polyhedral surfaces, the complexity of the usual RIC is $O(n \log n)$ which is optimal. In other words, without any modification, RIC nicely adapts to good cases of practical value. Our proofs also work for some other notions of nicely distributed point sets, such as (ϵ, κ)-samples. Along the way, we prove a probabilistic lemma for sampling without replacement, which may be of independent interest [16], [26].

In collaboration with Jean-Daniel Boissonnat, Kunal Dutta and Marc Glisse (project team DATASHAPE *).*

7.3.5. Random polytopes and the wet part for arbitrary probability distributions

We examine how the measure and the number of vertices of the convex hull of a random sample of n points from an arbitrary probability measure in $\mathbb{R}^d$ relates to the wet part of that measure. This extends classical results for the uniform distribution from a convex set [Bárány and Larman 1988]. The lower bound of Bárány and Larman continues to hold in the general setting, but the upper bound must be relaxed by a factor of $\log n$. We show by an example that this is tight [25].

In collaboration with Imre Barany (Rényi Institute of Mathematics) Matthieu Fradelizi (Laboratoire d'Analyse et de Mathématiques Appliquées) Alfredo Hubard (Laboratoire d'Informatique Gaspard-Monge) Günter Rote (Institut für Informatik, Berlin)

7.4. Discrete Geometric structures

Participants: Xavier Goaoc, Galatée Hemery Vaglica.

7.4.1. Shatter functions with polynomial growth rates

We study how a single value of the shatter function of a set system restricts its asymptotic growth. Along the way, we refute a conjecture of Bondy and Hajnal which generalizes Sauer's Lemma. [12]

7.4.2. The discrete yet ubiquitous theorems of Caratheodory, Helly, Sperner, Tucker, and Tverberg

We discuss five discrete results: the lemmas of Sperner and Tucker from combinatorial topology and the theorems of Carathéodory, Helly, and Tverberg from combinatorial geometry. We explore their connections and emphasize their broad impact in application areas such as game theory, graph theory, mathematical optimization, computational geometry, etc. [13]

7.4.3. Shellability is NP-complete

We prove that for every $d \geq 2$, deciding if a pure, d-dimensional, simplicial complex is shellable is NP-hard, hence NP-complete. This resolves a question raised, e.g., by Danaraj and Klee in 1978. Our reduction also yields that for every $d \geq 2$ and $k \geq 0$, deciding if a pure, d-dimensional, simplicial complex is k-decomposable is NP-hard. For $d \geq 3$, both problems remain NP-hard when restricted to contractible pure d-dimensional complexes. Another simple corollary of our result is that it is NP-hard to decide whether a given poset is CL-shellable. [15]

7.4.4. An Experimental Study of Forbidden Patterns in Geometric Permutations by Combinatorial Lifting

We study the problem of deciding if a given triple of permutations can be realized as geometric permutations of disjoint convex sets in $\mathbb{R}^3$. We show that this question, which is equivalent to deciding the emptiness of certain semi-algebraic sets bounded by cubic polynomials, can be "lifted" to a purely combinatorial problem. We propose an effective algorithm for that problem, and use it to gain new insights into the structure of geometric permutations. [20]

7.5. Classical Computational Geometry

Participants: Olivier Devillers, Sylvain Lazard, Leo Valque.

7.5.1. Rounding Meshes

Let $\mathcal{P}$ be a set of n polygons in $\mathbb{R}^3$, each of constant complexity and with pairwise disjoint interiors. We previously proposed [5] a rounding algorithm that maps $\mathcal{P}$ to a simplicial complex $\mathcal{Q}$ whose vertices have integer coordinates such that every face of $\mathcal{P}$ is mapped to a set of faces (or edges or vertices) of $\mathcal{Q}$ and the mapping from $\mathcal{P}$ to $\mathcal{Q}$ can be built through a continuous motion of the faces such that (i) the L_∞ Hausdorff distance between a face and its image during the motion is at most 3/2 and (ii) if two points become equal during the motion they remain equal through the rest of the motion. We developed [30] the first implementation of this algorithm, which is also the first implementation for rounding a mesh on a grid (whose fineness is independent of the input size) while preserving reasonable geometric and topological properties. We also provided some insight that this algorithm and implementation have practical average complexity in $O(n\sqrt{n})$ on “real data", which has to be compared to its $O(n^{15})$ worst-case time complexity. Our implementation is still too slow to be used in practice but it provides a good proof of concept.

7.5.2. Hardness results on Voronoi, Laguerre and Apollonius diagrams

We show that converting Apollonius and Laguerre diagrams from an already built Voronoi diagram of a set of n points in 2D requires at least $\Omega(n \log n)$ computation time. We also show that converting an Apollonius diagram of a set of n weighted points in 2D from a Laguerre diagram and vice-versa requires at least $\Omega(n \log n)$ computation time as well. Furthermore , we present a very simple randomized incremental construction algorithm that takes expected $O(n \log n)$ computation time to build an Apollonius diagram of non-overlapping circles in 2D [17].

In collaboration with Kevin Buchin (TU Eindhoven), Pedro de Castro (University Pernanbuco), and Menelaos Karavelas (University Heraklion).

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

- Company: WATERLOO MAPLE INC
  Duration: 2 years
  Participants: GAMBLE and OURAGAN Inria teams
  Abstract: A two-years licence and cooperation agreement was signed on April 1st, 2018 between WATERLOO MAPLE INC., Ontario, Canada (represented by Laurent Bernardin, its Executive Vice President Products and Solutions) and Inria. On the Inria side, this contract involves the teams GAMBLE and OURAGAN (Paris), and it is coordinated by Fabrice Rouillier (OURAGAN).

  F. Rouillier and GAMBLE are the developers of the ISOTOP software for the computation of topology of curves. One objective of the contract is to transfer a version of ISOTOP to WATERLOO MAPLE INC.

- Company: GeometryFactory
  Duration: permanent
  Participants: Inria and GeometryFactory
  Abstract: CGAL packages developed in Gamble are commercialized by GeometryFactory.

9. Partnerships and Cooperations

9.1. National Initiatives

9.1.1. ANR SoS

Project title: Structures on Surfaces
Duration: 4 years
Starting Date: April 1st, 2018
Coordinator: Monique Teillaud
Participants:

- Gamble project-team, Inria.
- LIGM (Laboratoire d'Informatique Gaspard Monge), Université Paris-Est Marne-la-Vallée. Local Coordinator: Éric Colin de Verdière.
- RMATH (Mathematics Research Unit), University of Luxembourg. National Coordinator: Hugo Parlier

SoS is co-funded by ANR (ANR-17-CE40-0033) and FNR (INTER/ANR/16/11554412/SoS) as a PRCI (Projet de Recherche Collaborative Internationale).

The central theme of this project is the study of geometric and combinatorial structures related to surfaces and their moduli. Even though they work on common themes, there is a real gap between communities working in geometric topology and computational geometry and SoS aims to create a long-lasting bridge between them. Beyond a common interest, techniques from both ends are relevant and the potential gain in perspective from long-term collaborations is truly thrilling.

In particular, SoS aims to extend the scope of computational geometry, a field at the interface between mathematics and computer science that develops algorithms for geometric problems, to a variety of unexplored contexts. During the last two decades, research in computational geometry has gained wide impact through CGAL, the Computational Geometry Algorithms Library. In parallel, the needs for non-Euclidean geometries are arising, e.g., in geometric modeling, neuromathematics, or physics. Our goal is to develop computational geometry for some of these non-Euclidean spaces and make these developments readily available for users in academy and industry.

To reach this aim, SoS will follow an interdisciplinary approach, gathering researchers whose expertise cover a large range of mathematics, algorithms and software. A mathematical study of the objects considered will be performed, together with the design of algorithms when applicable. Algorithms will be analyzed both in theory and in practice after prototype implementations, which will be improved whenever it makes sense to target longer-term integration into CGAL.

Our main objects of study will be Delaunay triangulations and circle patterns on surfaces, polyhedral geometry, and systems of disjoint curves and graphs on surfaces.

Project website: https://members.loria.fr/Monique.Teillaud/collab/SoS/.

9.1.2. ANR Aspag

Project title: Analyse et Simulation Probabilistes d'Algorithmes Géométriques
Duration: 4 years
Starting date: January 1st, 2018

Coordinator: Olivier Devillers
Participants:

- Gamble project-team, Inria.
- Labri (Laboratoire Bordelais de Recherche en Informatique), Université de Bordeaux. Local Coordinator: Philippe Duchon.
- Laboratoire de Mathématiques Raphaël Salem, Université de Rouen. Local Coordinator: Pierre Calka.
- LAMA (Laboratoire d'Analyse et de Mathématiques Appliquées), Université Paris-Est Marne-la-Vallée. Local Coordinator: Matthieu Fradelizi

Abstract: The ASPAG projet is funded by ANR under number ANR-17-CE40-0017 .

The analysis and processing of geometric data has become routine in a variety of human activities ranging from computer-aided design in manufacturing to the tracking of animal trajectories in ecology or geographic information systems in GPS navigation devices. Geometric algorithms and probabilistic geometric models are crucial to the treatment of all this geometric data, yet the current available knowledge is in various ways much too limited: many models are far from matching real data, and the analyses are not always relevant in practical contexts. One of the reasons for this state of affairs is that the breadth of expertise required is spread among different scientific communities (computational geometry, analysis of algorithms and stochastic geometry) that historically had very little interaction. The Aspag project brings together experts of these communities to address the problem of geometric data. We will more specifically work on the following three interdependent directions.

(1) Dependent point sets: One of the main issues of most models is the core assumption that the data points are independent and follow the same underlying distribution. Although this may be relevant in some contexts, the independence assumption is too strong for many applications.

(2) Simulation of geometric structures: The phenomena studied in (1) involve intricate random geometric structures subject to new models or constraints. A natural first step would be to build up our understanding and identify plausible conjectures through simulation. Perhaps surprisingly, the tools for an effective simulation of such complex geometric systems still need to be developed.

(3) Understanding geometric algorithms: the analysis of algorithms is an essential step in assessing the strengths and weaknesses of algorithmic principles, and is crucial to guide the choices made when designing a complex data processing pipeline. Any analysis must strike a balance between realism and tractability; the current analyses of many geometric algorithms are notoriously unrealistic. Aside from the purely scientific objectives, one of the main goals of Aspag is to bring the communities closer in the long term. As a consequence, the funding of the project is crucial to ensure that the members of the consortium will be able to interact on a very regular basis, a necessary condition for significant progress on the above challenges.

Project website: https://members.loria.fr/Olivier.Devillers/aspag/.

9.1.3. ANR MinMax

Project title: MIN-MAX
Duration: 4 years
Starting date: 2019
Coordinator: Stéphane Sabourau (Université Paris-Est Créteil)
Participants:

- Université Paris Est Créteil, Laboratoire d'Analyse et de Mathématiques Appliquées (LAMA). Local coordinator: Stéphane Sabourau
- Université de Tours, Institut Denis Poisson. Local coordinator: Laurent Mazet. This node includes two participants from Nancy, Benoît Daniel (IECL) and Xavier Goaoc (Loria, GAMBLE).

Abstract: The MinMax projet is funded by ANR under number ANR-19-CE40-0014

This collaborative research project aims to bring together researchers from various areas – namely, geometry and topology, minimal surface theory and geometric analysis, and computational geometry and algorithms – to work on a precise theme around min-max constructions and waist estimates.

9.1.4. Institut Universitaire de France

Xavier Goaoc was appointed *junior member* of the Institut Universitaire de France, a grant supporting a reduction in teaching duties and funding.

Starting Date: October 1st, 2014.
Duration: 5 years.

9.2. International Initiatives

9.2.1. Inria Associate Teams Not Involved in an Inria International Labs

9.2.1.1. TRIP

Title: Triangulation and Random Incremental Paths

International Partner (Institution - Laboratory - Researcher):

Carleton University (Canada) - CGLab - Prosenjit Bose

Start year: 2018

See also: https://members.loria.fr/Olivier.Devillers/trip/

The two teams are specialists of Delaunay triangulation with a focus on computation algorithms on the French side and routing on the Canadian side. We plan to attack several problems where the two teams are complementary:

- Stretch factor of the Delaunay triangulation in 3D.
- Probabilistic analysis of Theta-graphs and Yao-graphs.
- Smoothed analysis of a walk in Delaunay triangulation.
- Walking in/on surfaces.
- Routing un non-Euclidean spaces.

9.2.1.2. Astonishing

Title: ASsociate Team On Non-ISH euclIdeaN Geometry

International Partner (Institution - Laboratory - Researcher):

University of Groningen (Netherlands) - Bernoulli Institute for Mathematics, Computer Science and Artificial Intelligence - Gert Vegter

Start year: 2017

See also: https://members.loria.fr/Monique.Teillaud/collab/Astonishing/

Some research directions in computational geometry have hardly been explored. The spaces in which most algorithms have been designed are the Euclidean spaces $\mathbb{R}^d$. To extend further the scope of applicability of computational geometry, other spaces must be considered, as shown by the concrete needs expressed by our contacts in various fields as well as in the literature. Delaunay triangulations in non-Euclidean spaces are required, e.g., in geometric modeling, neuromathematics, or physics. Topological problems for curves and graphs on surfaces arise in various applications in computer graphics and road map design. Providing robust implementations of these results is a key towards their reusability in more applied fields. We aim at studying various structures and algorithms in other spaces than $\mathbb{R}^d$, from a computational geometry viewpoint. Proposing algorithms operating in such spaces requires a prior deep study of the mathematical properties of the objects considered, which raises new fundamental and difficult questions that we want to tackle.

9.3. International Research Visitors

9.3.1. Visits of International Scientists

Gert Vegter (University of Groningen, NL) spent two weeks in GAMBLE in the context of the Astonishing associate team.

Matthijs Ebbens (University of Groningen, NL) spent one week in GAMBLE in the context of the Astonishing associate team.

Hugo Parlier (University of Luxembourg) spent two days in GAMBLE in the context of the ANR project SoS.

Erin Wolf Chambers (Saint Louis University, USA) spent two days in GAMBLE

Vanessa Robins (Australian National University) spent two days in GAMBLE

Andreas Holmsen (KAIST, South Korea) and Zuzanna Patáková (IST Austria, Vienna) spent a week in GAMBLE

9.3.2. Visits to International Teams

Olivier Devillers and Monique Teilaud spent one week in June at the Computational Geometry Lab of Carleton University http://cglab.ca/ in the context of the TRIP associate team.

Vincent Despré spent a total of three week during 2019 at the Mathematical Research Unit of the University of Luxembourg in the context of the ANR SoS project.

Sylvain Lazard spent two weeks in September at the Computational Geometry Lab of Carleton University http://cglab.ca/ in the context of the TRIP associate team.

Monique Teillaud spent two weeks at Bernoulli Institute for Mathematics, Computer Science and Artificial Intelligence of the University of Groningen in the context of the Astonishing associate team.

Monique Teillaud spent two days at University of Luxembourg in the context of the ANR SoS project

Xavier Goaoc spent one week at UNAM Queretaro, in Mexico.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events Organization

10.1.1.1. Member of the Organizing Committees

Sylvain Lazard organized with S. Whitesides (Victoria University) the 18th Workshop on Computational Geometry at the Bellairs Research Institute of McGill University in Feb. (1 week workshop on invitation).

Olivier Devillers organized the Trip-Aspag Mini-workshop on routing in triangulations, October 21-25 in Nancy.

10.1.2. Scientific Events Selection

10.1.2.1. Member of the Conference Program Committees

Guillaume Moroz was in the program committee of the Maple Conference 2019

Xavier Goaoc was on the organizing committee of the Rouen probability meeting

Xavier Goaoc was on the program committee of the Iranian conference on Computational geometry

Xavier Goaoc was on the scientific committee of the Séminaire Francilien de Géométrie Algorithmique et Combinatoire

10.1.2.2. Reviewer

All members of the team are regular reviewers for the conferences of our field, namely the *Symposium on Computational Geometry* (SoCG) and the *International Symposium on Symbolic and Algebraic Computation* (ISSAC) and also SODA, CCCG, EuroCG.

10.1.3. Journal

10.1.3.1. Member of the Editorial Boards

Monique Teillaud is a managing editor of JoCG, *Journal of Computational Geometry* and a member of the editorial board of IJCGA, *International Journal of Computational Geometry and Applications*.

Marc Pouget and Monique Teillaud are members of the CGAL editorial board.

10.1.3.2. Reviewer - Reviewing Activities

All members of the team are regular reviewers for the journals of our field, namely *Discrete and Computational Geometry* (DCG), *Journal of Computational Geometry* (JoCG), *International Journal on Computational Geometry and Applications* (IJCGA), *Journal on Symbolic Computations* (JSC), *SIAM Journal on Computing* (SICOMP), *Mathematics in Computer Science* (MCS), etc.

10.1.4. Invited Talks

Olivier Devillers and Monique Teillaud gave talks at the workshop New Horizons in Computational Geometry and Topology

Monique Teillaud gave a talk at the Celebration for the CNRS Silver medal of Claire Mathieu

10.1.5. Leadership within the Scientific Community

10.1.5.1. Steering Committees

Monique Teillaud is chairing the Steering Committee of the Symposium on Computational Geometry (SoCG).

10.1.6. Research Administration

10.1.6.1. Hiring committees

Sylvain Lazard was vice chair of the hiring committee for researchers (CRCN) of Inria Nancy - Grand Est.

Monique Teillaud was a member of the hiring committee for a Professor position at Université Paris Est Marne-la-Vallée.

10.1.6.2. National committees

M. Teillaud is a member of the working group for the BIL, *Base d'Information des Logiciels* of Inria.

10.1.6.3. Local Committees and Responsabilities

O. Devillers: Elected member to *Pole AM2I* the council that gathers labs in mathematics, computer science, and control theory at *Université de Lorraine*.

L. Dupont is responsible of Fablab of IUT Charlemagne, Univerasité de Lorraine (since 2018, November). Member of *Comité Information Edition Scientifique* of LORIA.

X. Goaoc is a member of the council of the *Fédération Charles Hermite* since sep. 2018.

S. Lazard: Head of the PhD and Post-doc hiring committee for Inria Nancy-Grand Est (since 2009). Member of the *Bureau de la mention informatique* of the *École Doctorale IAEM* (since 2009). Head of the *Mission Jeunes Chercheurs* for Inria national (since 2018). Head of the Department Algo at LORIA (since 2014). Member of the *Conseil Scientifique* of LORIA (since 2014).

G. Moroz is head of the *Comité des utilisateurs des moyens informatiques* (since nov. 2019). He is member of the CDT, *Commission de développement technologique*, of Inria Nancy - Grand Est (since 2018). He is member of the CLHSCT *Comité local d'hygiène, de sécurité et des conditions de travail* of Inria Nancy - Grand Est (since jan. 2019).

M. Pouget is an elected member of the *Comité de centre*, and is secretary of the board of *AGOS-Nancy*.

M. Teillaud is “Chargée de Mission” as Scientific Advisor for Technologic Development for Inria Nancy-Grand Est. She is a member of the *Conseil de Laboratoire* of LORIA.

10.1.6.4. Websites

M. Teillaud is maintaining the Computational Geometry Web Pages http://www.computational-geometry.org/, hosted by Inria Nancy - Grand Est. This site offers general interest information for the computational geometry community, in particular the Web proceedings of the Video Review of Computational Geometry, part of the Annual/international Symposium on Computational Geometry.

10.2. Teaching - Supervision - Juries

10.2.1. Committees

L. Dupont is the secretary of *Commission Pédagogique Nationale Carrières Sociales / Information-Communication / Métiers du Multimédia et de l'Internet* (2017-2022).

L. Dupont: Head of the Bachelor diploma *Licence Professionnelle Animation des Communautés et Réseaux Socionumériques*, Université de Lorraine.

10.2.2. Teaching

Master: Olivier Devillers, *Modèles d'environnements, planification de trajectoires*, 18h, M2 AVR, Université de Lorraine. https://members.loria.fr/Olivier.Devillers/master/

Master: Vincent Despré, *Algorithmique*, 48h, M1, Polytech Nancy, France.

Master: Vincent Despré, *Programmation réseau*, 60h, M1, Polytech Nancy, France.

Master: Vincent Despré, *Architecture avancée*, 20h, M1, Polytech Nancy, France.

Master: Vincent Despré, *Architecture Java EE*, 72h, M1, Polytech Nancy, France.

Licence: Charles Duménil, *Algorithmique et programmation avancée*, 10h, M2, FST, Université de Lorraine, France.

Licence: Charles Duménil, *Décourverte de l'informatique*, 88h, L1, Polytech Nancy, Université de Lorraine, France.

Licence: Charles Duménil, *Logiciels scientifiques*, 8h, L3, Polytech Nancy, Université de Lorraine, France.

Licence: Laurent Dupont, *Web development*, 35h, L2, Université de Lorraine, France.

Licence: Laurent Dupont, *Web development*, 150h, L2, Université de Lorraine, France.

Licence: Laurent Dupont *Web development and Social networks* 100h L3, Université de Lorraine, France.

Licence: Xavier Goaoc, *Programmation*, 20 HETD, L3, École des Mines de Nancy, France.

Master: Xavier Goaoc, *Algorithms*, 32 HETD, M1, École des Mines de Nancy, France.

Master: Xavier Goaoc, *Computer architecture*, 32+24 HETD, M1, École des Mines de Nancy + Polytech Nancy, France.

Licence: Galatée Hemery, *Programmation*, 52 HETD, L3, École des Mines de Nancy, France.

Licence: Sylvain Lazard, *Algorithms and Complexity*, 20h, L3, Université de Lorraine, France.

Master: Marc Pouget, *Introduction to computational geometry*, 10.5h, M2, École Nationale Supérieure de Géologie, France.

10.2.3. Supervision

PhD: Iordan Iordanov, Delaunay triangulations of a family of symmetric hyperbolic surfaces in practice, defended March 12th, supervised by Monique Teillaud [11].

PhD in progress: Sény Diatta, Complexité du calcul de la topologie d'une courbe dans l'espace et d'une surface, started in Nov. 2014, supervised by Daouda Niang Diatta, Marie-Françoise Roy and Guillaume Moroz.

PhD in progress: Charles Duménil, Probabilistic analysis of geometric structures, started in Oct. 2016, supervised by Olivier Devillers.

PhD in progress: George Krait, Topology of singular curves and surfaces, applications to visualization and robotics, started in Nov. 2017, supervised by Sylvain Lazard, Guillaume Moroz and Marc Pouget.

PhD in progress: Galatée Hemery, Algorithmic and geometric aspects of inclusion-exclusion, started in Sep. 2018 , supervised by Xavier Goaoc and Éric Colin de Verdière (UPEM).

PhD in progress: Nuwan Herath, Fast algorithm for the visualization of surfaces, started in Nov. 2019, supervised by Sylvain Lazard, Guillaume Moroz and Marc Pouget.

10.2.4. Juries

M. Teillaud was a member of the PhD committee of Iordan Iordanov (Université de Lorraine)

X. Goaoc was on the reading and defense committees of the habilitation defense of Arnau Padrol (IMJ, Université Paris Sorbonne)

10.3. Popularization

10.3.1. Education

G. Moroz is member of the Mathematics Olympiades committee of the Nancy-Metz academy.

10.3.2. Interventions

L. Dupont participated in several events of popularization of computer science:

Day ♯4 FAN Project, April 23th, Inria project, adult audience.

ISN day, March 7th, adult continuing education of computer science for high-school teachers.

Atelier Google, April 13th, popularization of computer science, general audience.

Atelier Google, December 7th, popularization of computer science, general audience.

11. Bibliography

Major publications by the team in recent years

[1] N. Bonichon, P. Bose, J.-L. De Carufel, V. Despré, D. Hill, M. Smid.*Improved Routing on the Delaunay Triangulation*, in "ESA 2018 - 26th Annual European Symposium on Algorithms", Helsinki, Finland, 2018 [*DOI :* 10.4230/LIPIcs.ESA.2018.22], https://hal.archives-ouvertes.fr/hal-01881280

[2] L. Castelli Aleardi, O. Devillers.*Array-based Compact Data Structures for Triangulations: Practical Solutions with Theoretical Guarantees*, in "Journal of Computational Geometry", 2018, vol. 9, n^o 1, p. 247-289 [*DOI :* 10.20382/jocg.v9i1a8], https://hal.inria.fr/hal-01846652

[3] N. Chenavier, O. Devillers.*Stretch Factor in a Planar Poisson-Delaunay Triangulation with a Large Intensity*, in "Advances in Applied Probability", 2018, vol. 50, n^o 1, p. 35-56 [*DOI :* 10.1017/apr.2018.3], https://hal.inria.fr/hal-01700778

[4] O. DEVILLERS, M. KARAVELAS, M. TEILLAUD.*Qualitative Symbolic Perturbation: Two Applications of a New Geometry-based Perturbation Framework*, in "Journal of Computational Geometry", 2017, vol. 8, n$^{\text{o}}$ 1, p. 282–315 [*DOI :* 10.20382/JOCG.V8I1A11], https://hal.inria.fr/hal-01586511

[5] O. DEVILLERS, S. LAZARD, W. LENHART.*3D Snap Rounding*, in "Proceedings of the 34th International Symposium on Computational Geometry", Budapest, Hungary, June 2018, p. 30:1–30:14 [*DOI :* 10.4230/LIPICS.SOCG.2018.30], https://hal.inria.fr/hal-01727375

[6] R. IMBACH, G. MOROZ, M. POUGET.*Reliable Location with Respect to the Projection of a Smooth Space Curve*, in "Reliable Computing", 2018, vol. 26, p. 13-55, https://hal.archives-ouvertes.fr/hal-01920444

[7] I. IORDANOV, M. TEILLAUD.*Implementing Delaunay Triangulations of the Bolza Surface*, in "33rd International Symposium on Computational Geometry (SoCG 2017)", Brisbane, Australia, July 2017, p. 44:1–44:15 [*DOI :* 10.4230/LIPICS.SOCG.2017.44], https://hal.inria.fr/hal-01568002

[8] R. JHA, D. CHABLAT, L. BARON, F. ROUILLIER, G. MOROZ.*Workspace, Joint space and Singularities of a family of Delta-Like Robot*, in "Mechanism and Machine Theory", September 2018, vol. 127, p. 73-95 [*DOI :* 10.1016/J.MECHMACHTHEORY.2018.05.004], https://hal.archives-ouvertes.fr/hal-01796066

[9] S. LAZARD, M. POUGET, F. ROUILLIER.*Bivariate triangular decompositions in the presence of asymptotes*, in "Journal of Symbolic Computation", 2017, vol. 82, p. 123–133 [*DOI :* 10.1016/J.JSC.2017.01.004], https://hal.inria.fr/hal-01468796

[10] P. MACHADO MANHÃES DE CASTRO, O. DEVILLERS.*Expected Length of the Voronoi Path in a High Dimensional Poisson-Delaunay Triangulation*, in "Discrete and Computational Geometry", 2018, vol. 60, n$^{\text{o}}$ 1, p. 200–219 [*DOI :* 10.1007/S00454-017-9866-Y], https://hal.inria.fr/hal-01477030

Publications of the year

Doctoral Dissertations and Habilitation Theses

[11] I. IORDANOV.*Delaunay triangulations of a family of symmetric hyperbolic surfaces in practice*, Université de Lorraine, March 2019, https://hal.inria.fr/tel-02072155

Articles in International Peer-Reviewed Journal

[12] B. BUKH, X. GOAOC.*Shatter functions with polynomial growth rates*, in "SIAM Journal on Discrete Mathematics", 2019, vol. 33, n$^{\text{o}}$ 2, p. 784–794, https://arxiv.org/abs/1701.06632 , forthcoming [*DOI :* 10.1137/17M1113680], https://hal.inria.fr/hal-02050524

[13] J. A. DE LOERA, X. GOAOC, F. MEUNIER, N. MUSTAFA.*The discrete yet ubiquitous theorems of Caratheodory, Helly, Sperner, Tucker, and Tverberg*, in "Bulletin of the American Mathematical Society", 2019, vol. 56, p. 415-511, https://arxiv.org/abs/1706.05975 [*DOI :* 10.1090/BULL/1653], https://hal.inria.fr/hal-02050466

[14] V. DESPRÉ, F. LAZARUS.*Computing the Geometric Intersection Number of Curves*, in "Journal of the ACM (JACM)", November 2019, vol. 66, n$^{\text{o}}$ 6, p. 1-49, https://arxiv.org/abs/1511.09327 - 59 pages, 33 figures, revised version accepted to Journal of the ACM. The time complexity for testing if a curve is homotopic to a simple one has been reduced to $O(n + \ell \log \ell)$ [*DOI :* 10.1145/3363367], https://hal.archives-ouvertes.fr/hal-02385419

[15] X. GOAOC, P. PATÁK, Z. PATÁKOVÁ, M. TANCER, U. WAGNER.*Shellability is NP-complete*, in "Journal of the ACM (JACM)", 2019, vol. 66, n^{o} 3, https://arxiv.org/abs/1711.08436 , forthcoming [*DOI :* 10.1145/3314024], https://hal.inria.fr/hal-02050505

International Conferences with Proceedings

[16] J.-D. BOISSONNAT, O. DEVILLERS, K. DUTTA, M. GLISSE.*Randomized incremental construction of Delaunay triangulations of nice point sets*, in "ESA 2019 - 27th Annual European Symposium on Algorithms", Munich, Germany, September 2019 [*DOI :* 10.4230/LIPICS.ESA.2019.22], https://hal.inria.fr/hal-02185566

[17] K. BUCHIN, P. M. M. DE CASTRO, O. DEVILLERS, M. KARAVELAS.*Hardness results on Voronoi, Laguerre and Apollonius diagrams*, in "CCCG 2019 - Canadian Conference on Computational Geometry", Edmonton, Canada, 2019, https://hal.inria.fr/hal-02186693

[18] D. CHABLAT, G. MOROZ, F. ROUILLIER, P. WENGER.*Using Maple to analyse parallel robots*, in "Maple Conference 2019", Waterloo, Canada, October 2019, https://hal.inria.fr/hal-02406703

[19] S. DIATTA, G. MOROZ, M. POUGET.*Reliable Computation of the Singularities of the Projection in R3 of a Generic Surface of R4*, in "MACIS 2019", Gebze-Istanbul, Turkey, 2019, https://hal.inria.fr/hal-02406758

[20] X. GOAOC, A. HOLMSEN, C. NICAUD.*An experimental study of forbidden patterns in geometric permutations by combinatorial lifting*, in "35th International Symposium on Computational Geometry", Portland, United States, 2019, https://arxiv.org/abs/1903.03014 [*DOI :* 10.4230/LIPICS.SOCG.2019.40], https://hal.inria.fr/hal-02050539

[21] V. LEDOUX, G. MOROZ.*Evaluation of Chebyshev polynomials on intervals and application to root finding*, in "Mathematical Aspects of Computer and Information Sciences 2019", Gebze, Turkey, November 2019, https://arxiv.org/abs/1912.05843 , https://hal.inria.fr/hal-02405752

Conferences without Proceedings

[22] O. DEVILLERS, C. DUMÉNIL.*A Poisson sample of a smooth surface is a good sample*, in "EuroCG 2019", Utrecht, Netherlands, February 2019, https://hal.archives-ouvertes.fr/hal-02394144

[23] R. IMBACH, M. POUGET, C. YAP.*Clustering Complex Zeros of Triangular System of Polynomials*, in "CASC 2019", Moscow, Russia, 2019, https://arxiv.org/abs/1806.10164 , https://hal.archives-ouvertes.fr/hal-01825708

[24] G. KRAIT, S. LAZARD, G. MOROZ, M. POUGET.*Numerical Algorithm for the Topology of Singular Plane Curves*, in "EuroCG 2019", Utrecht, Netherlands, 2019, https://hal.archives-ouvertes.fr/hal-02294028

Research Reports

[25] I. BARANY, M. FRADELIZI, X. GOAOC, A. HUBARD, G. ROTE.*Random polytopes and the wet part for arbitrary probability distributions*, Rényi Institute of Mathematics ; University College London ; Université Paris-Est ; Université de Lorraine ; Freie Universität Berlin, 2019, https://arxiv.org/abs/1902.06519 , https://hal.inria.fr/hal-02050632

[26] J.-D. BOISSONNAT, O. DEVILLERS, K. DUTTA, M. GLISSE.*Randomized incremental construction of Delaunay triangulations of nice point sets*, Inria, 2019, https://hal.inria.fr/hal-01950119

[27] P. BOSE, J.-L. DE CARUFEL, O. DEVILLERS.*Expected Complexity of Routing in Θ 6 and Half-Θ 6 Graphs*, Inria, 2019, 18, https://arxiv.org/abs/1910.14289 , https://hal.inria.fr/hal-02338733

[28] V. DESPRÉ, J.-M. SCHLENKER, M. TEILLAUD.*Flipping Geometric Triangulations on Hyperbolic Surfaces*, Inria, December 2019, https://arxiv.org/abs/1912.04640 , https://hal.inria.fr/hal-02400219

[29] O. DEVILLERS, P. DUCHON, M. GLISSE, X. GOAOC.*On Order Types of Random Point Sets*, Inria, 2019, https://arxiv.org/abs/1812.08525 , https://hal.inria.fr/hal-01962093

Other Publications

[30] L. VALQUE.*3D Snap Rounding*, Université de Lyon, June 2019, https://hal.inria.fr/hal-02393625

References in notes

[31] D. ATTALI, J.-D. BOISSONNAT, A. LIEUTIER.*Complexity of the Delaunay triangulation of points on surfaces: the smooth case*, in "Proceedings of the 19th Annual Symposium on Computational Geometry", 2003, p. 201–210 [*DOI :* 10.1145/777792.777823], http://dl.acm.org/citation.cfm?id=777823

[32] F. AURENHAMMER, R. KLEIN, D. LEE.*Voronoi diagrams and Delaunay triangulations*, World Scientific, 2013, http://www.worldscientific.com/worldscibooks/10.1142/8685

[33] M. BOGDANOV, O. DEVILLERS, M. TEILLAUD.*Hyperbolic Delaunay complexes and Voronoi diagrams made practical*, in "Journal of Computational Geometry", 2014, vol. 5, p. 56–85

[34] M. BOGDANOV, M. TEILLAUD, G. VEGTER.*Delaunay triangulations on orientable surfaces of low genus*, in "Proceedings of the 32nd International Symposium on Computational Geometry", 2016, p. 20:1–20:15 [*DOI :* 10.4230/LIPICS.SOCG.2016.20], https://hal.inria.fr/hal-01276386

[35] J.-D. BOISSONNAT, O. DEVILLERS, S. HORNUS.*Incremental construction of the Delaunay graph in medium dimension*, in "Proceedings of the 25th Annual Symposium on Computational Geometry", 2009, p. 208–216, http://hal.inria.fr/inria-00412437/

[36] J.-D. BOISSONNAT, O. DEVILLERS, R. SCHOTT, M. TEILLAUD, M. YVINEC.*Applications of random sampling to on-line algorithms in computational geometry*, in "Discrete and Computational Geometry", 1992, vol. 8, p. 51–71, http://hal.inria.fr/inria-00090675

[37] Y. BOUZIDI, S. LAZARD, G. MOROZ, M. POUGET, F. ROUILLIER, M. SAGRALOFF.*Improved algorithms for solving bivariate systems via Rational Univariate Representations*, Inria, February 2015, https://hal.inria.fr/hal-01114767

[38] Y. BOUZIDI, S. LAZARD, M. POUGET, F. ROUILLIER.*Separating linear forms and Rational Univariate Representations of bivariate systems*, in "Journal of Symbolic Computation", May 2015, vol. 68, p. 84-119 [*DOI :* 10.1016/J.JSC.2014.08.009], https://hal.inria.fr/hal-00977671

[39] P. CALKA.*Tessellations, convex hulls and Boolean model: some properties and connections*, Université René Descartes - Paris V, 2009, Habilitation à diriger des recherches, https://tel.archives-ouvertes.fr/tel-00448249

[40] M. CAROLI, P. M. M. DE CASTRO, S. LORIOT, O. ROUILLER, M. TEILLAUD, C. WORMSER.*Robust and Efficient Delaunay Triangulations of Points on or Close to a Sphere*, in "Proceedings of the 9th International Symposium on Experimental Algorithms", Lecture Notes in Computer Science, 2010, vol. 6049, p. 462–473, http://hal.inria.fr/inria-00405478/

[41] M. CAROLI, M. TEILLAUD.*3D Periodic Triangulations*, in "CGAL User and Reference Manual", CGAL Editorial Board, 2009 [*DOI :* 10.1007/978-3-642-04128-0_6], http://doc.cgal.org/latest/Manual/packages.html#PkgPeriodic3Triangulation3Summary

[42] M. CAROLI, M. TEILLAUD.*Computing 3D Periodic Triangulations*, in "Proceedings of the 17th European Symposium on Algorithms", Lecture Notes in Computer Science, 2009, vol. 5757, p. 59–70

[43] M. CAROLI, M. TEILLAUD.*Delaunay Triangulations of Point Sets in Closed Euclidean d-Manifolds*, in "Proceedings of the 27th Annual Symposium on Computational Geometry", 2011, p. 274–282 [*DOI :* 10.1145/1998196.1998236], https://hal.inria.fr/hal-01101094

[44] B. CHAZELLE AND OTHERS.*Application challenges to computational geometry: CG impact task force report*, in "Advances in Discrete and Computational Geometry", Providence, B. CHAZELLE, J. E. GOODMAN, R. POLLACK (editors), Contemporary Mathematics, American Mathematical Society, 1999, vol. 223, p. 407–463

[45] P. CHOSSAT, G. FAYE, O. FAUGERAS.*Bifurcation of hyperbolic planforms*, in "Journal of Nonlinear Science", 2011, vol. 21, p. 465–498, http://link.springer.com/article/10.1007/s00332-010-9089-3

[46] V. DAMEROW, C. SOHLER.*Extreme points under random noise*, in "Proceedings of the 12th European Symposium on Algorithms", 2004, p. 264–274, http://dx.doi.org/10.1007/978-3-540-30140-0_25

[47] O. DEVILLERS.*The Delaunay hierarchy*, in "International Journal of Foundations of Computer Science", 2002, vol. 13, p. 163-180, https://hal.inria.fr/inria-00166711

[48] O. DEVILLERS, M. GLISSE, X. GOAOC.*Complexity analysis of random geometric structures made simpler*, in "Proceedings of the 29th Annual Symposium on Computational Geometry", June 2013, p. 167-175 [*DOI :* 10.1145/2462356.2462362], https://hal.inria.fr/hal-00833774

[49] O. DEVILLERS, M. GLISSE, X. GOAOC, R. THOMASSE.*On the smoothed complexity of convex hulls*, in "Proceedings of the 31st International Symposium on Computational Geometry", Lipics, 2015 [*DOI :* 10.4230/LIPICS.SOCG.2015.224], https://hal.inria.fr/hal-01144473

[50] L. DUPONT, D. LAZARD, S. LAZARD, S. PETITJEAN.*Near-optimal parameterization of the intersection of quadrics: I. The generic algorithm*, in "Journal of Symbolic Computation", 2008, vol. 43, n^{o} 3, p. 168–191 [*DOI :* 10.1016/J.JSC.2007.10.006], http://hal.inria.fr/inria-00186089/en

[51] L. DUPONT, D. LAZARD, S. LAZARD, S. PETITJEAN.*Near-optimal parameterization of the intersection of quadrics: II. A classification of pencils*, in "Journal of Symbolic Computation", 2008, vol. 43, n^{o} 3, p. 192–215 [*DOI :* 10.1016/J.JSC.2007.10.012], http://hal.inria.fr/inria-00186090/en

[52] L. DUPONT, D. LAZARD, S. LAZARD, S. PETITJEAN.*Near-Optimal Parameterization of the Intersection of Quadrics: III. Parameterizing Singular Intersections*, in "Journal of Symbolic Computation", 2008, vol. 43, n^{o} 3, p. 216–232 [*DOI :* 10.1016/J.JSC.2007.10.007], http://hal.inria.fr/inria-00186091/en

[53] M. GLISSE, S. LAZARD, J. MICHEL, M. POUGET.*Silhouette of a random polytope*, in "Journal of Computational Geometry", 2016, vol. 7, n$^{\text{o}}$ 1, 14, https://hal.inria.fr/hal-01289699

[54] M. HEMMER, L. DUPONT, S. PETITJEAN, E. SCHÖMER.*A complete, exact and efficient implementation for computing the edge-adjacency graph of an arrangement of quadrics*, in "Journal of Symbolic Computation", 2011, vol. 46, n$^{\text{o}}$ 4, p. 467-494 [*DOI :* 10.1016/J.JSC.2010.11.002], https://hal.inria.fr/inria-00537592

[55] J. HIDDING, R. VAN DE WEYGAERT, G. VEGTER, B. J. JONES, M. TEILLAUD.*Video: the sticky geometry of the cosmic web*, in "Proceedings of the 28th Annual Symposium on Computational Geometry", 2012, p. 421–422

[56] J. B. HOUGH, M. KRISHNAPUR, Y. PERES, B. VIRÁG.*Determinantal processes and independence*, in "Probab. Surv.", 2006, vol. 3, p. 206-229

[57] I. IORDANOV, M. TEILLAUD.*Implementing Delaunay triangulations of the Bolza surface*, in "Proceedings of the Thirty-third International Symposium on Computational Geometry", 2017, p. 44:1–44:15 [*DOI :* 10.4230/LIPICS.SOCG.2017.44], https://hal.inria.fr/hal-01568002

[58] S. LAZARD, L. M. PEÑARANDA, S. PETITJEAN.*Intersecting quadrics: an efficient and exact implementation*, in "Computational Geometry: Theory and Applications", 2006, vol. 35, n$^{\text{o}}$ 1-2, p. 74–99

[59] S. LAZARD, M. POUGET, F. ROUILLIER.*Bivariate triangular decompositions in the presence of ssymptotes*, Inria, September 2015, https://hal.inria.fr/hal-01200802

[60] M. MAZÓN, T. RECIO.*Voronoi diagrams on orbifolds*, in "Computational Geometry: Therory and Applications", 1997, vol. 8, p. 219–230

[61] A. PELLÉ, M. TEILLAUD.*Periodic meshes for the CGAL library*, 2014, International Meshing Roundtable, Research Note, https://hal.inria.fr/hal-01089967

[62] G. RONG, M. JIN, X. GUO.*Hyperbolic centroidal Voronoi tessellation*, in "Proceedings of the ACM Symposium on Solid and Physical Modeling", 2010, p. 117–126, http://dx.doi.org/10.1145/1839778.1839795

[63] A. RÉNYI, R. SULANKE.*Über die konvexe Hülle von n zufällig gerwähten Punkten I*, in "Z. Wahrsch. Verw. Gebiete", 1963, vol. 2, p. 75–84, http://dx.doi.org/10.1007/BF00535300

[64] A. RÉNYI, R. SULANKE.*Über die konvexe Hülle von n zufällig gerwähten Punkten II*, in "Z. Wahrsch. Verw. Gebiete", 1964, vol. 3, p. 138–147, http://dx.doi.org/10.1007/BF00535973

[65] F. SAUSSET, G. TARJUS, P. VIOT.*Tuning the fragility of a glassforming liquid by curving space*, in "Physical Review Letters", 2008, vol. 101, p. 155701(1)–155701(4), http://dx.doi.org/10.1103/PhysRevLett.101.155701

[66] M. SCHINDLER, A. C. MAGGS.*Cavity averages for hard spheres in the presence of polydispersity and incomplete data*, in "The European Physical Journal E", 2015, p. 38–97, http://dx.doi.org/10.1103/PhysRevE.88.022315

[67] D. A. SPIELMAN, S.-H. TENG.*Smoothed analysis: why the simplex algorithm usually takes polynomial time*, in "Journal of the ACM", 2004, vol. 51, p. 385–463, http://dx.doi.org/10.1145/990308.990310

[68] M. TEILLAUD.*Towards dynamic randomized algorithms in computational geometry*, Lecture Notes Comput. Sci., Springer-Verlag, 1993, vol. 758 [*DOI :* 10.1007/3-540-57503-0], http://www.springer.com/gp/book/9783540575030

[69] R. VAN DE WEYGAERT, G. VEGTER, H. EDELSBRUNNER, B. J. JONES, P. PRANAV, C. PARK, W. A. HELLWING, B. ELDERING, N. KRUITHOF, E. BOS, J. HIDDING, J. FELDBRUGGE, E. TEN HAVE, M. VAN ENGELEN, M. CAROLI, M. TEILLAUD.*Alpha, Betti and the megaparsec universe: on the homology and topology of the cosmic web*, in "Transactions on Computational Science XIV", Lecture Notes in Computer Science, Springer-Verlag, 2011, vol. 6970, p. 60–101, http://dx.doi.org/10.1007/978-3-642-25249-5_3

Project-Team LARSEN

Lifelong Autonomy and interaction skills for Robots in a Sensing ENvironment

IN COLLABORATION WITH: Laboratoire lorrain de recherche en informatique et ses applications (LORIA)

IN PARTNERSHIP WITH:
CNRS

Université de Lorraine

RESEARCH CENTER
Nancy - Grand Est

THEME
Robotics and Smart environments

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Project-Team LARSEN

Creation of the Team: 2015 January 01, updated into Project-Team: 2017 December 01

Keywords:

Computer Science and Digital Science:

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Other Research Topics and Application Domains:

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1. Team, Visitors, External Collaborators

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2. Overall Objectives

2.1. Overall Objectives

The goal of the LARSEN team is to move robots beyond the research laboratories and manufacturing industries: current robots are far from being the fully autonomous, reliable, and interactive robots that could co-exist with us in our society and run for days, weeks, or months. While there is undoubtedly progress to be made on the hardware side, robotics platforms are quickly maturing and we believe the main challenges to achieve our goal are now on the software side. We want our software to be able to run on low-cost mobile robots that are therefore not equipped with high-performance sensors or actuators, so that our techniques can realistically be deployed and evaluated in real settings, such as in service and assistive robotic applications. We envision that these robots will be able to cooperate with each other but also with intelligent spaces or apartments which can also be seen as robots spread in the environments. Like robots, intelligent spaces are equipped with sensors that make them sensitive to human needs, habits, gestures, etc., and actuators to be adaptive and responsive to environment changes and human needs. These intelligent spaces can give robots improved skills, with less expensive sensors and actuators enlarging their field of view of human activities, making them able to behave more intelligently and with better awareness of people evolving in their environment. As robots and intelligent spaces share common characteristics, we will use, for the sake of simplicity, the term robot for both mobile robots and intelligent spaces.

Among the particular issues we want to address, we aim at designing robots having the ability to:

- handle dynamic environment and unforeseen situations;
- cope with physical damage;
- interact physically and socially with humans;
- collaborate with each other;
- exploit the multitude of sensors measurements from their surrounding;
- enhance their acceptability and usability by end-users without robotics background.

All these abilities can be summarized by the following two objectives:

- *life-long autonomy*: continuously perform tasks while adapting to sudden or gradual changes in both the environment and the morphology of the robot;
- *natural interaction with robotics systems*: interact with both other robots and humans for long periods of time, taking into account that people and robots learn from each other when they live together.

3. Research Program

3.1. Lifelong Autonomy

3.1.1. Scientific Context

So far, only a few autonomous robots have been deployed for a long time (weeks, months, or years) outside of factories and laboratories. They are mostly mobile robots that simply "move around" (e.g., vacuum cleaners or museum "guides") and data collecting robots (e.g., boats or underwater "gliders" that collect data about the water of the ocean).

A large part of the long-term autonomy community is focused on simultaneous localization and mapping (SLAM), with a recent emphasis on changing and outdoor environments [25], [34]. A more recent theme is life-long learning: during long-term deployment, we cannot hope to equip robots with everything they need to know, therefore some things will have to be learned along the way. Most of the work on this topic leverages machine learning and/or evolutionary algorithms to improve the ability of robots to react to unforeseen changes [25], [32].

3.1.2. Main Challenges

The first major challenge is to endow robots with a stable situation awareness in open and dynamic environments. This covers both the state estimation of the robot itself as well as the perception/representation of the environment. Both problems have been claimed to be solved but it is only the case for static environments [30].

In the LARSEN team, we aim at deployment in environments shared with humans which imply dynamic objects that degrade both the mapping and localization of a robot, especially in cluttered spaces. Moreover, when robots stay longer in the environment than for the acquisition of a snapshot map, they have to face structural changes, such as the displacement of a piece of furniture or the opening or closing of a door. The current approach is to simply update an implicitly static map with all observations with no attempt at distinguishing the suitable changes. For localization in not-too-cluttered or not-too-empty environments, this is generally sufficient as a significant fraction of the environment should remain stable. But for life-long autonomy, and in particular navigation, the quality of the map, and especially the knowledge of the stable parts, is primordial.

A second major obstacle to move robots outside of labs and factories is their fragility: Current robots often break in a few hours, if not a few minutes. This fragility mainly stems from the overall complexity of robotic systems, which involve many actuators, many sensors, and complex decisions, and from the diversity of situations that robots can encounter. Low-cost robots exacerbate this issue because they can be broken in many ways (high-quality material is expensive), because they have low self-sensing abilities (sensors are expensive and increase the overall complexity), and because they are typically targeted towards non-controlled environments (e.g., houses rather than factories, in which robots are protected from most unexpected events). More generally, this fragility is a symptom of the lack of adaptive abilities in current robots.

3.1.3. Angle of Attack

To solve the state estimation problem, our approach is to combine classical estimation filters (Extended Kalman Filters, Unscented Kalman Filters, or particle filters) with a Bayesian reasoning model in order to internally simulate various configurations of the robot in its environment. This should allow for adaptive estimation that can be used as one aspect of long-term adaptation. To handle dynamic and structural changes in an environment, we aim at assessing, for each piece of observation, whether it is static or not.

We also plan to address active sensing to improve the situation awareness of robots. Literally, active sensing is the ability of an interacting agent to act so as to control what it senses from its environment with the typical objective of acquiring information about this environment. A formalism for representing and solving active sensing problems has already been proposed by members of the team [24] and we aim to use this to formalize decision making problems of improving situation awareness.

Situation awareness of robots can also be tackled by cooperation, whether it be between robots or between robots and sensors in the environment (led out intelligent spaces) or between robots and humans. This is in rupture with classical robotics, in which robots are conceived as self-contained. But, in order to cope with as diverse environments as possible, these classical robots use precise, expensive, and specialized sensors, whose cost prohibits their use in large-scale deployments for service or assistance applications. Furthermore, when all sensors are on the robot, they share the same point of view on the environment, which is a limit for perception. Therefore, we propose to complement a cheaper robot with sensors distributed in a target environment. This is an emerging research direction that shares some of the problematics of multi-robot operation and we are therefore collaborating with other teams at Inria that address the issue of communication and interoperability.

To address the fragility problem, the traditional approach is to first diagnose the situation, then use a planning algorithm to create/select a contingency plan. But, again, this calls for both expensive sensors on the robot for the diagnosis and extensive work to predict and plan for all the possible faults that, in an open and dynamic environment, are almost infinite. An alternative approach is then to skip the diagnosis and let the robot discover by trial and error a behavior that works in spite of the damage with a reinforcement learning algorithm [39], [32]. However, current reinforcement learning algorithms require hundreds of trials/episodes to learn a single, often simplified, task [32], which makes them impossible to use for real robots and more ambitious tasks. We therefore need to design new trial-and-error algorithms that will allow robots to learn with a much smaller number of trials (typically, a dozen). We think the key idea is to guide online learning on the physical robot with dynamic simulations. For instance, in our recent work, we successfully mixed evolutionary search in simulation, physical tests on the robot, and machine learning to allow a robot to recover from physical damage [33], [1].

A final approach to address fragility is to deploy several robots or a swarm of robots or to make robots evolve in an active environment. We will consider several paradigms such as (1) those inspired from collective natural phenomena in which the environment plays an active role for coordinating the activity of a huge number of biological entities such as ants and (2) those based on online learning [29]. We envision to transfer our knowledge of such phenomenon to engineer new artificial devices such as an intelligent floor (which is in fact a spatially distributed network in which each node can sense, compute and communicate with contiguous nodes and can interact with moving entities on top of it) in order to assist people and robots (see the principle in [37], [29], [23]).

3.2. Natural Interaction with Robotic Systems

3.2.1. Scientific Context

Interaction with the environment is a primordial requirement for an autonomous robot. When the environment is sensorized, the interaction can include localizing, tracking, and recognizing the behavior of robots and humans. One specific issue lies in the lack of predictive models for human behavior and a critical constraint arises from the incomplete knowledge of the environment and the other agents.

On the other hand, when working in the proximity of or directly with humans, robots must be capable of safely interacting with them, which calls upon a mixture of physical and social skills. Currently, robot operators are usually trained and specialized but potential end-users of robots for service or personal assistance are not skilled robotics experts, which means that the robot needs to be accepted as reliable, trustworthy and efficient [42]. Most Human-Robot Interaction (HRI) studies focus on verbal communication [38] but applications such as assistance robotics require a deeper knowledge of the intertwined exchange of social and physical signals to provide suitable robot controllers.

3.2.2. Main Challenges

We are here interested in building the bricks for a situated Human-Robot Interaction (HRI) addressing both the physical and social dimension of the close interaction, and the cognitive aspects related to the analysis and interpretation of human movement and activity.

The combination of physical and social signals into robot control is a crucial investigation for assistance robots [40] and robotic co-workers [36]. A major obstacle is the control of physical interaction (precisely, the control of contact forces) between the robot and the human while both partners are moving. In mobile robots, this problem is usually addressed by planning the robot movement taking into account the human as an obstacle or as a target, then delegating the execution of this “high-level” motion to whole-body controllers, where a mixture of weighted tasks is used to account for the robot balance, constraints, and desired end-effector trajectories [26].

The first challenge is to make these controllers easier to deploy in real robotics systems, as currently they require a lot of tuning and can become very complex to handle the interaction with unknown dynamical systems such as humans. Here, the key is to combine machine learning techniques with such controllers.

The second challenge is to make the robot react and adapt online to the human feedback, exploiting the whole set of measurable verbal and non-verbal signals that humans naturally produce during a physical or social interaction. Technically, this means finding the optimal policy that adapts the robot controllers online, taking into account feedback from the human. Here, we need to carefully identify the significant feedback signals or some metrics of human feedback. In real-world conditions (i.e., outside the research laboratory environment) the set of signals is technologically limited by the robot’s and environmental sensors and the onboard processing capabilities.

The third challenge is for a robot to be able to identify and track people on board. The motivation is to be able to estimate online either the position, the posture, or even moods and intentions of persons surrounding the robot. The main challenge is to be able to do that online, in real-time and in cluttered environments.

3.2.3. Angle of Attack

Our key idea is to exploit the physical and social signals produced by the human during the interaction with the robot and the environment in controlled conditions, to learn simple models of human behavior and consequently to use these models to optimize the robot movements and actions. In a first phase, we will exploit human physical signals (e.g., posture and force measurements) to identify the elementary posture tasks during balance and physical interaction. The identified model will be used to optimize the robot whole-body control as prior knowledge to improve both the robot balance and the control of the interaction forces. Technically, we will combine weighted and prioritized controllers with stochastic optimization techniques. To adapt online the control of physical interaction and make it possible with human partners that are not robotics experts, we will exploit verbal and non-verbal signals (e.g., gaze, touch, prosody). The idea here is to estimate online from these signals the human intent along with some inter-individual factors that the robot can exploit to adapt its behavior, maximizing the engagement and acceptability during the interaction.

Another promising approach already investigated in the LARSEN team is the capability for a robot and/or an intelligent space to localize humans in its surrounding environment and to understand their activities. This is an important issue to handle both for safe and efficient human-robot interaction.

Simultaneous Tracking and Activity Recognition (STAR) [41] is an approach we want to develop. The activity of a person is highly correlated with his position, and this approach aims at combining tracking and activity recognition to benefit one from another. By tracking the individual, the system may help infer its possible activity, while by estimating the activity of the individual, the system may make a better prediction of his/her possible future positions (especially in the case of occlusions). This direction has been tested with simulator and particle filters [28], and one promising direction would be to couple STAR with decision making formalisms like partially observable Markov decision processes (POMDPs). This would allow us to formalize problems such as deciding which action to take given an estimate of the human location and activity. This could also formalize other problems linked to the active sensing direction of the team: how the robotic system should choose its actions in order to have a better estimate of the human location and activity (for instance by moving in the environment or by changing the orientation of its cameras)?

Another issue we want to address is robotic human body pose estimation. Human body pose estimation consists of tracking body parts by analyzing a sequence of input images from single or multiple cameras.

Human posture analysis is of high value for human robot interaction and activity recognition. However, even if the arrival of new sensors like RGB-D cameras has simplified the problem, it still poses a great challenge, especially if we want to do it online, on a robot and in realistic world conditions (cluttered environment). This is even more difficult for a robot to bring together different capabilities both at the perception and navigation level [27]. This will be tackled through different techniques, going from Bayesian state estimation (particle filtering), to learning, active and distributed sensing.

4. Application Domains

4.1. Personal Assistance

During the last fifty years, many medical advances as well as the improvement of the quality of life have resulted in a longer life expectancy in industrial societies. The increase in the number of elderly people is a matter of public health because although elderly people can age in good health, old age also causes embrittlement, in particular on the physical plan which can result in a loss of autonomy. That will force us to re-think the current model regarding the care of elderly people. [0] Capacity limits in specialized institutes, along with the preference of elderly people to stay at home as long as possible, explain a growing need for specific services at home.

Ambient intelligence technologies and robotics could contribute to this societal challenge. The spectrum of possible actions in the field of elderly assistance is very large. We will focus on activity monitoring services, mobility or daily activity aids, medical rehabilitation, and social interactions. This will be based on the experimental infrastructure we have built in Nancy (Smart apartment platform) as well as the deep collaboration we have with OHS. [0]

4.2. Civil Robotics

Many applications for robotics technology exist within the services provided by national and local government. Typical applications include civil infrastructure services [0] such as: urban maintenance and cleaning; civil security services; emergency services involved in disaster management including search and rescue; environmental

[0]See the Robotics 2020 Multi-Annual Roadmap [35].
[0]OHS (*Office d'Hygiène Sociale*) is an association managing several rehabilitation or retirement home structures.
[0]See the Robotics 2020 Multi-Annual Roadmap [35], section 2.5.

services such as surveillance of rivers, air quality, and pollution. These applications may be carried out by a wide variety of robot and operating modality, ranging from single robots or small fleets of homogeneous or heterogeneous robots. Often robot teams will need to cooperate to span a large workspace, for example in urban rubbish collection, and operate in potentially hostile environments, for example in disaster management. These systems are also likely to have extensive interaction with people and their environments.

The skills required for civil robots match those developed in the LARSEN project: operating for a long time in potentially hostile environment, potentially with small fleets of robots, and potentially in interaction with people.

5. Highlights of the Year

5.1. Highlights of the Year

- Arrival of a Talos robot in our team (Fig. 1). This is a full-scale humanoid (1.7 m / 100kg / 32 degrees of freedom) that can be fully torque-controlled. The robot is made by PAL Robotics, a Spanish company and is funded by the CPER “Cyber-Entreprise”.
- Arrival of Pauline Maurice as a CRCN (CNRS).

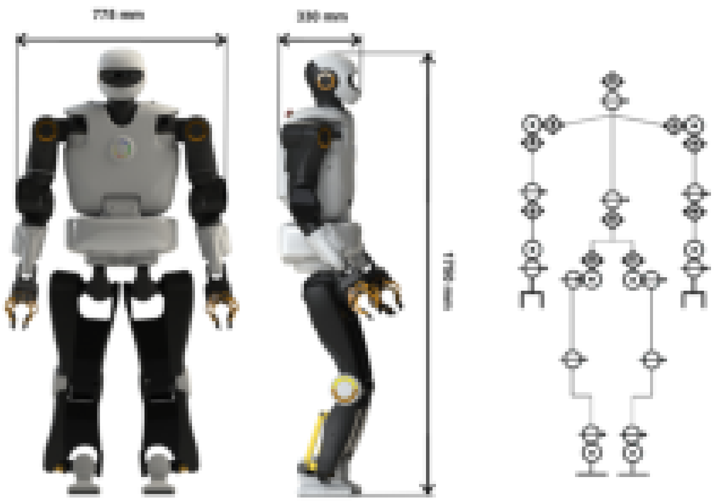

Figure 1. The Talos robot.

5.1.1. Awards

- International Society for Artificial Life (ISAL) award for the Outstanding Publication of the Decade 2004-2014: Clune J, Mouret JB, Lipson H. The evolutionary origins of modularity. Proceedings of the Royal Society b: Biological sciences. 2013 Mar 22;280(1755):20122863.

BEST PAPERS AWARDS :

[16]

N. GAUVILLE, F. CHARPILLET.*Exploration et couverture par stigmergie d’un environnement inconnu avec une flotte de robots autonomes réactifs*, in "JFSMA 2019 - 27emes Journées Francophones sur les Systèmes Multi-Agents", Toulouse, France, Cépaduès 2019, ISBN 9782364937192, July 2019, https://hal.inria.fr/hal-02195812

6. New Software and Platforms

6.1. ROS Qt Control

KEYWORDS: Control - Robot Operating System (ROS) - 2D

SCIENTIFIC DESCRIPTION: This ROS module allows to easily develop different controllers for wheeled mobile robots: Controller class just has to be inherited, the new class only needing a constructor and a chooseVelocities method. A graphical user interface using Qt makes it easy to choose a controller and to set its parameters, and it displays odometric data sent by ROS and the velocities sent to ROS by the controller.

NEWS OF THE YEAR: The code structure has been modified in order to propose a class hierarchy, with controllers aiming to reach a given state and others built to follow a selected trajectory.

- Participant: Alexis Scheuer
- Contact: Alexis Scheuer

6.2. ISeeML

Introducing a Smooth, Efficient and Easy-to-use Motion Library

KEYWORDS: Mobile Computing, Transportation - Optimal control - Planning

SCIENTIFIC DESCRIPTION: The main interest of this library is to offer smooth (continuous-curvature) efficient (close to the optimal) motions for mobile robots. Obtained paths correspond to locally optimal motions with constant velocity for wheeled mobile robots, either car-like or with differential-wheels (e.g. Thymio or Turtlebot). Classical paths (with a discontinuous curvature profile) are also provided. Both paths can also be used for aerial robots, as the motion constraints of those are similar to those of wheeled mobile robots.

RELEASE FUNCTIONAL DESCRIPTION: Additionnal functionnalities for optimal control using ROS.

NEWS OF THE YEAR: Additionnal functionnalities for optimal control using ROS.

- Participant: Alexis Scheuer
- Contact: Alexis Scheuer
- Publication: inria-00527913v1
- URL: http://iseeml.loria.fr

7. New Results

7.1. Lifelong autonomy

7.1.1. Motion planning for robot audition

Participants: François Charpillet, Francis Colas, Van Quan Nguyen.

We collaborated on this subject with Emmanuel Vincent from the Multispeech team (Inria Nancy – Grand Est).

Robot audition refers to a range of hearing capabilities which help robots explore and understand their environment. Among them, sound source localization is the problem of estimating the location of a sound source given measurements of its angle of arrival with respect to a microphone array mounted on the robot. In addition, robot motion can help quickly solve the front-back ambiguity existing in a linear microphone array. In this work, we focus on the problem of exploiting robot motion to improve the estimation of the location of an intermittent and possibly moving source in a noisy and reverberant environment. We first propose a robust extended mixture Kalman filtering framework for jointly estimating the source location and its activity over time. Building on this framework, we then propose a long-term robot motion planning algorithm based on Monte Carlo tree search to find an optimal robot trajectory according to two alternative criteria: the Shannon entropy or the standard deviation of the estimated belief on the source location. Experimental results show the robustness of the proposed estimation framework to false angle of arrival measurements within $\pm 20°$ and 10% false source activity detection rate. The proposed robot motion planning technique achieves an average localization error 48.7% smaller than a one-step-ahead method.

Publication: [10]

7.1.2. Addressing Active Sensing Problems through Monte-Carlo Tree Search (MCTS)

Participants: Vincent Thomas, Gabriel Belouze, Sylvain Geiser, Olivier Buffet.

The problem of active sensing is of paramount interest for building self awareness in robotic systems. It consists in planning actions in a view to gather information (*e.g.*, measured through the entropy over certain state variables) in an optimal way. In the past, we have proposed an original formalism, ρ-POMDPs, and new algorithms for representing and solving such active sensing problems [24] by using point-based algorithms, assuming either convex or Lipschitz-continuous criteria. More recently, we have developed new approaches based on Monte-Carlo Tree Search (MCTS), and in particular Partially Observable Monte-Carlo Planning (POMCP), which provably converge only assuming the continuity of the criterion. We are now going towards algorithms more suitable to certain robotic tasks by allowing for continuous state and observation spaces.

Publication: [20]

7.1.3. Heuristic Search for (Partially Observable) Stochastic Games

Participants: Olivier Buffet, Vincent Thomas.

Collaboration with Jilles Dibangoye (INSA-Lyon, Inria team CHROMA) and Abdallah Saffidine (University of New South Wales (UNSW), Sydney, Australia).

Many robotic scenarios involve multiple interacting agents, robots or humans, *e.g.*, security robots in public areas. We have mainly worked in the past on the collaborative setting, all agents sharing one objective, in particular through solving Dec-POMDPs by (i) turning them into occupancy MDPs and (ii) using heuristic search techniques and value function approximation [2]. A key idea is to take the point of view of a central planner and reason on a sufficient statistic called *occupancy state*. We are now working on applying similar approaches in the important 2-player zero-sum setting, *i.e.*, with two competing agents. As a preliminary step, we have proposed and evaluated an algorithm for (fully observable) stochastic games, which does not require any problem transformation. Then we have proposed an algorithm for partially observable stochastic games, here turning the problem into an occupancy Markov game.

[This line of research will be pursued through Jilles Dibangoye's ANR JCJC PLASMA.]

7.1.4. Interpretable Action Policies

Participant: Olivier Buffet.

Collaboration with Iadine Chadès and Jonathan Ferrer Mestres (CSIRO, Brisbane, Australia), and Thomas G. Dietterich (Oregon State University, USA).

Computer-aided task planning requires providing user-friendly plans, in particular, plans that make sense to the user. In probabilistic planning (in the MDP formalism), such interpretable plans can be derived by constraining action policies (if X happens, do Y) to depend on a reduced subset of (abstract) states or state variables. We have (i) formalized the problem of finding a set of at most K abstract states (forming a partition of the original state space) such that any optimal policy of the induced abstract MDP is as close as possible to optimal policies of the original MDP, and (ii) proposed 3 solution algorithms with theoretical and empirical evaluations.

7.1.5. Perspective: hierarchical quality diversity, from materials to machines

Participant: Jean-Baptiste Mouret.

Collaboration with CSIRO (Australia) and Vrije Universiteit Amsterdam (Netherlands).

Natural lifeforms specialize to their environmental niches across many levels, from low-level features such as DNA and proteins, through to higher-level artefacts including eyes, limbs and overarching body plans. We propose ‘multi-level evolution’, a bottom-up automatic process that designs robots across multiple levels and niches them to tasks and environmental conditions. Multi-level evolution concurrently explores constituent molecular and material building blocks, as well as their possible assemblies into specialized morphological and sensorimotor configurations. Multi-level evolution provides a route to fully harness a recent explosion in available candidate materials and ongoing advances in rapid manufacturing processes. We outline a feasible architecture that realizes this vision, highlight the main roadblocks and how they may be overcome, and show robotic applications to which multi-level evolution is particularly suited. By forming a research agenda to stimulate discussion between researchers in related fields, we hope to inspire the pursuit of multi-level robotic design all the way from material to machine.

Publication: [5]

7.1.6. Improving Embodied Evolutionary Robotics

Participant: Amine Boumaza.

Multi-robots learning is a hard still unsolved problem. When framed into the machine learning theoretical setting, it suffers from a high complexity when seeking optimal solutions. On the other hand, when sub-optimal solutions are acceptable Embodied Evolutionary Robotics, can provide solutions that perform well in practice. Improving these algorithms in terms of run-time or solution quality is an important research question.

It has been long known from the theoretical work on evolution strategies, that recombination improves convergence towards better solution and improves robustness against selection error in noisy environment. We propose to investigate the effect of recombination in online embodied evolutionary robotics, where evolution is decentralized on a swarm of agents. We hypothesize that these properties can also be observed in these algorithms and thus could improve their performance. We introduce the $(\mu/\mu, 1)$-On-line Embedded Evolutionary Algorithm (EEA) which uses a recombination operator inspired from evolution strategies and apply it to learn three different collective robotics tasks, locomotion, item collection and item foraging. Different recombination operators are investigated and compared against a purely mutative version of the algorithm. The experiments show that, when correctly designed, recombination improves significantly the adaptation of the swarm in all scenarios.

Publication: [13] [12]

7.1.7. Multi-robot exploration of an unknown environment

Participants: Nicolas Gauville, François Charpillet.

Different approaches exist for multi-robot autonomous exploration. These include frontier approaches, where robots are assigned to unexplored areas of the map, which provide good performance but require sharing the map and centralizing decision-making. The Brick and Mortar approaches, on the other hand, use a ground marking with local decision-making, but give much lower performance. The algorithm developped by Nicolas Gauville during his pre-thesis period is a trade-off between these two approaches, allowing local decision-making and, surprisingly, performances are closed to centralized frontier approaches. We also propose a comparative study of the performance of the three different approaches : *Brick & Mortar*, *Global Frontiers* and *Local Frontiers*. Our local algorithm is also complete for the exploration problem and can be easily distributed on robots with a minor loss of performance. This work follows the *Cart-O-Matic* project in which our team participated, which aimed to explore and map a building while recognizing specific objects inside with a team of 5 mobile robots.

Publication: [16]

7.2. Natural Interaction with Robotics Systems

Thanks to the arrival of Pauline Maurice and the AnDy H2020 project, our activities about interaction are currently focused on ergnonomic interaction, which requires good foundations in motion analysis.

7.2.1. Digital human modeling for collaborative robotics

Participant: Pauline Maurice.

Collaboration with Vincent Padois (Inria Bordeaux and Sorbonne Université), Yvan Measson (CEA-LIST) and Philippe Bidaud (ONERA and Sorbonne Université).

Work-related musculoskeletal disorders in industry represent a major and growing health problem in many developed countries. Collaborative robotics, which allows the joint manipulation of objects by both a robot and a person, is a possible solution provided that it is possible to assess the ergonomic benefit they offer. Using a digital human model (DHM) can cut down the development cost and time by replacing the physical mock-up by a virtual one easier to modify. The first part of this work details the challenges of digital ergonomic assessment for collaborative robotics. State-of-the-art work on DHM simulations with collaborative robots is reviewed to identify which questions currently remain open. The second part of this work focuses on a specific use case and presents a DHM-based method to optimize design parameters of a collaborative robot for an industrial task.

Publication: [21]

7.2.2. Probabilistic decision making for collaborative robotics

Participants: Yang You, Vincent Thomas, Olivier Buffet, François Charpillet, Francis Colas.

Collaboration with Rachid Alami (LAAS, France).

This work is part of the ANR Flying Co-Worker project and focuses on high-level decision making for collaborative robotics. When a robot has to assist a human worker, it does not have direct access to his current intention or his preferences but has to adapt its behaviour to help the human completing his task. To achieve this, we followed what has been proposed by [31] to model a situation of interaction as a Partially Observable Markov Decision Process (POMDP) by assuming that (i) the robot and the human act sequentially, one after another, and that (ii) the human is rational and makes his decision without considering the future robot's action.

7.2.3. Ativity recognition and prediction

Participants: François Charpillet, Francis Colas, Serena Ivaldi, Niyati Rawal, Vincent Thomas.

This work is part of the ANR Flying Co-Worker project and focuses on activity recognition and long-term prediction for collaborative robotics. Recognizing and predicting human activities is fundamental for a robot to help a human. Previous work in the team on activity recognition [6] rely on Hidden Markov Models (HMM) with, in particular, the Markov assumption stating that the distribution on the next state is independent from former states given the current state. This assumption, at the heart of the recurrent expression of the inference in HMM, has the unfortunate consequence to constrain the a priori distribution on the duration in each state to exponential distributions. However, it can be observed in datasets that this is not the case for many activities, which have a typical duration. This discrepancy is negligeable for recognition where HMM models achieve good performance thanks to the observations, but prevents longer-term activity prediction.

In the master project of Niyati Rawal, we investigated a slightly different model, Explicit Duration Hidden Markov Model (EDHMM), in which the duration of the activity can be modeled more finely. Preliminary results show that the recognition performance was similar to HMM but with a better prediction performance.

7.2.4. Humanoid Whole-Body Movement Optimization from Retargeted Human Motions

Participants: Waldez Azevedo Gomes Junior, Vishnu Radhakrishnan, Luigi Penco, Valerio Modugno, Jean-Baptiste Mouret, Serena Ivaldi.

Motion retargeting and teleoperation are powerful tools to demonstrate complex whole-body movements to humanoid robots: in a sense, they are the equivalent of kinesthetic teaching for manipulators. However, retargeted motions may not be optimal for the robot: because of different kinematics and dynamics, there could be other robot trajectories that perform the same task more efficiently, for example with less power consumption. We propose to use the retargeted trajectories to bootstrap a learning process aimed at optimizing the whole-body trajectories w.r.t. a specified cost function. To ensure that the optimized motions are safe, i.e., they do not violate system constraints, we used constrained optimization algorithms. We compared both global and local optimization approaches, since the optimized robot solution may not be close to the demonstrated one. We evaluated our framework with the humanoid robot iCub on an object lifting scenario, initially demonstrated by a human operator wearing a motion-tracking suit. By optimizing the initial retargeted movements, we can improve robot performance by over 40%.

Publication: [14]

7.2.5. Tele-operation of Humanoids

Participants: Luigi Penco, Waldez Gomes, Valerio Modugno, Serena Ivaldi.

We envision a world where robots can act as physical avatars and effectively replace humans in hazardous scenarios by means of teleoperation, which we see as a particular way of interacting with a robot. However, teleoperating humanoids is a challenging task because of differences in kinematics (e.g., structure and joint limits) and dynamics (e.g., mass distribution, inertia) are still significant. Another crucial issue is ensuring the dynamic balance of the robot while trying to imitate the human motion. We propose a multi-mode teleoperation framework for controlling humanoid robots for loco-manipulation tasks that address the aforementioned challenges by using two levels of teleoperation: a low-level for manipulation, realized via whole-body teleoperation, and a high-level for locomotion, based on the generation of reference velocities that are then tracked by the humanoid. We believe that this combination of different modes of teleoperation will considerably ease the burden of controlling humanoids, ultimately increasing their adaptability to complex situations which cannot be handled satisfactorily by fully autonomous systems.

Publication: [11]

7.2.6. Activity Recognition for Ergonomics Assessment of Industrial Tasks with Automatic Feature Selection

Participants: Adrien Malaisé, Pauline Maurice, Francis Colas, Serena Ivaldi.

In industry, ergonomic assessment is currently performed manually based on the identification of postures and actions by experts. We aim at proposing a system for automatic ergonomic assessment based on activity recognition. In this work, we define a taxonomy of activities, composed of four levels, compatible with items evaluated in standard ergonomic worksheets. The proposed taxonomy is applied to learn activity recognition models based on Hidden Markov Models. We also identify dedicated sets of features to be used as input of the recognition models so as to maximize the recognition performance for each level of our taxonomy. We compare three feature selection methods to obtain these subsets. Data from 13 participants performing a series of tasks mimicking industrial tasks are collected to train and test the recognition module. Results show that the selected subsets allow us to successfully infer ergonomically relevant postures and actions.

Publication: [6]

7.2.7. Human movement and ergonomics: An industry-oriented dataset for collaborative robotics

Participants: Pauline Maurice, Adrien Malaisé, Serena Ivaldi.

With the participation of Clélie Amiot, Nicolas Paris and Guy-Junior Richard, interns from Université de Lorraine during the summer 2018.

Improving work conditions in industry is a major challenge that can be addressed with new emerging technologies such as collaborative robots. Machine learning techniques can improve the performance of those robots, by endowing them with a degree of awareness of the human state and ergonomics condition. The availability of appropriate datasets to learn models and test prediction and control algorithms, however, remains an issue. This work presents a dataset of human motions in industry-like activities, fully labeled according to the ergonomics assessment worksheet EAWS, widely used in industries such as car manufacturing. Thirteen participants performed several series of activities, such as screwing and manipulating loads under different conditions, resulting in more than 5 hours of data. The dataset contains the participants' whole-body kinematics recorded both with wearable inertial sensors and marker-based optical motion capture, finger pressure force, video recordings, and annotations by three independent annotators of the performed action and the adopted posture following the EAWS postural grid. Sensor data are available in different formats to facilitate their reuse. The dataset is intended for use by researchers developing algorithms for classifying, predicting, or evaluating human motion in industrial settings, as well as researchers developing collaborative robotics solutions that aim at improving the workers' ergonomics. The annotation of the whole dataset following an ergonomics standard makes it valuable for ergonomics-related applications, but we expect its use to be broader in the robotics, machine learning, and human movement communities.

Publication: [8]

7.2.8. Objective and Subjective Effects of a Passive Exoskeleton on Overhead Work

Participants: Pauline Maurice, Serena Ivaldi.

Collaboration with Jernej Čamernik, Daša Gorjan and Jan Babič (Jozef Stefan Institute, Ljubljana, Slovenia), with Benjamin Schirrmeister and Jonas Bornmann (Otto Bock SE & Co. KGaA, Duderstadt, Germany), with Luca Tagliapietra, Claudia Latella and Daniele Pucci (Istituto Italiano di Tecnologia, Genova, Italy), and with Lars Fritzsche (IMK Automotive, Chemitz, Germany).

Overhead work is a frequent cause of shoulder work-related musculoskeletal disorders. Exoskeletons offering arm support have the potential to reduce shoulder strain, without requiring large scale reorganization of the workspace. Assessment of such systems however requires to take multiple factors into consideration. This work presents a thorough in-lab assessment of PAEXO, a novel passive exoskeleton for arm support during overhead work. A list of evaluation criteria and associated performance metrics is proposed to cover both objective and subjective effects of the exoskeleton, on the user and on the task being performed. These metrics are measured during a lab study, where 12 participants perform an overhead pointing task with and without the exoskeleton, while their physical, physiological and psychological states are monitored. Results show that using PAEXO reduces shoulder physical strain as well as global physiological strain, without increasing low back strain nor degrading balance. These positive effects are achieved without degrading task performance. Importantly, participant' opinions of PAEXO are positive, in agreement with the objective measures. Thus, PAEXO seems a promising solution to help prevent shoulder injuries and diseases among overhead workers, without negatively impacting productivity.

Publication: [7], [19]

7.2.9. Assessing and improving human movements using sensitivity analysis and digital human simulation

Participant: Pauline Maurice.

Collaboration with Vincent Padois (Inria Bordeaux and Sorbonne Université), Yvan Measson (CEA-LIST) and Philippe Bidaud (ONERA and Sorbonne Université).

Enhancing the performance of technical movements aims both at improving operational results and at reducing biomechanical demands. Advances in human biomechanics and modeling tools allow to evaluate human performance with more and more details. Finding the right modifications to improve the performance is, however, still addressed with extensive time consuming trial-and-error processes. This work presents a framework for easily assessing human movements and automatically providing recommendations to improve their performances. An optimization-based whole-body controller is used to dynamically replay human movements from motion capture data, to evaluate existing movements. Automatic digital human simulations are then run to estimate performance indicators when the movement is performed in many different ways. Sensitivity indices are thereby computed to quantify the influence of postural parameters on the performance. Based on the results of the sensitivity analysis, recommendations for posture improvement are provided. The method is successfully validated on a drilling activity.

Publication: [9]

7.2.10. Human Motion analysis for assistance

Participants: François Charpillet, Jessica Colombel.

Collaboration with David Daney (Inria Bordeaux, Auctus Team)

Different sort of sensors can be used for rehabilitation at home. This year we have evaluated the usabily of a Kinect 2. The proposed approach is to improve joint angle estimates. It is based on a constrained extended Kalman Filter that tracks inputted measured joint centers. Since the proposed approach uses a biomechanical model, it allows to obtain physically consistent constrained joint angles and constant segment lengths. A practical method, that is not sensor specific, for the optimal tuning of the extended Kalman filter covariance matrices is provided. It uses reference data obtained from a stereophotogrammetric system but it has to be tuned only once since it is task specific only. The improvement of optimal tuning over classical methods for setting the covariance matrices is shown with a statistical parametric mapping analysis. The proposed approach was tested with six healthy subjects performing 4 rehabilitation tasks. Joint estimates accuracy was assessed with a reference stereophotogrammetric system. Even if some joints such as the internal/external rotations were not well estimated, the proposed optimized algorithm reached a satisfactory average root mean square difference of 9.7deg and a correlation coefficient 0.86 of for all joints. Our results show that affordable RGB-D sensor can be used for simple in-home rehabilitation when using a constrained biomechanical model.

A work carried out this year, takes the search for a sensor for personal assistance a step further with the study of the new Kinect Azure. Human-robot interaction requires a robust estimate of human motion in real-time. This work presents a fusion algorithm for joint center positions tracking from multiple depth cameras to improve human motion analysis accuracy. The proposed algorithm is based on body tracking measurements fusion with an extended Kalman filter and anthropomorphic constraints. However, the effectiveness and robustness of such algorithm depends on the A direct comparison of joint center positions estimated with a reference stereophotogrammetric system and the ones estimated with the new Kinect 3 (Azure Kinect) sensor and its older version the Kinect 2 (Kinect for Windows) has been made. The proposed approach improves body tracker data even for Kinect 3 which has not the same characteristics than Kinect 2. This study shows also the importance of defining good heuristics to merge data depending on how the body tracking works. Thus, with proper heuristics, the joint center position estimates are improved by at least 14.6 %. Finally, we propose an additional comparison between Kinect 2 and Kinect 3 exhibiting the pros and cons of the two sensors. This study is now in submission for an international conference.

Finally, a state of the art on biological motion was realized. The purpose of this study is to understand and develop methods for decomposing motion. The EWalk dataset (http://gamma.cs.unc.edu/GAIT/#EWalk) will allow us to test emotion recognition from simple decompositions and classifiers. Then, we will extend the methods to other cognitive parameters.

7.2.11. Reliable localization of pedestrians in a smart home using multi-sensor data fusion

Participants: François Charpillet, Lina Achaji.

Collaboration with Maan Badaoui EL Najjar(Cristal Laboratory Lille, DiCOT Team), Mohamad Daher (the Lebanese University Faculty of technology, Tripoli)

One objective of the Larsen team is to develop technologies allowing older people to live independently as long as possible in their own homes instead of in specialized institutions. However, elderly people face physical problems that reduce their autonomy, and consequently their capacity to achieve daily activities. The integration of environmental or body sensors in what is called nowadays smart habitats is a solution that is appealing to provide a better quality of life with safer conditions. Localization and tracking of people in indoor environments are one of the primary services to be developed to follow them up at home, permitting to evaluate their physical states through the observation of their Activities of Daily Living (ADL). We proposed during the internship of Lina Achaji to localize and track the center of pressure (CoP) of people (one or two) in a smart home using a load sensing floor equipped with around 400 load sensors as well as wearable sensors. The data fusion is made using an informational filter where an inverted pendulum bio-mechanical model is introduced. The obtained results are very promising and were validated using a motion tracking system and force plates.

Publication: [4]

7.2.12. Ambient assisting living

Participants: François Charpillet, Yassine El Khadiri.

Collaboration with Cedric Rose from Diatelic compagny.

The ageing of the population confronts modern societies with an unprecedented demographic transformation. These include the imbalance in our pension systems and the cost of caring for the elderly. On this last point, apart from the economic aspects, the placement of elderly people is often only a choice of reason and can be quite badly experienced by people. One response to this societal problem is the development of technologies that make it easier to keep elderly people at home. The state of the art in this field abounds with upstream projects that are moving in this direction. Many of them are seeking to develop home monitoring systems. Their objectives are to detect and even prevent the occurrence of worrying or critical situations and to assess the physical condition or even fragility of the people being monitored. It is within this framework that this contribution is made. In this work, we have focused on the particular problem of monitoring the quality of sleep as well as the detection of nocturnal waking of a person living alone at home. The home is equipped with simple ambient sensors such as binary motion detectors. We have developed a Bayesian inference method that allows our solution to be flexible and robust enough for different types of installations and apartment configurations while maintaining a prediction accuracy of 0.94. This solution is currently being deployed on several dozen apartments in Lorraine by Diatelic and Pharmagest compagnies.

Publication: [15]

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Grants with Industry

8.1.1. Cifre with Diatelic Pharmagest

Participants: François Charpillet, Yassine El Khadiri.

We have a long term collaboration with Diatelic compagny which is a start-up created among other by François Charpillet in 2002. Currently we have a collaboration through a Cifre PhD whose the objective is to work on daily activity recognition for monitoring elderly people at home. The work will be included in a product that will be launched next year (carelib solution).

8.1.2. Cifre with PSA

Participants: François Charpillet, Julien Uzzan.

This work is done in collaboration with François Aioun, Thomas Hannagan and Franck Guillemard from PSA.

The subject of the thesis is : « Reinforcement learning for the autonomous vehicle in urban-like environments ». This PhD started in January on the Vélizy site where he stayed for 3 months and the he moved to Inria Nancy in the LARSEN team and we started working on applications of deep reinforcement learning algorithms for autonomous vehicles. The first one was a decision-making problem for autonomous driving on highways using the Deep Q-Networks algorithm. The aim was to build a controler outputing high level decisions (like changing to left/right lane, braking. . .) to navigate on highways and interacting with many other actors. Even though the results were convicing for simple simulations like a basic overtaking or just following a leader car, the performances on the general case were lackluster, so this is still an ongoing work. The other application we worked on later this year is a longitudinal control application. The aim was to create a controller able to drive behind a leader, but this time, the controller is low-level, meaning that it has to output direct commands, like an acceleration. More recently, we have been testing a idea meant to enhance the performances of the deep reinforcement learning algorithm by adding noise to the observations during training in order to obtain a safer and more cautious controller.

8.1.3. Cifre with SAFRAN

Participants: François Charpillet, Nicolas Gauville, Christophe Guettier.

The thesis began on May 6, 2019 after a "prethesis" of 6 month and is related to the Furious Project. The objective is to propose new Coordination mechanisms for a group of autonomous robotic evolving in an unknown environment for search and rescue (Robot Search and Rescue). The thesis is a continuation of a previous work made during the Cartomatic project which won in 2012 the French robotics contest Defi CAROTTE organized by the General Delegation for Armaments (DGA) and French National Research Agency (ANR).

8.1.4. Cifre iFollow

Participants: Francis Colas, Jérôme Truc, Cédric Pradalier, Nirmal Giftsun.

Cédric Pradalier is co-supervisor at GeorgiaTech Lorraine and Nirmal Giftsun is at iFollow.

iFollow is a startup, located in Paris area, providing solutions for shopping carts. Their first market of interest is logistics, wherein they develop robots for alleviating the workload of order pickers. Their second, longer-term, target is retail, with the development of intelligent shopping carts to help persons with disabilities.

The aim of this Cifre program is to endow the robots with more intelligent behaviors. In warehouses, the aim will be to improve the autonomy of the robots to better assist the pickers, leveraging the knowledge of the current order being prepared. In supermarket, the shopping carts should learn to properly interact with other carts and people while positioning themselves to better serve its current user.

This year, Jérôme Truc set up a simulated warehouse environment modeled on an actual warehouse from a logistic partner of iFollow. In this environment, he tested and compared several behaviors for a cart robot helping an order picker.

For personal reasons, Jérôme Truc had to resign from his PhD in July 2019.

9. Partnerships and Cooperations

9.1. Regional Initiatives

9.1.1. LUE C-Shift

Program: LUE Impact (Lorraine Université d’Excellence)

Project acronym: C-Shift

Project title: Cobots in the Service of Human activity at work In consistence with the challenges of Industry of the FuTure

Duration: October 2019 - December 2022

Coordinator: Benoit Iung (University of Lorraine)

PI for Inria/Loria: Serena Ivaldi

Abstract:

Le projet IMPACT « C-SHIFT » (Cobots in the Service of Human activity at work In consistence with the challenges of Industry of the FuTure) labélisé LUE (Lorraine Université d’Excellence) en collaboration avec les laboratoires de recherches LORIA, CRAN, CEREFIGE, PErSEUS, DevAH, LGIPM et les centres d’expertise et ressources AIPL-SMART et Ergosim et qui vise à étudier l’impact de la mise en œuvre de dispositifs collaboratifs intelligents tels que les cobots dans le cadre des défis de l’industrie du futur.

9.1.2. LUE Acceptability

Program: LUE PhD program (Lorraine Université d’Excellence)

Project title: elderly-technology interaction: accessibility and acceptability of assistive technology at home

Partners : Inria-Loria and Psychology and neuroscience lab - EA7489 (2LPN)

participants : Jérome Dinet, François Charpillet, Eloïse Zehner

Duration: October 2018 - September 2021

Abstract:

This PhD program is funded by the LUE PhD program, which among other has the objective to strength cooperation with associated institutions or companies supporting one of the six socio-economic challenges, here "Ageing and Health" challenge. This Ph.D. thesis, is aiming:

- at identifying sustainable actions to promote seniors' quality of life, intended to investigate this kind of interaction in terms of accessibility and acceptability that senior citizen experience with technological devices autonomy at home;
- at understanding more of technology use by older people. We have insight in the actual situation on older people's use and acceptance of technology, but locally and segmented, and more descriptive than explanatory. Most attention goes to the role of technology in the home with a particular focus on the interaction between people and assistive robots.

9.1.3. Project Psyphine Hors les Murs

Title: Psyphine Hors les Murs

Program: PEPS blanc 2019 de l'INS2I

Duration: January 2017 - January 2019

Coordinator: LORIA UMR (UMR 7503)

LARSEN member: Amine Boumaza

Psyphine is an interdisciplinary and exploratory project that gathers philosophers, psychologists, ethnologist, and computer scientists. The long term goal of the project is to explore the idea of assignments of intelligence or intentionality. Assuming that our intersubjectivity and our natural tendency to anthropomorphize plays a central role in this process, the project members investigate the elements that drive humans to attribute intelligence to robotic devices. Some of the questions that we aim to answer are: is it possible to give the illusion of cognition and/or intelligence through a technical device? How elaborate must be the control algorithms or "behaviors" of such a device so as to fool the observer? How many degrees of freedom must it have?

Partner institutions: InterPsy (EA 4432), ATILF (UMR 7118), Archives Henri-Poincaré (UMR7117), Inria Bordeaux Sud-Ouest, Loria (UMR7503) and MSH Lorraine (USR3261).

9.2. National Initiatives

9.2.1. ANR : The Flying Co-Worker

Program: ANR

Project acronym: Flying Co-Worker

Project title: Flying Co-Worker

Duration: October 2019 - october 2023

Coordinator: Daniel Sidobre (Laas Toulouse)

PI for Inria: François Charpillet

Abstract: Bringing together the recent progresses in physical and decisional interaction between humans and robots with the control of aerial manipulators, this project addresses the flying coworker, an aerial manipulator robot that act as a teammate of a human worker to transport a long bar or to realise complex tasks. Safety and human-aware robot abilities are at the core of the proposed research to progressively build robots capable to do cooperative handling and to assist a worker by notably delivering objects directly in a safe, efficient, pertinent and acceptable manner. The methodologies developed for ground manipulators cannot be directly used for aerial manipulator systems because of the floating base, of a limited payload, and of strong actuation and energy constraints. From the perception and the interpretation of the human activity, the objective of the project is to build an aerial manipulator capable to plan and control human aware motions to achieve collaborative tasks.

9.3. European Initiatives

9.3.1. FP7 & H2020 Projects

9.3.1.1. RESIBOTS

Title: Robots with animal-like resilience

Program: H2020

Type: ERC

Duration: May 2015 - April 2020

Coordinator: Inria

Inria contact: Jean Baptiste Mouret

Despite over 50 years of research in robotics, most existing robots are far from being as resilient as the simplest animals: they are fragile machines that easily stop functioning in difficult conditions. The goal of this proposal is to radically change this situation by providing the algorithmic foundations for low-cost robots that can autonomously recover from unforeseen damages in a few minutes. It is here contended that trial-and-error learning algorithms provide an alternate approach that does not require diagnostic, nor pre-defined contingency plans. In this project, we will develop and study a novel family of such learning algorithms that make it possible for autonomous robots to quickly discover compensatory behaviors.

9.3.1.2. ANDY

Title: Advancing Anticipatory Behaviors in Dyadic Human-Robot Collaboration

Programme: H2020

Type: ICT RIA (No. 731540)

Duration: January 2017 - December 2020

Coordinator: IIT

PI for Inria: Serena Ivaldi

Recent technological progress permits robots to actively and safely share a common workspace with humans. Europe currently leads the robotic market for safety-certified robots, by enabling robots to react to unintentional contacts. AnDy leverages these technologies and strengthens European leadership by endowing robots with the ability to control physical collaboration through intentional interaction.

To achieve this interaction, AnDy relies on three technological and scientific breakthroughs. First, AnDy will innovate the way of measuring human whole-body motions by developing the wearable AnDySuit, which tracks motions and records forces. Second, AnDy will develop the AnDyModel, which combines ergonomic models with cognitive predictive models of human dynamic behavior in collaborative tasks, which are learned from data acquired with the AnDySuit. Third, AnDy will propose the AnDyControl, an innovative technology for assisting humans through predictive physical control, based on AnDyModel.

By measuring and modeling human whole-body dynamics, AnDy provides robots with an entirely new level of awareness about human intentions and ergonomy. By incorporating this awareness online in the robot's controllers, AnDy paves the way for novel applications of physical human-robot collaboration in manufacturing, health-care, and assisted living.

AnDy will accelerate take-up and deployment in these domains by validating its progress in several realistic scenarios. In the first validation scenario, the robot is an industrial collaborative robot, which tailors its controllers to individual workers to improve ergonomy. In the second scenario, the robot is an assistive exoskeleton which optimizes human comfort by reducing physical stress. In the third validation scenario, the robot is a humanoid, which offers assistance to a human while maintaining the balance of both.

Partners: Italian Institute of Technology (IIT, Italy, coordinator), Josef Stefan Institute (JSI, Slovenia), DLR (Germany), IMK Automotive Gmbh (Germany), XSens (Netherlands), AnyBody Technologies (Denmark)

9.3.2. Collaborations in European Programs, Except FP7 & H2020

9.3.2.1. HEAP

- Program: CHIST-ERA
- Project acronym: HEAP
- Project title: HEAP: Human-Guided Learning and Benchmarking of Robotic Heap Sorting
- Duration: March 2019–Feb. 2022
- Coordinator: Gerhard Neumann (Univ. of Lincoln, UK)
- PI for Inria: Serena Ivaldi
- Other partners: Italian Insitute of Technology (Italy), Technische Universitat Wien (Austria), Idiap Research Institute (Switzerland), Inria
- This project will provide scientific advancements for benchmarking, object recognition, manipulation and human-robot interaction. We focus on sorting a complex, unstructured heap of unknown objects –resembling nuclear waste consisting of a set of broken deformed bodies– as an instance of an extremely complex manipulation task. The consortium aims at building an end-to-end benchmarking framework, which includes rigorous scientific methodology and experimental tools for application in realistic scenarios. Benchmark scenarios will be developed with off-the-shelf manipulators and grippers, allowing to create an affordable setup that can be easily reproduced both physically and in simulation. We will develop benchmark scenarios with varying complexities, i.e., grasping and pushing irregular objects, grasping selected objects from the heap, identifying all object instances and sorting the objects by placing them into corresponding bins. We will provide scanned CAD models of the objects that can be used for 3D printing in order to recreate our benchmark scenarios. Benchmarks with existing grasp planners and manipulation algorithms will be implemented as baseline controllers that are easily exchangeable using ROS. The ability of robots to fully autonomously handle dense clutters or a heap of unknown objects has been very limited due to challenges in scene understanding, grasping, and decision making. Instead, we will rely on semi-autonomous approaches where a human operator can interact with the system (e.g. using tele-operation but not only) and giving high-level commands to complement the autonomous skill execution. The amount of autonomy of our system will be adapted to the complexity of the situation. We will also benchmark our semi-autonomous task execution with different human operators and quantify the gap to the current SOTA in autonomous manipulation. Building on our semi-autonomous control framework, we will develop a manipulation skill learning system that learns from demonstrations and corrections of the human operator and can therefore learn complex manipulations in a data-efficient manner. To improve object recognition and segmentation in cluttered heaps, we will develop new perception algorithms and investigate interactive perception in order to improve the robot's understanding of the scene in terms of object instances, categories and properties.

9.4. International Research Visitors

9.4.1. Visits of International Scientists

This year we had the visit of Professor Sozo Inoue from Kyushu Institute of Technology (https://sozolab.jp) for one week in September. He was accompanied with one PhD student and two Master students, and a Postdoc. The objective was to organise together the collection of a Dataset and propose an international challenge for testing action and activity recognition algorithms.

9.4.1.1. Internships

- Luan Wei (University of Osnabrück, Germany), 5 months (supervisor: Jean-Baptiste Mouret)
- Ivan Bergonzi (University of Roma — La Sapienza, Italy), 5 months (supervisor: Jean-Baptiste Mouret)
- Lorenzo Vianello (University of Roma — La Sapienza, Italy), 6 months (supervisor: Serena Ivaldi)
- Andrea Macrí (University of Roma — La Sapienza, Italy), 5 months (supervisor: Serena Ivaldi)
- Lina Achaji (University Lebanese University – Faculty of Engineering – Tripoli), 3 months (supervision: François Charpillet)
- Niyati Rawal (Rovira i Virgili University & Open University of Catalonia (Spain)), 5 months (supervision: Francis Colas, Serena Ivaldi, Vincent Thomas)
- Yang You (Cranfield University), 5 months (supervision Vincent Thomas, Olivier Buffet, François Charpillet).

9.4.2. PhD students

- Niels Justesen (IT University of Copenhagen), 3 months (supervisor: Jean-Baptiste Mouret)
- Anji Ma (Bejing Institute of Technology), 1 year (supervisor: Serena Ivaldi)
- Moe Matsuki (Kyushu Institute of Technology) 2 weeks (supervisor: François Charpillet).

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events: Organisation

10.1.1.1. General Chair, Scientific Chair

- Conference Chair for the 30th International Conference on Automated Planning and Scheduling (ICAPS 2020), which will take place in Nancy in June 2020 (https://icaps20.icaps-conference.org/) [Olivier Buffet].
- Co-chair and co-organizer with Olivier Simonin the JNRR (National bi-annual conference on Robotics) 2019, in Vittel [François Chapillet]

10.1.1.2. Member of the Organizing Committees

- Conference “Drôles d’objets - Un nouvel art de faire 2020” that will take place in La Rochelle in april 2020 [Amine Boumaza, co-organizer]
- Workshop at the International Conference on Robotics and Automation (ICRA 2019) (*Human movement science for physical human-robot collaboration)* [Pauline Maurice and Serena Ivaldi, co-organizers]
- Local Organization Committee of the 30th International Conference on Automated Planning and Scheduling (ICAPS 2020) [Vincent Thomas]
- Workshop “Women in Robotics V” at the international conference Robotics: Science and Systems (RSS 2019) [Serena Ivaldi]

- Workshop “Tele-operation of Humanoid Robots” at IEEE-RAS International Conference on Humanoid Robots (HUMANOIDS 2019) [Serena Ivaldi]

10.1.2. Scientific Events: Selection

10.1.2.1. Chair of Conference Program Committees

- Program chair of the 2019 IEEE-RAS International Conference on Humanoid Robots (Toronto, Canada) [Serena Ivaldi]
- Co-chair of the track “Evolutionary Machine Learning” at GECCO 2019 (Prague, Czech Republic) [Jean-Baptiste Mouret]

10.1.2.2. Awards Chair of Conference Program Committees

- Awards co-chair of the 12th International Workshop on Human-Friendly Robotics (HFR 2019) [Serena Ivaldi]

10.1.2.3. Member of the Conference Program Committees

- 24th European Conference on Artificial Intelligence (ECAI 2020) [Francis Colas, Vincent Thomas, F. Charpillet]
- 36th International Conference on Machine Learning (ICML 2019) [Olivier Buffet]
- 28th International Joint Conference on Artificial Intelligence (IJCAI 2019) [Olivier Buffet, Vincent Thomas]
- *Journées Francophones sur la Planification, la Décision et l’Apprentissage pour la conduite de systèmes* (JFPDA 2019) [Olivier Buffet, Vincent Thomas]
- 34th AAAI Conference on Artificial Intelligence (AAAI 2020) [Olivier Buffet, F. Charpillet]
- 33th AAAI Conference on Artificial Intelligence (AAAI 2019) [Olivier Buffet, F. Charpillet]
- ALIFE 2019 (European Conference on Artificial Life) [Amine Boumaza, Jean-Baptiste Mouret]
- GECCO 2019 (Genetic and Evolutionary Computation Conference) [Amine Boumaza, Jean-Baptiste Mouret]
- EA 2019 (Artificial Evolution) [Amine Boumaza, Jean-Baptiste Mouret]
- IEEE/RAS International Conference on Robotics and Automation (ICRA 2020) [Pauline Maurice – Associate editor]
- 12th International Workshop on Human-Friendly Robotics (HFR 2019) [Pauline Maurice]
- 27emes Journées Francophones sur les Systèmes Multi-Agents (JFSMA 2019)[François Charpillet]
- 11th International Conference on Agents and Artificial Intelligence (ICAART 2019)[François Charpillet]

10.1.2.4. Reviewer

- Robotics: Science and Systems (RSS 2019) [Francis Colas, Serena Ivaldi]
- IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2019) [Francis Colas, Pauline Maurice, Jean-Baptiste Mouret]
- IEEE International Conference on Robotics and Automation (ICRA 2020) [Pauline Maurice, Jean-Baptiste Mouret]
- IEEE-RAS International Conference on Humanoid Robots (Humanoids 2019) [Francis Colas, Jean-Baptiste Mouret]
- 24th European Conference on Artificial Intelligence (ECAI 2020) [Francis Colas, Vincent Thomas, François Charpillet]
- 36th International Conference on Machine Learning (ICML 2019) [Olivier Buffet, Vincent Thomas]
- 28th International Joint Conference on Artificial Intelligence (IJCAI 2019) [Olivier Buffet, Vincent Thomas]

- *Journées Francophones sur la Planification, la Décision et l'Apprentissage pour la conduite de systèmes* (JFPDA 2019) [Olivier Buffet, Vincent Thomas]
- 34th AAAI Conference on Artificial Intelligence (AAAI 2020) [Olivier Buffet]
- 33th AAAI Conference on Artificial Intelligence (AAAI 2020) [François Charpillet]
- IEEE International Conference on Advanced Robotics ans its Social Impacts (ARSO 2019) [Pauline Maurice]
- Conference on Robot Learning (CoRL 2019) [Jean-Baptiste Mouret]
- ACM WomeENcourage 2019 [Serena Ivaldi]
- 27emes Journées Francophones sur les Systèmes Multi-Agents (JFSMA 2019)[François Charpillet]
- 11th International Conference on Agents and Artificial Intelligence (ICAART 2019)[François Charpillet]

10.1.3. Journal

10.1.3.1. Member of the Editorial Boards

- IEEE Robotics and Automation Letters [Serena Ivaldi – associate editor]
- ACM Transactions on Evolutionary Learning and Optimization [Jean-Baptiste Mouret – associate editor]
- Frontiers in AI and Robotics – review editors [Amine Boumaza, Jean-Baptiste Mouret]

10.1.3.2. Reviewer - Reviewing Activities

- Artificial Intelligence Journal (AIJ) [Olivier Buffet]
- Journal of Artificial Intelligence Research (JAIR) [Olivier Buffet].
- Genetic Programming and Evolvable Machines [Amine Boumaza]
- Robotica [Francis Colas]
- Robotics and Automation Letter [Francis Colas, Jean-Baptiste Mouret]
- Artificial Life [Jean-Baptiste Mouret]
- ACM Transactions on Evolutionary Learning and Optimization (TELO) [Jean-Baptiste Mouret]
- ACM Transactions on Human-Robot Interaction [Pauline Maurice]
- PloS One [Pauline Maurice]
- Paladyn Journal of Behavioral Robotics [Pauline Maurice]
- The Journal on Multimodal User Interfaces [Pauline Maurice]
- Frontiers in Neurorobotics [Serena Ivaldi]
- IEEE Robotics and Automation Magazine [Serena Ivaldi]

10.1.4. Invited Talks

- Keynote at the 10th International Conference on Information, Intelligence, Systems and Applications, Patras (Greece) [Jean-Baptiste Mouret]
- Keynote at the 12th International Workshop on Human-Friendly Robotics (HFR 2019) in Reggio Emilia (Italy) [Serena Ivaldi]
- Invited talk at the Conference on “Novel technological innovations for occupational safety and health” organised by the Polish Central Institute for Labour Protection – National Research Institute (CIOP-PIB), Warsaw (Poland) [Pauline Maurice]
- Invited talk at the workshop on “Closing the Reality Gap in Sim2real Transfer for Robotic Manipulation” at RSS 2019, Freiburg (Germany) [Jean-Baptiste Mouret]
- Invited talk at the CNRS GDR ISIS (Information, Signal, Image et ViSion), special day on robot learning, Paris (France) [Jean-Baptiste Mouret]

- talk at Workshop on “Task-Informed Grasping” at RSS 2019,Freiburg (Germany) [Serena Ivaldi]
- invited talk at the HUMANOIDS 2019 Workshop “Can we build Baymax?”, Toronto (Canada) [Serena Ivaldi]
- invited talk at HUMANOIDS 2019 Workshop on “Humanoid Teleoperation”, Toronto (Canada) [Serena Ivaldi]
- invited talk at the HUMANOIDS 2019 Workshop on “Challenges and solutions for HRI and collaboration”, Toronto (Canada) [Serena Ivaldi]
- invited talk at the IROS 2019 “Cutting Edge Forum on Cognitive architecture for humanoids: where are we in our quest to achieve human-level AI in robotics?”, Macau (China) [Serena Ivaldi]
- invited talk at the IROS 2019 Workshop on “Progress in Ergonomic Physical Human-Robot Collaboration”, Macau (China) [Serena Ivaldi]
- invited talk at the IROS 2019 Workshop on “Open-Ended Learning for Object Perception and Grasping: Current Successes and Future Challenges”, Macau (China) [Serena Ivaldi]

10.1.5. Research Administration

- Serena Ivaldi is member of the scientific council of the Federation Charles Hermite
- Jean-Baptiste Mouret is a member of the “Bureau du Comité des Projets” of Inria Nancy – Grand-Est
- François Charpillet is member of the scientific commitee of the Robotic GDR (All the teams in France contributing to research in Robotics are members of the Groupe de Recherche (GDR) en Robotique, an open national Research Group established by the CNRS).
- François Charpillet is co-leading with Pr Rossignol the SCIARAT plateform of the CPER IT2MP

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Master: Alexis Scheuer, “Introduction à la robotique autonome”, 30h eq. TD, M1 informatique, Univ. Lorraine, France.

Master: Alexis Scheuer, “Vie artificielle”, 22,5h eq. TD, 3ème année, CentraleSupélec, France.

Master: Francis Colas, “Robotique autonome”, 18h eq. TD, M2 “Systèmes Interactifs et Robotiques”, CentraleSupélec, France.

Master: Francis Colas, “Planification de trajectoires”, 12h eq. TD, M2 “Apprentissage, Vision, Robotique”, Univ. Lorraine, France.

Master: Alexis Scheuer, “Modélisation et commande en robotique”, 16h eq. TD, M2 “Apprentissage, Vision, Robotique”, Univ. Lorraine, France.

Master: Francis Colas, “Autonomous Robotics”, 39.5h eq. TD, M1, CentraleSupélec, France.

Master: Pauline Maurice, “Analyse Comportementale”, 10h eq. TD, M2 “Sciences Cognitives”, Univ. Lorraine, France.

Master: Jean-Baptiste Mouret, “Creative automatic design”, 3h, M2, M2 “Management de l’innovation”, Mines de Paris, France

Master: Serena Ivaldi, “Analyse Comportementale”, 16h CM/TD, M2 “Sciences Cognitives”, Univ. Lorraine, France.

Master: Amine Boumaza, “Méta-heuristiques et recherche locale stochastique”, 30h eq. TD, M1 informatique, Univ. Lorraine, France.

Tutorial: Olivier Buffet, “Planification dans l’incertain", 3h CM, CNRS Formation Entreprise.

Tutorial, Jean-Baptiste Mouret, “Evolutionary robotics”, 3h, ACM GECCO 2019 (with S. Doncieux and N. Bredeche, Sorbonne Université)

10.2.2. Supervision

PhD in progress: Adrien Malaisé, "*Capteurs portés dans la robotique collaborative : de l'apprentissage du mouvement à l'acceptabilité de cette technologie*", started in January 2017, Francis Colas (advisor), Serena Ivaldi (co-advisor).

PhD in progress: Yang You, "*Modèles probabilistes pour la collaboration humain-robot*", started in October 2019, Olivier Buffet (advisor), Vincent Thomas (co-advisor)

PhD canceled: Jérôme Truc, "*Apprentissage de comportement et interactions prédictives pour un robot d'assistance en environnement structuré*", started in September 2018, canceled in July 2019, Francis Colas (advisor)

PhD in progress: Rituraj Kaushik, "*Damage recovery by trial and error and multiple simulation priors*", started in October 2016, Jean-Baptiste Mouret (advisor)

PhD in progress: Adam Gaier, "*Surrogate-based illumination for aerodynamics*", started in October 2016, Jean-Baptiste Mouret (Advisor)

PhD in progress: Vladislav Tempez, "*Learning to fly a micro-UAVs in highly confined environments*", started in October 2018, Jean-Baptiste Mouret (advisor), Franck Ruffier (co-advisor, CNRS/Aix-Marseille Université)

PhD in progress: Waldez Azevedo Gomes Junior, "*Intelligent Human-Robot collaboration*", started in October 2018, Jean-Baptiste Mouret (advisor), Serena Ivaldi (co-advisor)

PhD in progress: Yoann Fleytoux, "*Human-guided manipulation learning of irregular objects*", started in April 2019, Jean-Baptiste Mouret (advisor), Serena Ivaldi (co-advisor)

PhD in progress: Luigi Penco, "*Intelligent whole-body tele-operation of humanoid robots*", started in April 2019, Jean-Baptiste Mouret (advisor), Serena Ivaldi (co-advisor)

PhD in progress: Lorenzo Vianello, "*Adaptation in human-robot collaboration*", started in December 2019, Alexis Aubry (advisor, CRAN, Univ. Lorraine), Serena Ivaldi (co-advisor)

PhD in progress : Yassine EL Khadiri, Cifre with Diatelic, "*Machine learning for Ambient Assisted Living (AAL)*", started in June 2017, François Charpillet adviser.

PhD in progress : Eloise Zehnder, "*Elderly-technology interaction: accessibility and acceptability of assistive technology (at) at home*", started October 2018, François Charpillet (advisor), Jérome Dinet (advisor, 2LPN).

PhD in progress : Julien Uzzan, Cifre with PSA, "*navigation of an autonomous vehicle in a complex environment using unsupervised or semi-supervised learning*", started in January 2019, François Charpillet (advisor), François Aioun (co-advisor, PSA).

PhD in progress : Jessica Colombel, "*Analysis of human movement for assistance*", started in Feburary 2019, François Charpillet (advisor) David Daney(advisor, Auctus team, Bordeaux)

PhD in progress : Nicolas Gauville, CIFRE with SAFRAN, "*Coordination of autonomous robots evolving in unstructured and unknown environment for Search and Rescue*", started in May 2019, François Charpillet (advisor), Christophe Guettier (co-adviser, Safran).

10.2.3. Juries

- François Charpillet was a reviewer for the HDR of Antony Fleury (Lille University)
- François Charpillet was a reviewer for the HDR of François Portet (LIG, Grenoble Alpes University)
- Pauline Maurice was an examinator for the PhD of Nolwenn Briquet-Kerestedjian (Univ. Paris-Saclay)
- Jean-Baptiste Mouret was a reviewer for the PhD of Christophe Reymann (INSA Toulouse / LAAS)
- Jean-Baptiste Mouret was a reviewer for the PhD of Daniele Gravina (University of Malta)
- Serena Ivaldi was an examiner for the PhD of Rohan Budhiraja (LAAS)

- François Charpillet was a reviewer for the PhD of Facundo Benavides Olivera (ISAE, Toulouse University & Universidad de la República, Uruguay)
- François Charpillet was a reviewer for the PhD of Mehdi Othmani-Guibourg (Sorbonne University)
- François Charpillet was a reviewer for the PhD of Sandra Castellanos (LIG, Grenoble Alpes University)
- François Charpillet was a examiner for the PhD of Pavan Vasishta(Grenoble Alpes University)

10.3. Popularization

10.3.1. Internal or external Inria responsibilities

- Amine Boumaza is a member of the editorial board of “Interstice”.

10.3.2. Articles and contents

- Pauline Maurice gave an interview for Radio Canada (radio).
- Serena Ivaldi gave an interview to France 3 (TV) during the inauguration of the Creativ’Lab.

10.3.3. Education

- Vincent Thomas gave a tutorial on path planning for teachers during “journées ISN-EPI 2019” (Nancy, France).

10.3.4. Interventions

- Public workshop on robot programming with Thymio at “Fête de la Science” [Alexis Scheuer, Olivier Buffet, Jessica Colombel, Francis Colas, Yassine El Khadiri, Vincent Thomas, Yang You]
- Pauline Maurice gave a talk at the Forum Sciences Cognitives 2019 in Université de Lorraine.
- Jean-Baptiste Mouret was invited to debate about artificial intelligence at “La Tronche en Biais”, an online popularization channel (27k view for this video)
- Eloïse Dalin and Pierre Desreumaux participated to a “Café des Sciences” artificial intelligence and robotics at the “Cité des Sciences et de l’Industrie” (Paris)
- Serena Ivaldi participated to the “Fête de la Science” as tutor for school children in Inria/Loria

11. Bibliography

Major publications by the team in recent years

[1] A. Cully, J. Clune, D. Tarapore, J.-B. Mouret.*Robots that can adapt like animals*, in "Nature", May 2015, vol. 521, n^o 7553, p. 503-507 [*DOI :* 10.1038/NATURE14422], https://hal.archives-ouvertes.fr/hal-01158243

[2] J. S. Dibangoye, C. Amato, O. Buffet, F. Charpillet.*Optimally Solving Dec-POMDPs as Continuous-State MDPs*, in "Journal of Artificial Intelligence Research", February 2016, vol. 55, p. 443-497 [*DOI :* 10.1613/JAIR.4623], https://hal.inria.fr/hal-01279444

Publications of the year

Articles in International Peer-Reviewed Journal

[3] K. Chatzilygeroudis, V. Vassiliades, F. Stulp, S. Calinon, J.-B. Mouret.*A survey on policy search algorithms for learning robot controllers in a handful of trials*, in "IEEE Transactions on Robotics", 2020, forthcoming, https://hal.inria.fr/hal-02393432

[4] M. Daher, J. A. Hage, M. El Badaoui El Najjar, A. Diab, K. Mohamad, F. Charpillet. *Toward High Integrity Personal Localization System Based on Informational Formalism*, in "IEEE Transactions on Instrumentation and Measurement", November 2019, vol. 68, n^{o} 11, p. 4590-4599 [*DOI :* 10.1109/TIM.2018.2886976], https://hal.inria.fr/hal-02427488

[5] D. Howard, A. E. Eiben, D. F. Kennedy, J.-B. Mouret, P. Valencia, D. Winkler. *Evolving embodied intelligence from materials to machines*, in "Nature Machine Intelligence", January 2019, vol. 1, n^{o} 1, p. 12-19 [*DOI :* 10.1038/s42256-018-0009-9], https://hal.inria.fr/hal-01986599

[6] A. Malaisé, P. Maurice, F. Colas, S. Ivaldi. *Activity Recognition for Ergonomics Assessment of Industrial Tasks with Automatic Feature Selection*, in "IEEE Robotics and Automation Letters", January 2019, vol. 4, n^{o} 2, p. 1132-1139 [*DOI :* 10.1109/LRA.2019.2894389], https://hal.archives-ouvertes.fr/hal-01985013

[7] P. Maurice, J. Camernik, D. Gorjan, B. Schirrmeister, J. Bornmann, L. Tagliapietra, C. Latella, D. Pucci, L. Fritzsche, S. Ivaldi, J. Babič. *Objective and Subjective Effects of a Passive Exoskeleton on Overhead Work*, in "IEEE Transactions on Neural Systems and Rehabilitation Engineering", 2019, forthcoming [*DOI :* 10.1109/TNSRE.2019.2945368], https://hal.archives-ouvertes.fr/hal-02301922

[8] P. Maurice, A. Malaisé, C. Amiot, N. Paris, G.-J. Richard, O. Rochel, S. Ivaldi. *Human Movement and Ergonomics: an Industry-Oriented Dataset for Collaborative Robotics*, in "The International Journal of Robotics Research", 2019, forthcoming [*DOI :* 10.1177/0278364919882089], https://hal.archives-ouvertes.fr/hal-02289107

[9] P. Maurice, V. Padois, Y. Measson, P. Bidaud. *Assessing and improving human movements using sensitivity analysis and digital human simulation*, in "International Journal of Computer Integrated Manufacturing", 2019, forthcoming [*DOI :* 10.1080/0951192X.2019.1599432], https://hal.archives-ouvertes.fr/hal-01221647

[10] Q. V. Nguyen, F. Colas, E. Vincent, F. Charpillet. *Motion planning for robot audition*, in "Autonomous Robots", December 2019, vol. 43, n^{o} 8, p. 2293-2317 [*DOI :* 10.1007/s10514-019-09880-1], https://hal.inria.fr/hal-02188342

[11] L. Penco, N. Scianca, V. Modugno, L. Lanari, G. Oriolo, S. Ivaldi. *A Multi-Mode Teleoperation Framework for Humanoid Loco-Manipulation*, in "IEEE Robotics and Automation Magazine", December 2019, https://hal.inria.fr/hal-02291907

International Conferences with Proceedings

[12] A. Boumaza. *Introducing Weighted Intermediate Recombination in On-line Collective Robotics, the (μ/μ W , 1)-On-line EEA*, in "Applications of Evolutionary Computation", Leipzig, Germany, April 2019, https://hal.inria.fr/hal-02185694

[13] A. Boumaza. *When Mating Improves On-line Collective Robotics*, in "GECCO'19 Proceedings of the 2019 Genetic and Evolutionary Computation Conference", Prague, Czech Republic, July 2019, https://hal.inria.fr/hal-02185645

[14] W. GOMES, V. RADHAKRISHNAN, L. PENCO, V. MODUGNO, J.-B. MOURET, S. IVALDI.*Humanoid Whole-Body Movement Optimization from Retargeted Human Motions*, in "IEEE/RAS Int. Conf. on Humanoid Robots", Toronto, Canada, August 2019, https://hal.archives-ouvertes.fr/hal-02290473

National Conferences with Proceeding

[15] Y. EL-KHADIRI, G. CORONA, C. ROSE, F. CHARPILLET.*Une Approche Bayésienne pour la reconnaissance des périodes de sommeil à l'aide de capteurs de mouvement*, in "Journées d'Etude sur la TéléSanté", Paris, France, Sorbonne Universités, May 2019, https://hal.archives-ouvertes.fr/hal-02161066

[16] *Best Paper*
N. GAUVILLE, F. CHARPILLET.*Exploration et couverture par stigmergie d'un environnement inconnu avec une flotte de robots autonomes réactifs*, in "JFSMA 2019 - 27emes Journées Francophones sur les Systèmes Multi-Agents", Toulouse, France, Cépaduès 2019, ISBN 9782364937192, July 2019, https://hal.inria.fr/hal-02195812.

[17] N. GAUVILLE, N. FATÈS, I. MARCOVICI.*Diagnostic décentralisé à l'aide d'automates cellulaires*, in "JFSMA 2019 - 27emes Journées Francophones sur les Systèmes Multi-Agents", Toulouse, France, Cépaduès, July 2019, ISBN 9782364937192, https://hal.inria.fr/hal-02195799

Conferences without Proceedings

[18] E. DALIN, P. DESREUMAUX, J.-B. MOURET.*Learning and adapting quadruped gaits with the "Intelligent Trial & Error" algorithm*, in "IEEE ICRA Workshop on "Learning legged locomotion"", Montreal, Canada, 2019, https://hal.inria.fr/hal-02084619

[19] P. MAURICE, J. CAMERNIK, D. GORJAN, B. SCHIRRMEISTER, J. BORNMANN, L. TAGLIAPIETRA, C. LATELLA, D. PUCCI, L. FRITZSCHE, S. IVALDI, J. BABIČ.*Evaluation of PAEXO, a novel passive exoskeleton for overhead work*, in "44ème Congrès de la Société de Biomécanique", Poitiers, France, October 2019, https://hal.archives-ouvertes.fr/hal-02348588

[20] V. THOMAS, G. HUTIN, O. BUFFET.*Planification Monte Carlo orientée information*, in "JFPDA 2019 - Journées Francophones sur la Planification, la Décision et l'Apprentissage pour la conduite de systèmes", Toulouse, France, July 2019, https://hal.archives-ouvertes.fr/hal-02350573

Scientific Books (or Scientific Book chapters)

[21] P. MAURICE, V. PADOIS, Y. MEASSON, P. BIDAUD.*Digital Human Modeling for Collaborative Robotics*, in "DHM and Posturography", August 2019, https://hal.archives-ouvertes.fr/hal-02389726

Other Publications

[22] O. DERMY, S. BOUCENNA, A. PITTI, A. BLANCHARD.*Developmental Learning of Audio-Visual Integration From Facial Gestures Of a Social Robot*, July 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-02185423

References in notes

[23] M. ANDRIES, F. CHARPILLET.*Multi-robot taboo-list exploration of unknown structured environments*, in "2015 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2015)", Hamburg, Germany, September 2015, https://hal.inria.fr/hal-01196008

[24] M. ARAYA-LÓPEZ, O. BUFFET, V. THOMAS, F. CHARPILLET.*A POMDP Extension with Belief-dependent Rewards*, in "Advances in Neural Information Processing Systems (NIPS)", Vancouver, Canada, MIT Press, December 2010, https://hal.inria.fr/inria-00535560

[25] T. BARFOOT, J. KELLY, G. SIBLEY.*Special Issue on Long-Term Autonomy*, in "The International Journal of Robotics Research", 2013, vol. 32, n^o 14, p. 1609–1610

[26] A. DEL PRETE, F. NORI, G. METTA, L. NATALE.*Prioritized Motion-Force Control of Constrained Fully-Actuated Robots: "Task Space Inverse Dynamics"*, in "Robotics and Autonomous Systems", 2014, http://dx.doi.org/10.1016/j.robot.2014.08.016

[27] A. DIB, F. CHARPILLET.*Pose Estimation For A Partially Observable Human Body From RGB-D Cameras*, in "IEEE/RJS International Conference on Intelligent Robots and Systems (IROS)", Hamburg, Germany, September 2015, 8, https://hal.inria.fr/hal-01203638

[28] A. FANSI TCHANGO, V. THOMAS, O. BUFFET, F. FLACHER, A. DUTECH.*Simultaneous Tracking and Activity Recognition (STAR) using Advanced Agent-Based Behavioral Simulations*, in "ECAI - Proceedings of the Twenty-first European Conference on Artificial Intelligence", Pragues, Czech Republic, August 2014, https://hal.inria.fr/hal-01073424

[29] I. FERNÁNDEZ PÉREZ, A. BOUMAZA, F. CHARPILLET.*Comparison of Selection Methods in On-line Distributed Evolutionary Robotics*, in "ALIFE 14: The fourteenth international conference on the synthesis and simulation of living systems", New York, United States, Artificial Life 14, July 2014 [*DOI :* 10.7551/978-0-262-32621-6-CH046], https://hal.inria.fr/hal-01091119

[30] U. FRESE.*Interview: Is SLAM Solved?*, in "KI - Künstliche Intelligenz", 2010, vol. 24, n^o 3, p. 255-257, http://dx.doi.org/10.1007/s13218-010-0047-x

[31] A. KARAMI, L. JEANPIERRE, A. MOUADDIB.*Partially Observable Markov Decision Process for Managing Robot Collaboration with Human*, in "2009 21st IEEE International Conference on Tools with Artificial Intelligence", 2009, p. 518-521

[32] J. KOBER, J. A. BAGNELL, J. PETERS.*Reinforcement Learning in Robotics: A Survey*, in "The International Journal of Robotics Research", August 2013

[33] S. KOOS, A. CULLY, J.-B. MOURET.*Fast damage recovery in robotics with the t-resilience algorithm*, in "The International Journal of Robotics Research", 2013, vol. 32, n^o 14, p. 1700–1723

[34] F. POMERLEAU, P. KRÜSI, F. COLAS, P. FURGALE, R. SIEGWART.*Long-term 3D map maintenance in dynamic environments*, in "Robotics and Automation (ICRA), 2014 IEEE International Conference on", IEEE, 2014, p. 3712–3719

[35] SPARC.*Robotics 2020 Multi-Annual Roadmap*, 2014, http://www.eu-robotics.net/ppp/objectives-of-our-topic-groups/

[36] J. SHAH, J. WIKEN, B. WILLIAMS, C. BREAZEAL.*Improved human-robot team performance using Chaski, A human-inspired plan execution system*, in "ACM/IEEE International Conference on Human-Robot Interaction (HRI)", 2011, p. 29-36

[37] O. SIMONIN, T. HURAUX, F. CHARPILLET.*Interactive Surface for Bio-inspired Robotics, Re-examining Foraging Models*, in "23rd IEEE International Conference on Tools with Artificial Intelligence (ICTAI)", Boca Raton, United States, IEEE, November 2011, https://hal.inria.fr/inria-00617155

[38] N. STEFANOV, A. PEER, M. BUSS.*Role determination in human-human interaction*, in "3rd Joint EuroHaptics Conf. and World Haptics", 2009, p. 51-56

[39] R. S. SUTTON, A. G. BARTO.*Introduction to Reinforcement Learning*, MIT Press, 1998

[40] A. TAPUS, M. MATARIĆ, B. SCASSELLATI.*The grand challenges in Socially Assistive Robotics*, in "IEEE Robotics and Automation Magazine - Special Issue on Grand challenges in Robotics", 2007, vol. 14, n^{o} 1, p. 1-7

[41] D. WILSON, C. ATKESON.*Simultaneous Tracking and Activity Recognition (STAR) Using Many Anonymous, Binary Sensors*, in "Pervasive Computing", H.-W. GELLERSEN, R. WANT, A. SCHMIDT (editors), Lecture Notes in Computer Science, Springer Berlin Heidelberg, 2005, vol. 3468, p. 62-79, http://dx.doi.org/10.1007/11428572_5

[42] G. WOLBRING, S. YUMAKULOV.*Social Robots: Views of Staff of a Disability Service Organization*, in "International Journal of Social Robotics", 2014, vol. 6, n^{o} 3, p. 457-468

Team MAGRIT

Visual Augmentation of Complex Environments

Inria teams are typically groups of researchers working on the definition of a common project, and objectives, with the goal to arrive at the creation of a project-team. Such project-teams may include other partners (universities or research institutions).

RESEARCH CENTER
Nancy - Grand Est

THEME
Vision, perception and multimedia interpretation

Table of contents

Team MAGRIT

Creation of the Team: 2019 January 01

Keywords:

Computer Science and Digital Science:

A5.3. - Image processing and analysis
A5.4. - Computer vision
A5.4.1. - Object recognition
A5.4.5. - Object tracking and motion analysis
A5.4.6. - Object localization
A5.6. - Virtual reality, augmented reality
A5.10.2. - Perception

Other Research Topics and Application Domains:

B2.6. - Biological and medical imaging
B5.9. - Industrial maintenance
B9.5.3. - Physics

1. Team, Visitors, External Collaborators

Research Scientists

Marie-Odile Berger [Team leader, Inria, Senior Researcher, HDR]
Erwan Kerrien [Inria, Researcher, HDR]

Faculty Members

Fabien Pierre [Univ de Lorraine, Associate Professor]
Gilles Simon [Univ de Lorraine, Associate Professor, HDR]
Frédéric Sur [Univ de Lorraine, Professor, HDR]
Pierre-Frédéric Villard [Univ de Lorraine, Associate Professor]
Brigitte Wrobel-Dautcourt [Univ de Lorraine, Associate Professor]

Technical Staff

Thomas Mangin [Univ de Lorraine, Engineer, from Mar 2019]

PhD Students

Jaime Garcia Guevara [Inria, PhD Student, co-supervision with MIMESIS]
Vincent Gaudilliere [Inria, PhD Student]
Daryna Panicheva [Univ de Lorraine, PhD Student]
Raffaela Trivisonne [Inria, PhD Student, co-supervision with MIMESIS]
Matthieu Zins [Inria, PhD Student, from Oct 2019]

2. Overall Objectives

2.1. Augmented Reality

The basic concept of Augmented Reality (AR) is to place information correctly registered with the environment into the user's perception. What makes AR stand out is that this new technology offers the potential for big changes in many application fields such as industrial maintenance, creative technologies, image guided medical gestures, entertainment...

Augmented reality technologies have made major advances in recent years, both in terms of capability, mobile development and integration into current mobile devices. Most applications are dedicated to multimedia and entertainment, games, lifestyle and healthcare and use rough localization information provided by the sensors of the mobile phones. Cutting-edge augmented reality applications which take place in complex environments and require high accuracy in augmentation are less prevalent. There are indeed still technological barriers that prevent applications from reaching the robustness and the accuracy required by such applications.

The aim of the MAGRIT project is to develop vision-based methods which allow significant progress of AR technologies in terms of ease of implementation, reliability and robustness. An expected consequence is the widening of the current application field of AR.

The team is active in both medical and classical applications of augmented reality for which accurate integration of the virtual objects within the scene is essential. Key requirements of AR systems are the availability of registration techniques, both rigid and elastic, that allow the virtual objects to be correctly aligned with the environment, as well as means to build 3D models which are appropriate for pose computation and for handling interactions between the virtual objects and the real scene. Considering the common needs for tracking, navigation, advanced modeling and visualization technologies in both medical and industrial applications, the team focuses on three main objectives: matching, localization and modeling. Methods are developed with a view to meet the expected robustness and accuracy over time and to provide the user with a realistic perception of the augmented scene, while satisfying the real-time achievements required by these procedures.

3. Research Program

3.1. Matching and 3D tracking

One of the most basic problems currently limiting AR applications is the registration problem. The objects in the real and virtual worlds must be properly aligned with respect to each other, or the illusion that the two worlds coexist will be compromised.

As a large number of potential AR applications are interactive, real time pose computation is required. Although the registration problem has received a lot of attention in the computer vision community, the problem of real-time registration is still far from being a solved problem, especially for unstructured environments. Ideally, an AR system should work in all environments, without the need to prepare the scene ahead of time, independently of the variations in experimental conditions (lighting, weather condition,...)

For several years, the MAGRIT project has been aiming at developing on-line and marker-less methods for camera pose computation. The main difficulty with on-line tracking is to ensure robustness of the process over time. For off-line processes, robustness is achieved by using spatial and temporal coherence of the considered sequence through move-matching techniques. To get robust open-loop systems, we have investigated various methods, ranging from statistical methods to the use of hybrid camera/sensor systems. Many of these methods are dedicated to piecewise-planar scenes and combine the advantage of move-matching methods and model-based methods. In order to reduce statistical fluctuations in viewpoint computation, which lead to unpleasant jittering or sliding effects, we have also developed model selection techniques which allow us to noticeably improve the visual impression and to reduce drift over time. Another line of research which has been considered in the team to improve the reliability and the robustness of pose algorithms is to combine the camera with another form of sensor in order to compensate for the shortcomings of each technology.

The success of pose computation over time largely depends on the quality of the matching at the initialization stage. Indeed, the current image may be very different from the appearances described in the model both on the geometrical and the photometric sides. Research is thus conducted in the team on the use of probabilistic methods to establish robust correspondences of features. The use of *a contrario* methods has been investigated to achieve this aim [7]. We especially addressed the complex case of matching in scenes with repeated patterns which are common in urban scenes. We are also investigating the problem of matching images taken from very different viewpoints which is central for the re-localization issue in AR. Within the context of a scene model acquired with structure-from-motion techniques, we are currently investigating the use of viewpoint simulation in order to allow successful pose computation even if the considered image is far from the positions used to build the model [15].

Recently, the issue of tracking deformable objects has gained importance in the team. This topic is mainly addressed in the context of medical applications through the design of bio-mechanical models guided by visual features [2]. We have successfully investigated the use of such models in laparoscopy, with a vascularized model of the liver and with a hyper-elastic model for tongue tracking in ultrasound images. However, these results have been obtained so far in relatively controlled environments, with non-pathological cases. When clinical routine applications are to be considered, many parameters and considerations need to be taken into account. Among the problems that need to be addressed are more realistic model representations, the specification of the range of physical parameters and the need to enforce the robustness of the tracking with respect to outliers, which are common in the interventional context.

3.2. Image-based Modeling

Modeling the scene is a fundamental issue in AR for many reasons. First, pose computation algorithms often use a model of the scene or at least some 3D knowledge on the scene. Second, effective AR systems require a model of the scene to support interactions between the virtual and the real objects such as occlusions, lighting reflections, contacts... in real-time. Unlike pose computation which has to be performed in a sequential way, scene modeling can be considered as an off-line or an on-line problem depending on the requirements of the targeted application. Interactive in-situ modeling techniques have thus been developed with the aim to enable the user to define what is relevant at the time the model is being built during the application. On the other hand, we also proposed off-line multimodal techniques, mainly dedicated to AR medical applications, with the aim of obtaining realistic and possibly dynamic models of organs suitable for real-time simulation [3].

In-situ modeling

In-situ modeling allows a user to directly build a 3D model of his/her surrounding environment and verify the geometry against the physical world in real-time. This is of particular interest when using AR in unprepared environments or building scenes that either have an ephemeral existence (e.g., a film set) or cannot be accessed frequently (e.g., a nuclear power plant). We have especially investigated two systems, one based on the image content only and the other based on multiple data coming from different sensors (camera, inertial measurement unit, laser rangefinder). Both systems use the camera-mouse principle [34] (i.e., interactions are performed by aiming at the scene through a video camera) and both systems have been designed to acquire polygonal textured models, which are particularly useful for camera tracking and object insertion in AR.

Multimodal modeling for real-time simulation

With respect to classical AR applications, AR in medical context differs in the nature and the size of the data which are available: a large amount of multimodal data is acquired on the patient or possibly on the operating room through sensing technologies or various image acquisitions [32]. The challenge is to analyze these data, to extract interesting features, to fuse and to visualize this information in a proper way. Within the MAGRIT team, we address several key problems related to medical augmented environments. Being able to acquire multimodal data which are temporally synchronized and spatially registered is the first difficulty we face when considering medical AR. Another key requirement of AR medical systems is the availability of 3D (+t) models of the organ/patient built from images, to be overlaid onto the users' view of the environment.

Methods for multimodal modeling are strongly dependent on the imaging modalities and the organ specificities. We thus only address a restricted number of medical applications –interventional neuro-radiology, laparoscopic surgery– for which we have a strong expertise and close relationships with motivated clinicians. In these applications, our aim is to produce realistic models and then realistic simulations of the patient to be used for the training of surgeons or the re-education of patients.

One of our main applications is about neuroradiology. For the last 20 years, we have been working in close collaboration with the neuroradiology laboratory (CHRU-University Hospital of Nancy) and GE Healthcare. As several imaging modalities are now available in an intraoperative context (2D and 3D angiography, MRI, ...), our aim is to develop a multi-modality framework to assist therapeutic decision and treatment.

We have mainly been interested in the effective use of a multimodality framework in the treatment of arteriovenous malformations (AVM) and aneurysms in the context of interventional neuroradiology. The goal of interventional gestures is to guide endoscopic tools towards the pathology with the aim to perform embolization of the AVM or to fill the aneurysmal cavity by placing coils. We have proposed and developed multimodality and augmented reality tools which make various image modalities (2D and 3D angiography, fluoroscopic images, MRI, ...) cooperate in order to assist physicians in clinical routine. One of the successes of this collaboration is the implementation of the concept of *augmented fluoroscopy*, which helps the surgeon to guide endoscopic tools towards the pathology. Lately, in cooperation with the team MIMESIS, we have proposed new methods for implicit modeling of the vasculature with the aim of obtaining near real-time simulation of the coil deployment in the aneurysm [3]. These works open the way towards near real-time patient-based simulations of interventional gestures both for training and for planning.

3.3. Parameter estimation

Many problems in computer vision or image analysis can be formulated in terms of parameter estimation from image-based measurements. This is the case of many problems addressed in the team such as pose computation or image-guided estimation of 3D deformable models. Often traditional robust techniques which take into account the covariance on the measurements are sufficient to achieve reliable parameter estimation. However, depending on their number, their spatial distribution and the uncertainty on these measurements, some problems are very sensitive to noise and there is a considerable interest in considering how parameter estimation could be improved if additional information on the noise were available. Another common problem in our field of research is the need to estimate constitutive parameters of the models, such as (bio)-mechanical parameters for instance. Direct measurement methods are destructive, and elaborating image-based methods is thus highly desirable. Besides designing appropriate estimation algorithms, a fundamental question is to understand what group of parameters under study can be reliably estimated from a given experimental setup.

This line of research is relatively new in the team. One of the challenges is to improve image-based parameter estimation techniques considering sensor noise and specific image formation models. In a collaboration with the Pascal Institute (Clermont Ferrand), metrological performance enhancement for experimental solid mechanics has been addressed through the development of dedicated signal processing methods [6]. In the medical field, specific methods based on an adaptive evolutionary optimization strategy have been designed for estimating respiratory parameters [8]. In the context of designing realistic simulators for neuroradiology, we are now considering how parameters involved in the simulation could be adapted to fit real images.

4. Application Domains

4.1. Augmented reality

We have a significant experience in AR that allowed good progress in building usable, reliable and robust AR systems. Our contributions cover the entire process of AR: matching, pose initialization, 3D tracking, in-situ modeling, handling interaction between real and virtual objects....

4.2. Medical Imaging

For 20 years, we have been working in close collaboration with University Hospital of Nancy and GE Healthcare in interventional neuroradiology. Our common aim is to develop a multimodality framework to assist therapeutic decisions and interventional gestures. Contributions of the team focus on the development of AR tools for neuro-navigation as well as the development of simulation tools for training or planning.

Laparoscopic surgery is another field of interest with the development of methods for tracking deformable organs based on bio-mechanical models. Some of these projects are developed in collaboration with the MIMESIS project team.

4.3. Experimental mechanics

In experimental solid mechanics, an important problem is to characterize properties of specimens subject to mechanical constraints, which makes it necessary to measure tiny strains. Contactless measurement techniques have emerged in the last few years and are spreading quickly. They are mainly based on images of the surface of the specimen on which a regular grid or a random speckle has been deposited. We are engaged since June 2012 in a transdisciplinary collaboration with Institut Pascal (Clermont-Ferrand Université). The aim is to characterize the metrological performances of these techniques limited by, e.g., the sensor noise, and to improve them by several dedicated image processing tools.

5. Highlights of the Year

5.1. Highlights of the Year

Two patents have been filed during this year: [28] relates to computational photomechanics and [27] relates to localization from objects.

6. New Software and Platforms

6.1. PoLAR

Portable Library for Augmented Reality

FUNCTIONAL DESCRIPTION: PoLAR (Portable Library for Augmented Reality) is a framework which aims to help creating graphical applications for augmented reality, image visualization and medical imaging. PoLAR was designed to offer powerful visualization functionalities without the need to be a specialist in Computer Graphics. The framework provides an API to state-of-the-art libraries: Qt to build GUIs and OpenSceneGraph for high-end visualization, for researchers and engineers with a background in Computer Vision to be able to create beautiful AR applications, with little programming effort. The framework is written in C++ and published under the GNU GPL license

- Contact: Erwan Kerrien
- URL: http://polar.inria.fr

6.2. Fast>VP

KEYWORDS: Vanishing points - Image rectification

FUNCTIONAL DESCRIPTION: Fast>VP is a fast and effective tool to detect vanishing points in uncalibrated images of urban or indoor scenes.

This tool also allows automatic rectification of the vertical planes in the scene, namely generating images where these planes appear as if they were observed from a fronto-parallel view.

It is the Matlab implementation of the algorithm described in [5].

- Contact: Gilles Simon
- URL: https://members.loria.fr/GSimon/fastvp/

6.3. NoLoDuDoCT

A non-local dual-domain cartoon and texture decomposition

KEYWORDS: Image analysis - Cartoon and texture decomposition

FUNCTIONAL DESCRIPTION: This is an algorithm decomposing images into cartoon and texture components. Spectrum components of textures are detected on the basis of a statistical hypothesis test, the null hypothesis modeling a purely cartoon patch. Statistics are estimated in a non-local way.

- Contact: Frédéric Sur
- Publication: A non-local dual-domain approach to cartoon and texture decomposition
- URL: https://members.loria.fr/FSur/software/NoLoDuDoCT/

6.4. TheGridMethod

The grid method toolbox

KEYWORD: Experimental mechanics

FUNCTIONAL DESCRIPTION: This Matlab toolbox implements several efficient and state-of-the art algorithms to estimate displacement and strain fields from grid images deposited on the surface of a specimen submitted to mechanical testing.

NEWS OF THE YEAR: Informal contacts told us that this library is used in academia and industry.

- Contact: Frédéric Sur
- Publication: The grid method for in-plane displacement and strain measurement: a review and analysis
- URL: http://www.thegridmethod.net/

6.5. BSpeckleRender

A Boolean model for deformed speckle rendering

KEYWORDS: Boolean model - Monte Carlo estimation - Experimental mechanics - Displacement fields

FUNCTIONAL DESCRIPTION: This library implements a new method for synthesizing speckle images deformed by an arbitrary deformation field set by the user. Such images are very useful for assessing the different methods based on digital image correlation (DIC) for estimating displacement fields in experimental mechanics. Since the deformations are very small, it is necessary to ensure that no additional bias is introduced by the image synthesis algorithm. The proposed method is based on the Monte Carlo evaluation of images generated by a Boolean model.

- Contact: Frédéric Sur
- Publication: Rendering Deformed Speckle Images with a Boolean Model
- URL: https://members.loria.fr/FSur/software/BSpeckleRender/

7. New Results

7.1. Matching and localization

Participants: Marie-Odile Berger, Vincent Gaudilliere, Gilles Simon, Frédéric Sur, Matthieu Zins.

7.1.1. View synthesis for efficient and accurate pose computation

Estimating the pose of a camera from a scene model is a challenging problem when the camera is in a position not covered by the views used to build the model, because feature matching is difficult. Several viewpoint simulation techniques have been recently proposed in this context. They generally come with a high computational cost, are limited to specific scenes such as urban environments or object-centred scenes, or need an initial pose guess. A new method based on viewpoint simulation is presented in [15]. In this article, we show that view synthesis dramatically improves pose computation and that both the synthesis process and pose computation can be done in a very efficient way. Two major problems are especially addressed: the positioning of the virtual viewpoints with respect to the scene, and the synthesis of geometrically consistent patches. Experiments show that patch synthesis dramatically improves the accuracy of the pose in case of difficult registration, with a limited computational cost.

7.1.2. Localization from objects

We are interested in AR applications which take place in man-made GPS-denied environments, such as industrial or indoor scenes. In such environments, relocalization may fail due to repeated patterns and large changes in appearance which occur even for small changes in viewpoint. During this year, we have investigated a new method for relocalization which operates at the level of objects and takes advantage of the impressive progress realized in object detection. Recent works have opened the way towards object oriented reconstruction from elliptic approximation of objects detected in images. We have gone beyond that and have proposed a new method for pose computation based on ellipse/ellipsoid correspondences. In [18], we have proved that a closed form estimate of the translation can be uniquely inferred from the rotation matrix of the pose. When two or more correspondences are available, the rotation matrix is deduced through an optimization problem with three degrees of freedom. However, the pose cannot be uniquely computed from one correspondence. In [19], we consider the practical common case where an initial guess of the rotation matrix of the pose is known, for instance with an inertial sensor or from the estimation of orthogonal vanishing points [10]. The translation is recovered as in [18], [24]. We proved the effectiveness of the method on real scenes from a set of object detections generated by YOLO [33]. Globally, considering pose at the level of objects allows us to avoid common failures due to repeated structures. In addition, due to the small combinatorics induced by object correspondences, our method is well suited to fast rough localization even in large environments.

A patent was filed on this method in May 2019 [27]. An Inria technological transfer action (ATT) on the subject of object based localization will start in January 2020 with the aim to produce a demonstrator for industrial maintenance in complex environments.

7.2. Handling non-rigid deformations

Participants: Marie-Odile Berger, Jaime Garcia Guevara, Erwan Kerrien, Daryna Panicheva, Raffaella Trivisonne, Pierre-Frédéric Villard.

7.2.1. Compliance-based non rigid registration

Within J. Guevara's PhD thesis, we are investigating non rigid registration methods which exploit the matching of the vascular trees and are able to cope with large deformations of the organ. This year, we have developed a matching method which is entirely based on the mechanical properties of the organ. We thus avoid tedious parameter tuning which is required by many methods and instead use parameters whose values are known or can be measured. Our method makes use of an advanced biomechanical model which handles heterogeneities and anisotropy due to vasculature. The main originality of the method lies in the definition of a better and novel metric for generating improved graph-matching hypotheses, based on the notion of compliance, the inverse of stiffness. This method reduces the computation time by predicting first the most plausible matching hypotheses on a mechanical basis and reduces the sensitivity on the search space parameters. These contributions improve the registration quality and meet intra-operative timing constraints. Experiments have been conducted on ten realistic synthetic datasets and two real porcine datasets which where automatically segmented. This work was recently accepted in the journal *Annals of Biomedical Engineering* [9], [11].

7.2.2. Individual-specific heart valve modeling

Recent works on computer-based models of mitral valve behavior rely on manual extraction of the complex valve geometry, which is tedious and requires a high level of expertise. On the contrary, in the context of D. Panicheva's PhD thesis, we are investigating methods to segment the chordae with little human supervision which produce mechanically-coherent simulations of the mitral valve.

Valve chordae are generalized cylinders: Instead of being limited to a line, the central axis is a continuous curve; instead of a constant radius, the radius varies along the axis. Most of the time, chordae sections are flattened ellipses and classical model-based methods commonly used for vessel enhancement or vessel segmentation fail. We have exploited the fact that there are no other generalized cylinders than the chordae in the CT scan and we have proposed a topology-based method for chordae extraction. This approach is flexible and only requires the knowledge of an upper bound of the maximum radius of the chordae. The method has been tested on three CT scans. Overall, non-chordae structures are correctly identified and detected chordae ending points match up with actual chordae attachment points [21].

We then worked on evaluating the effectiveness of our approach. The valve behavior was simulated with a biomechanical framework based on the Finite Element Method. A structural model with no fluid-structure interaction was used. Physiological behavior was simulated by mechanical forces such as blood pressure, contact forces and tension forces applied from chordae tensions. The chordae segmentation was validated by comparing the simulation results to those obtained with manually segmented chordae [22].

7.2.3. Image-based biomechanical simulation of the diaphragm during mechanical ventilation

When intensive care patients are subjected to mechanical ventilation, the ventilator causes damage to the muscles that govern the normal breathing, leading to Ventilator Induced Diaphragmatic Dysfunction (VIDD). The INVIVE project aims to study the mechanics of respiration through numerical simulation in order to learn more about the onset of VIDD. We have worked during this year on how to compute solutions of the static linear elasticity equation using last year's work on the diaphragm geometry [26]. Since obtaining an analytical formulation of the boundary conditions in 3D is complex, we have worked on adapting our method to implicit geometries built from 2D data of the diaphragm. The idea is to have an analytical formulation of both the geometry and the boundary conditions to validate our radial basis framework. It is based on points belonging to a cross-section that has been chosen in the middle of the diaphragm. Points are gathered in groups inside rectangles based on a K-means classification. Rectangle dimensions are set so as to ensure cross-coverage. Curve patches are then computed for each rectangle using radial basis functions. A list of local curves is obtained from both the thoracic and abdomen zones and by combining them it is possible to evaluate the global implicit curve of the diaphragm.

7.2.4. 3D catheter navigation from monocular images

In interventional radiology, the 3D shape of the micro-tool (guidewire, micro-catheter or micro-coil) can be very difficult, if not impossible to infer from fluoroscopy images. We consider this question as a single view 3D curve reconstruction problem. Our aim is to assess whether, and under which conditions, a sophisticated physics-based model can be effective to compensate for the incomplete data in this ill-posed problem.

Raffaella Trivisonne started her PhD thesis in November 2015 (co-supervised by Stéphane Cotin, from MIMESIS team in Strasbourg) to address this research topic. An unscented Kalman filter is used as a fusion mechanism, in a non-rigid shape-from-motion approach: the observations are image data (opaque markers placed along the device), and the model is implemented through interactive physics-based simulation. Our contribution is to handle contacts, which introduce discontinuities in the first and second order derivatives of motion (resp. velocity and forces). Extensive validation on both synthetic and phantom-based data has been carried out this year [30], and various state vector parametrizations have been investigated, in particular in a view to achieve data assimilation of mechanical parameters to improve the predictability of simulation.

In this context, validation is made very complex by the need to acquire ground truth 3D curve shapes that are subjected to contacts and demonstrate highly transient dynamic deformations (e.g. stick and slip transitions after contact). Thomas Mangin was hired on a 1-year engineer contract (started in March 2019) to design and develop an experimental platform to acquire such ground truth data. The catheter is inserted in a translucent, silicon vascular phantom to generate contacts with no visual occlusion of the catheter shape. It is reconstructed from images acquired by a stereo rig made of two orthogonal high speed cameras. The motion is fully controlled by an original 3D-printed active device that induces accurate translation and rotation motions to the micro-tool. Monte-Carlo simulations are currently being carried out to certify the accuracy of the ground truth data produced by this system.

7.3. Image processing

Participants: Marie-Odile Berger, Fabien Pierre, Frédéric Sur.

7.3.1. Computational photomechanics

In computational photomechanics, mainly two methods are available for estimating displacement and strain fields on the surface of a material specimen subjected to a mechanical test, namely digital image correlation (DIC) and localized spectrum analysis (LSA). With both methods, a contrasted pattern marks the surface of the specimen: either a random speckle pattern for DIC or a regular pattern for LSA, this latter method being based on Fourier analysis. It is a challenging problem since strains are tiny quantities giving deformations often not visible to the naked eye. The recent outcomes of our collaboration with Institut Pascal (Université Clermont-Auvergne) focus on two areas.

We have investigated the optimization of the pattern marking the specimen [13], which is the topic of several recent papers. Checkerboard is the optimized pattern in terms of sensor noise propagation when the signal is correctly sampled, but its periodicity causes convergence issues with DIC. The consequence is that checkerboards are not used in DIC applications although they are optimal in terms of sensor noise propagation. We have shown that it is possible to use LSA to estimate displacement and strain fields from checkerboard images, although LSA was originally designed to process 2D grid images. A comparative study of checkerboards and grids shows that, under similar experimental conditions, the noise level in displacement and strain maps obtained with checkerboards is lower than that obtained with classic 2D grids. A patent on this topic was filed [28].

Another scientific contribution concerns the restoration of displacement and strain maps. DIC and LSA both provide displacement fields equal to the actual one convoluted by a kernel known a priori. The kernel indeed corresponds to the Savitzky-Golay filter in DIC, and to the analysis window of the windowed Fourier transform used in LSA. While convolution reduces noise level, it also gives a systematic measurement error. We have proposed a deconvolution method to retrieve the actual displacement and strain fields from the output of DIC or LSA [12]. The proposed algorithm can be considered as a variant of Van Cittert deconvolution, based on the small strain assumption. It is demonstrated that it allows enhancing fine details in displacement and strain maps, while improving spatial resolution.

7.3.2. Cartoon-texture decomposition

Decomposing an image as the sum of geometric and textural components is a popular problem of image analysis. In this problem, known as cartoon and texture decomposition, the cartoon component is piecewise smooth, made of the geometric shapes of the images, and the texture component is made of stationary or quasi-stationary oscillatory patterns filling the shapes. Microtextures being characterized by their power spectrum, we propose to extract cartoon and texture components from the information provided by the power spectrum of image patches. The contribution of texture to the spectrum of a patch is detected as statistically significant spectral components with respect to a null hypothesis modeling the power spectrum of a non-textured patch. The null-hypothesis model is built upon a coarse cartoon representation obtained by a basic yet fast filtering algorithm of the literature. The coarse decomposition is obtained in the spatial domain and is an input of the proposed spectral approach. We thus design a "dual domain" method. The statistical model is also built upon the power spectrum of patches with similar textures across the image. The proposed approach therefore falls within the family of non-local methods. Compared to variational methods or fast filers, the proposed non-local dual-domain approach [16] is shown to achieve a good compromise between computation time and accuracy. Matlab code is publicly available.

7.3.3. Variational methods for image processing

The work described in [20] aims to couple the powerful prediction of the convolutional neural network (CNN) to the accuracy at pixel scale of the variational methods. We have focused on a CNN which is able to compute a statistical distribution of the colors for each pixel of the image based on a learning stage on a large color image database. A variational method able to select a color candidate among a given set while performing regularization of the result is combined with a CNN, to design a fully automatic image colorization framework with an improved accuracy in comparison with CNN alone. To solve the proposed model, we have proposed in [17] a novel accelerated alternating optimization scheme to solve block biconvex nonsmooth problems whose objectives can be split into smooth (separable) regularizers and simple coupling terms. The proposed method performs a Bregman distance-based generalization of the well-known forward–backward splitting for each block, along with an inertial strategy which aims at getting empirical acceleration. We discuss the theoretical convergence of the proposed scheme and provide numerical experiments on image colorization.

8. Partnerships and Cooperations

8.1. Regional Initiatives

The project *Imagerie et Robotique Médicale Grand Est (IRMGE)* started in 2018. Clinical and interventional imagery is a major public health issue. Teams from the Grand-Est region involved in medical imaging (Inria, ICuve, CRESTIC) have thus proposed a research project to broaden and strenghten cooperation. The three axes of the project are about optic imagery, nuclear imagery and medical image processing. The Magrit team is especially involved in the third axis, with the aim to improve interventional procedures.

8.2. National Initiatives

8.2.1. ANR JCJC ICaRes

Participant: F. Sur

This 3-year project (2019-2022) headed by B. Blaysat (Université Clermont-Auvergne), is supported by the Agence Nationale de la Recherche. It addresses residual stresses, which are introduced in the bulk of materials during processing or manufacturing. Since unintended residual stresses often initiate early failure, it is of utmost importance to correctly measure them. The goal of the ICaRes project is to improve the performance of residual stress estimation through the so-called virtual digital image correlation (DIC) which will be developed. The basic idea of virtual DIC is to mark the specimen with virtual images coming from a controlled continuous image model, instead of the standard random pattern. Virtual DIC is expected to outperform standard DIC by, first, matching real images of the materials with the virtual images, then, to run DIC on the virtual images on which strain fields are estimated, giving ultimately residual stresses.

8.2.2. Projet RAPID EVORA

(2016-2010) Participants: M.-O. Berger, V. Gaudillière, G. Simon.

This 4-years project is supported by DGA/DGE and led by the SBS-Interactive company. The objective is to develop a prototype for location and object recognition in large-scale industrial environments (factories, ships...), with the aim to enrich the operator's field of view with digital information and media. The main issues concern the size of the environment, the nature of the objects (often non textured, highly specular...) and the presence of repeated patterns.

This year we have built a demonstrator to locate a camera in a factory modeled by a set of registered RGB-D panoramic images. The panoramic image closest to the current image is selected using a CNN descriptor calculated inside proposed boxes. Points and edges are then detected and matched between the current image and the selected panoramic image by using our method published at ICIP 2018 [31]. The camera pose can finally be obtained with regard to the scene by transitivity (image $\longleftrightarrow$ panoramic view $\longleftrightarrow$ scene).

8.3. International Initiatives

8.3.1. Inria International Labs

Inria@EastCoast
Associate Team involved in the International Lab:

8.3.1.1. CURATIVE

Title: CompUteR-based simulAtion Tool for mItral Valve rEpair

International Partner (Institution - Laboratory - Researcher):

Harvard University (United States) - Harvard Biorobotics Lab (HBL)- Robert Howe

Start year: 2017

See also: https://team.inria.fr/curative/

The mitral valve of the heart ensures one-way flow of oxygenated blood from the left atrium to the left ventricle. However, many pathologies damage the valve anatomy producing undesired backflow, or regurgitation, decreasing cardiac efficiency and potentially leading to heart failure if left untreated. Such cases could be treated by surgical repair of the valve. However, it is technically difficult and outcomes are highly dependent upon the experience of the surgeon.

One way to facilitate the repair is to simulate the mechanical behavior of the pathological valve with subject-specific data. Our main goal is to provide surgeons with a tool to study solutions of mitral valve repairs. This tool would be a computer-based model that can simulate a potential surgical repair procedure in order to evaluate its success. The surgeons would be able to customize the simulation to a patient and to a technique of valve repair. Our methodology will realistically simulate valve closure based on segmentation methods faithful enough to capture subject-specific anatomy and based on a biomechanical model that can accurately model the range of properties exhibited by pathological valves.

8.3.2. Inria International Partners

8.3.2.1. Informal International Partners

- Pierre-Frédéric Villard is a co-investigator in the INVIVE project (http://www.it.uu.se/research/scientific_computing/project/rbf/biomech) funded by the Swedish Research Council and realized within a collaboration with Uppsala University and Karolinska Institute. Within this project, he is the co-supervisor of Igor Tominec (Uppsala University) with Elisabeth Larsson (Uppsala University) as the main advisor.
- Gabriele Steidl (Technische Universität Kaiserslautern, Germany) invited Fabien Pierre during two days in her team to work on convolution on Riemannian manifolds for color images. The goal of this collaboration is the design of a CNN to process images which values are on a Manifolds.

8.4. International Research Visitors

8.4.1. Visits of International Scientists

- Pete Hammer, a senior researcher at Harvard University (http://www.childrenshospital.org/researchers/peter-e-hammer), visited the MAGRIT team in July 2019. He gave a talk to the Department 1 in Loria, he helped out with mechanical modeling of the mitral valve and he provided advice to Daryna Panicheva during one week.
- Douglas Perrin, a senior researcher at Harvard University (http://www.childrenshospital.org/researchers/douglas-perrin), visited the MAGRIT team in September 2019. He gave a talk to the Department 1 in Loria, he worked on the segmentation of the mitral valve leaflet and he provided advice to Daryna Panicheva during one week.

- Ioana Ilea, Technical University Cluj-Napoca visited the Magrit team in October. She gave a talk entitled “Robust classification on covariance matrix space: Application to texture”.

8.4.1.1. Internships

Anastasiia Onanko from Kiev Polytechnique Institute was hosted to fulfill her Master internship (Erasmus mobility program). She worked to initiate a new research line in collaboration with our partners from CHRU Nancy, who were interested in having faster, more automated, but still faithful, means of detecting intracranial aneurysms from 3D magnetic resonance angiography (MRA) images. The deep learning approach that was followed addressed three challenges: the impossibility to use full-sized 3D MRA as input to a deep Convolutional Neural Network (CNN), the difficulty to collect annotated data, and the scarcity of aneurysms within the whole brain vasculature (about 50 voxels in a volume that counts millions of voxels). We designed two patch-based classification approaches, with roughly annotated data, and experimented with various data augmentation protocols. Results are preliminary and need to be consolidated. In particular, the current (limited) database will be expanded in the next few months.

8.4.2. Visits to International Teams

8.4.2.1. Research Stays Abroad

- Pierre-Frédéric Villard spent one month (May 2019) at Uppsala University working on the INVIVE project. His work there includes supervising PhD student Igor Tominec, meeting with a physiologist expert in respiration muscles and working on an implicit surface representation of the diaphragm.
- Daryna Panicheva and Pierre-Frédéric Villard stayed in Harvard University in Cambridge (USA) respectively 2 weeks and 1 month in the context of the CURATIVE team. Each of them gave a talk to the Harvard Biorobotics Lab. An acquisition of a porcine mitral valve was done with 4 different amounts of pressure with a microCT scan. Biomechanical simulations on the mitral valve were also studied in term of stability and convergence.

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. Scientific Events: Selection

9.1.1.1. Reviewer

- Marie-Odile Berger was reviewer for ISMAR (International Symposium for Mixed and Augmented Reality), IPCAI (International Conference on Information Processing in Computer-Assisted Interventions), IROS (International Conference on Intelligent Robots and Systems), ICRA (International conference on Robotics and Automation), RSS (Robotics: Science and Systems), AE-CAI (Workshop on Augmented Environments for Computer Assisted Interventions), ORASIS (French conference on computer vision)
- Erwan Kerrien was reviewer for MICCAI 2019, IPCAI 2020, MIAR/AE-CAI/CARE 2019 workshop and Orasis 2019
- Gilles Simon was reviewer for IEEE VR 2019 and IEEE ISMAR 2019
- Pierre-Frederic Villard was a reviewer for MICCAI 2019, the Eurographics Workshop on Visual Computing for Biology and Medicine 2019 and the International Conference on Computer Graphics, Visualization, Computer Vision And Image Processing 2019

9.1.2. Journal

- Marie-Odile Berger was a reviewer for the International Journal of Computer Assisted Radiology and Surgery.
- Erwan Kerrien was a reviewer for IEEE Transactions on Medical Imaging

- Frédéric Sur was a reviewer for IEEE Transactions on Medical Imaging, Experimental Mechanics, Signal Processing: Image Communication, Digital Signal Processing, IEEE Transactions on Image Processing, SIAM Journal on Imaging Science
- Gilles Simon was a reviewer for IEEE Transactions on Visualization & Computer Graphics
- Pierre-Frédéric Villard was a reviewer for the International Journal of Computer Assisted Radiology and Surgery.

9.1.3. Invited Talks

- Fabien Pierre gave an invited talk entitled “Coupling Variational Method with CNN for Image Colorization” at the workshop “Variational methods and optimization in imaging” (Paris), at Jean Kuntzmann’s laboratory (Grenoble), at ENSEEIHT(Toulouse) and at the one day workshop géométrie de la couleur, organized by GDR ISIS.
- Gilles Simon gave an invited talk at the Nanjing Institute of Advanced AI in China entitled "Camera localization for AR in large indoor environments".
- Pierre-Frédéric Villard gave a seminar at the department of information technology of Uppsala University. Title: “Segmentation of Mitral Valve Chordae”.
- Daryna Panicheva gave a talk at the Harvard Biorobotics Lab. Title: “Physically-coherent Extraction of Mitral Valve Chordae”.
- Pierre-Frederic Villard gave a talk at the Harvard Biorobotics Lab. Title: “An Overview of Deformable Models”.

9.1.4. Scientific Expertise

- Erwan Kerrien was an expert to evaluate NExT Isite (https://next-isite.fr/) calls for projects.

9.1.5. Research Administration

- Marie-Odile Berger is the president of the Association française pour la reconnaissance et l’interprétation des formes (AFRIF).
- Marie-Odile Berger was a member of the Inria evaluation committee.
- Frédéric Sur was a member of the recruitment committee for a Professor at IUT Charlemagne.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

The academic members of the MAGRIT team actively teach at Université de Lorraine with an annual number of around 200 teaching hours in computer sciences each, some of them being accomplished in the field of image processing. Inria researchers have punctual teaching activities in computer vision and shape recognition mainly in the computer science Master of Nancy and in several Engineering Schools near Nancy (ENSMN Nancy, SUPELEC Metz, ENSG). Our goal is to attract Master students with good skills in applied mathematics towards the field of computer vision.

The complete list of courses given by staff members is detailed below:

- M.-O. Berger
  - Master : Shape recognition, 24 h, Université de Lorraine.
  - Master : Introduction to image processing, 12 h, École des Mines de Nancy .
  - Master : Image processing for Geosciences, ENSG, 12h.
- E. Kerrien
  - Master : Introduction to image processing, 15 h, École des Mines de Nancy.
  - Licence: Basics of computer science, 71h, IUT Saint-Dié-des-Vosges.

  - Professional training: Computer science unplugged for science teachers, 6h, INSPE de Lorraine.
- Fabien Pierre
  - Licence: Introduction au traitement d'image, 30h, IUT Saint-Dié des Vosges.
  - Master: Introduction à l'apprentissage automatique, 16 h, Université de Lorraine.
  - Licence: Algorithmique et programmation, 87h, IUT Saint-Dié des Vosges
  - Licence: Culture scientifique et traitement de l'information, 69h, IUT Saint-Dié des Vosges
  - Licence: Programmation objet et évènementielle, 35h, IUT Saint-Dié des Vosges
  - Licence: Initiation à l'intelligence artificiell, 8h, IUT Saint-Dié des Vosges
- G. Simon
  - Master: Augmented reality, 24 h, Télécom-Nancy.
  - Master : Augmented reality, 3 h, SUPELEC Metz.
  - Master: Augmented reality, 24h, M2 Informatique FST
  - Master: Visual data modeling, 12h, M1 Informatique FST
  - Image processing and computer vision, 12h, M1 informatique, FST
  - Licence pro : 3D modeling and integration, 40h FST - CESS d'Epinal
- F. Sur
  - Master: Introduction to machine learning, 60 h, Mines Nancy
  - Master: Time series analysis, 30h, Mines Nancy
  - Licence: Javascript programming, 150h, IUT Charlemagne
  - Introduction to signal processing, 20h, IUT Charlemagne
- P.-F. Villard
  - Licence: Computer Graphics with webGL, 30h, IUT Saint-Dié des Vosges.
  - Licence: Game design with Unity3D, 15h, IUT Saint-Dié des Vosges.
  - Licence: Virtual and Augmented Reality in Industrial Maintenance, 2h, Faculty of Science and Technology, Université de Lorraine
  - Master : Augmented and Virtual Reality, 16h, M2 Cognitive Sciences and Applications, Institut des Sciences du Digital, Université de Lorraine
  - Virtual and Augmented Reality within Unity, 15h, Glyndwr University, Wrexham, UK (ERASMUS+ program)
  - Licence: Web programming, 20h, IUT Saint-Dié des Vosges.
  - Licence: Graphical user interface programming, 30h, IUT Saint-Dié des Vosges.
  - Licence: Object-oriented programming, 20h, IUT Saint-Dié des Vosges.
  - Licence: UML modeling,16h, IUT Saint-Dié des Vosges.
  - Licence: Security and life privacy with internet, 2h, IUT Saint-Dié des Vosges.
  - Licence: Parallel programming, 18h, IUT Saint-Dié des Vosges.
- Brigitte Wrobel-Dautcourt
  - Master: modélisation objet et conception des systèmes d'information, 30h, Télécom
  - Master: projet de conception et développement java, 27h, Télécom 2A
  - Licence: bases de la programmation objet, 44h, Faculté des Sciences et Techniques, Université de Lorraine
  - Licence: interfaces graphiques,22h, Faculté des Sciences et Techniques, Université de Lorraine
  - Licence: projet de synthèse (activité intégratrice), 30 h, Faculté des Sciences et Techniques, Université de Lorraine
  - Licence: système, 24h, Faculté des Sciences et Techniques, Université de Lorraine
  - Licence: compilation, 16, Faculté des Sciences et Techniques, Université de Lorraine

9.2.2. Supervision

PhD: Jaime Garcia Guevara, Biomechanical graph matching for hepatic intra-operative image registration, October 2015, Marie-Odile Berger, Stéphane Cotin (MIMESIS). PhD defended in December 2019.

PhD in progress: Raffaella Trivisonne, Image-guided real-time simulation using stochastic filtering, November 2015, Erwan Kerrien, Stéphane Cotin (MIMESIS).

PhD in progress: Vincent Gaudillière, Reconnaissance de lieux et d'objets pour la réalité augmentée en milieux complexes, December 2016, Marie-Odile Berger, Gilles Simon.

PhD in progress: Daryna Panicheva, Image-based Biomechanical Simulation of Mitral Valve Closure, October 2017, Marie-Odile Berger, Pierre-Frédéric Villard.

PhD in progress: Matthieu Zins, Localization in a world of objects, October 2019, Marie-Odile Berger, Gilles Simon.

9.2.3. Juries

- Marie-Odile Berger was an external reviewer of the PhD of Karim Makki (IMT Atlantique, Brest) and of the HdR of Guillaume Caron (Univ Picardie Jules Verne). She was examiner of the PhD of Yilin Zhou (IGN, Paris), Florian Tilquin (ICUBE, Strasbourg) and of the HdR of Omar Ait Aider (Institut Pascal, Clermont Ferrand)
- Erwan Kerrien was an external reviewer for the PhD of Alessio Virzì (Université Paris Saclay and Telecom ParisTech) and Emmanuelle Poulain (I3S, Université Côte d'Azur)
- Frédéric Sur was an external reviewer for the PhD thesis of Debolina Chakraborty (IIEST Shibpur, India) and Alberto Lavatelli (Polytecnico di Milano, Italy)

9.3. Popularization

9.3.1. Internal or external Inria responsibilities

Erwan Kerrien is Chargé de Mission for scientific mediation at Inria Nancy-Grand Est, and thereby is part of the Inria scientific mediation network. As such, he is a member of the steering committee of "la Maison pour la Science de Lorraine" [0], and member of the IREM [0] steering council.

9.3.2. Education

- Pierre-Frédéric Villard is involved with the secondary school of Champigneulles (France) as a "Collège Pilote" of "La Main à la pâte" foundation. He gave a seminar on augmented and virtual realities to the pupils, he helped the teacher with preparing some activities with augmented and virtual reality technologies. Finally, he is supervising Université de Lorraine students to produce teaching applications with augmented and virtual reality technologies that will be used in secondary school classes.
- Erwan Kerrien participated in the creation and animation of a MOOC for teachers of the new SNT class (Sciences du Numérique et Technologie - *Digital Science and Technology* included in the 1st year of core curriculum in upper secondary education, see https://www.fun-mooc.fr/courses/course-v1:inria+41018+session01/about), where he brought his expertise in image processing. This MOOC is part of the Class'Code project (https://pixees.fr/classcode-v2).

  He also participates in *MOOCFOLIO*, a PIA3-funded project https://www.fun-mooc.fr/news/pia-3-le-projet-moocfolio-est-laureat/). The objective is to create a MOOC to help students choose their undergraduate studies to pursue after high schools. Erwan is part of a working group to create a module about studies and professions related to digital usages and sciences.

[0]"Houses for Science" project, see http://maisons-pour-la-science.org/en

[0]Institut de Recherche sur l'Enseignement des Mathématiques - *Research Institute for Teaching Mathematics*

He also participated in the creation, and teaching, of a 5-day training course for scientific animators (in a broad sense, from science club animators to science teachers). This course was funded by Région Grand-Est (see https://fan.loria.fr).

He gave a 2-day class about the use of unplugged computer science to introduce computer science in science class, along with another researcher and 2 secondary school maths teachers. This class has been organized with Maison pour la Science since 2015, and is proposed to around 20 maths and science secondary school teachers each year.

9.3.3. Interventions

Erwan Kerrien was an associate researcher to a MATh.en.JEANS workshop (https://www.mathenjeans.fr) within Loritz high school in Nancy.

He also regularly intervenes to demonstrate computer science unplugged activities and/or give conferences to secondary school pupils and teachers.

9.3.4. Internal action

Pierre-Frédéric Villard participated to open days and science festival in the IUT of Saint-Dié des Vosges. He presented augmented and virtual reality demos and their link to the high school mathematics program.

10. Bibliography

Major publications by the team in recent years

[1] J. GARCIA GUEVARA, I. PETERLIK, M.-O. BERGER, S. COTIN.*Biomechanics-based graph matching for augmented CT-CBCT*, in "International Journal of Computer Assisted Radiology and Surgery", April 2018, vol. 13, n^o^ 6, p. 805-813 [*DOI :* 10.1007/s11548-018-1755-1], https://hal.inria.fr/hal-01761521

[2] N. HAOUCHINE, S. COTIN, I. PETERLIK, J. DEQUIDT, M. SANZ-LOPEZ, E. KERRIEN, M.-O. BERGER.*Impact of Soft Tissue Heterogeneity on Augmented Reality for Liver Surgery*, in "IEEE Transactions on Visualization and Computer Graphics", 2015, vol. 21, n^o^ 5, p. 584-597 [*DOI :* 10.1109/TVCG.2014.2377772], https://hal.inria.fr/hal-01136728

[3] E. KERRIEN, A. YUREIDINI, J. DEQUIDT, C. DURIEZ, R. ANXIONNAT, S. COTIN.*Blood vessel modeling for interactive simulation of interventional neuroradiology procedures*, in "Medical Image Analysis", January 2017, vol. 35, p. 685-698 [*DOI :* 10.1016/J.MEDIA.2016.10.003], https://hal.inria.fr/hal-01390923

[4] P. ROLIN, M.-O. BERGER, F. SUR.*Viewpoint simulation for camera pose estimation from an unstructured scene model*, in "International Conference on Robotics and Automation", Seattle, United States, May 2015, https://hal.archives-ouvertes.fr/hal-01166785

[5] G. SIMON, A. FOND, M.-O. BERGER.*A-Contrario Horizon-First Vanishing Point Detection Using Second-Order Grouping Laws*, in "ECCV 2018 - European Conference on Computer Vision", Munich, Germany, September 2018, https://hal.inria.fr/hal-01865251

[6] F. SUR, M. GREDIAC.*Measuring the Noise of Digital Imaging Sensors by Stacking Raw Images Affected by Vibrations and Illumination Flickering*, in "SIAM J. on Imaging Sciences", March 2015, vol. 8, n^o^ 1, p. 611-643 [*DOI :* 10.1137/140977035], https://hal.inria.fr/hal-01133358

[7] F. SUR, N. NOURY, M.-O. BERGER.*An A Contrario Model for Matching Interest Points under Geometric and Photometric Constraints*, in "SIAM Journal on Imaging Sciences", 2013, vol. 6, n° 4, p. 1956-1978 [*DOI :* 10.1137/120871766], http://hal.inria.fr/hal-00876215

[8] F. P. VIDAL, P.-F. VILLARD, E. LUTTON.*Tuning of patient specific deformable models using an adaptive evolutionary optimization strategy*, in "IEEE Transactions on Biomedical Engineering", October 2012, vol. 59, n° 10, p. 2942-2949 [*DOI :* 10.1109/TBME.2012.2213251], https://hal.inria.fr/hal-00731910

Publications of the year

Doctoral Dissertations and Habilitation Theses

[9] J. GARCIA GUEVARA.*Biomechanical graph matching for hepatic intra-operative image registration*, Universite de Lorraine, Inria, Nancy, France, December 2019, https://hal.archives-ouvertes.fr/tel-02408339

[10] G. SIMON.*Positionnement visuel pour la réalité augmentée en environnement plan*, Université de Lorraine, December 2019, Habilitation à diriger des recherches, https://hal.inria.fr/tel-02403014

Articles in International Peer-Reviewed Journal

[11] J. GARCIA GUEVARA, I. PETERLIK, M.-O. BERGER, S. COTIN.*Elastic registration based on compliance analysis and biomechanical graph matching*, in "Annals of Biomedical Engineering", September 2019, https://arxiv.org/abs/1912.06353 [*DOI :* 10.1007/s10439-019-02364-4], https://hal.archives-ouvertes.fr/hal-02401280

[12] M. GREDIAC, B. BLAYSAT, F. SUR.*A robust-to-noise deconvolution algorithm to enhance displacement and strain maps obtained with local DIC and LSA*, in "Experimental Mechanics", 2019, vol. 59, n° 2, p. 219-243 [*DOI :* 10.1007/s11340-018-00461-4], https://hal.archives-ouvertes.fr/hal-01926058

[13] M. GREDIAC, B. BLAYSAT, F. SUR.*Extracting displacement and strain fields from checkerboard images with the Localized Spectrum Analysis*, in "Experimental Mechanics", 2019, vol. 59, n° 2, p. 207-218 [*DOI :* 10.1007/s11340-018-00439-2], https://hal.archives-ouvertes.fr/hal-01926054

[14] M. GREDIAC, B. BLAYSAT, F. SUR.*Comparing several spectral methods used to extract displacement fields from checkerboard images*, in "Optics and Lasers in Engineering", 2020, vol. 127, p. 1-33 [*DOI :* 10.1016/j.optlaseng.2019.105984], https://hal.archives-ouvertes.fr/hal-02436572

[15] P. ROLIN, M.-O. BERGER, F. SUR.*View synthesis for pose computation*, in "Machine Vision and Applications", 2019, vol. 30, n° 7-8, p. 1209-1227 [*DOI :* 10.1007/s00138-019-01045-5], https://hal.archives-ouvertes.fr/hal-02279616

[16] F. SUR.*A non-local dual-domain approach to cartoon and texture decomposition*, in "IEEE Transactions on Image Processing", 2019, vol. 28, n° 4, p. 1882-1894 [*DOI :* 10.1109/TIP.2018.2881906], https://hal.archives-ouvertes.fr/hal-01925890

[17] P. TAN, F. PIERRE, M. NIKOLOVA.*Inertial Alternating Generalized Forward-Backward Splitting for Image Colorization*, in "Journal of Mathematical Imaging and Vision", February 2019, vol. 61, n° 5, p. 672–690 [*DOI :* 10.1007/s10851-019-00877-0], https://hal.archives-ouvertes.fr/hal-01792432

International Conferences with Proceedings

[18] V. Gaudillière, G. Simon, M.-O. Berger.*Camera Pose Estimation with Semantic 3D Model*, in "IROS 2019 - 2019 IEEE/RSJ International Conference on Intelligent Robots and Systems", Macau, Macau SAR China, November 2019, p. 4568-4576, https://hal.archives-ouvertes.fr/hal-02181962

[19] V. Gaudillière, G. Simon, M.-O. Berger.*Camera Relocalization with Ellipsoidal Abstraction of Objects*, in "ISMAR 2019 - 18th IEEE International Symposium on Mixed and Augmented Reality", Beijing, China, October 2019, p. 19-29, https://hal.archives-ouvertes.fr/hal-02170784

[20] T. Mouzon, F. Pierre, M.-O. Berger.*Joint CNN and Variational Model for Fully-automatic Image Colorization*, in "SSVM 2019 - Seventh International Conference on Scale Space and Variational Methods in Computer Vision", Hofgeismar, Germany, Scale Space and Variational Methods in Computer Vision, June 2019, p. 535-546, https://hal.archives-ouvertes.fr/hal-02059820

[21] D. Panicheva, P.-F. Villard, M.-O. Berger.*Toward an automatic segmentation of mitral valve chordae*, in "SPIE Medical Imaging", San Diego, United States, B. Gimi, A. Kro (editors), SPIE, February 2019, vol. 10953, p. 1095315-1095323 [*DOI :* 10.1117/12.2511943], https://hal.inria.fr/hal-02050846

[22] D. Panicheva, P.-F. Villard, P. Hammer, M.-O. Berger.*Physically-coherent Extraction of Mitral Valve Chordae*, in "International Conference in Computing in Cardiology", Singapore, Singapore, Proceedings of Computers in Cardiology, IEEE Engineering in Medicine and Biology Society, 2019, vol. 46, 4, https://hal.inria.fr/hal-02368810

[23] A. Renaudeau, F. Lauze, F. Pierre, J.-F. Aujol, J.-D. Durou.*Alternate Structural-Textural Video Inpainting for Spot Defects Correction in Movies*, in "SSVM 2019 - Seventh International Conference on Scale Space and Variational Methods in Computer Vision", Hofgeismar, Germany, 2019, https://hal.archives-ouvertes.fr/hal-02433997

National Conferences with Proceeding

[24] V. Gaudillière, G. Simon, M.-O. Berger.*Estimation de pose de caméra à partir de correspondances ellipse - ellipsoïde*, in "ORASIS 2019 - Journées francophones des jeunes chercheurs en vision par ordinateur", Saint-Dié-des-Vosges, France, May 2019, https://hal.archives-ouvertes.fr/hal-02148633

[25] A. Renaudeau, F. Lauze, F. Pierre, J.-F. Aujol, J.-D. Durou.*Inpainting vidéo pour la restauration de films par reconstructions alternées de la structure et de la texture*, in "ORASIS", Saint-Dié-des-Vosges, France, 2019, https://hal.archives-ouvertes.fr/hal-02433990

Conferences without Proceedings

[26] N. Cacciani, E. Larsson, I. Tominec, P.-F. Villard.*Meshfree Simulation of Human Respiratory Muscles*, in "CSE 19 - SIAM Conference on Computational Science and Engineering", Spokane, United States, February 2019, https://hal.inria.fr/hal-02057413

Patents and standards

[27] M.-O. Berger, V. Gaudillière, G. Simon.*Dispositif de traitement de prise de vue*, May 2019, n^{O} FR1905535, https://hal.inria.fr/hal-02429562

[28] M. GREDIAC, B. BLAYSAT, F. SUR.*Method for measuring fields of movements and of deformations with check pattern marking and spectral method processing*, August 2019, n$^{\mathrm{o}}$ FR3078190 WO2019162449, https://hal.archives-ouvertes.fr/hal-02272747

Other Publications

[29] V. GAUDILLIÈRE, G. SIMON, M.-O. BERGER.*Perspective-12-Quadric: An analytical solution to the camera pose estimation problem from conic - quadric correspondences*, March 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-02054882

[30] R. TRIVISONNE, E. KERRIEN, S. COTIN.*Constrained Stochastic State Estimation for 3D Shape Reconstruction of Catheters and Guidewires in Fluoroscopic Images*, April 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-02072386

References in notes

[31] V. GAUDILLIÈRE, G. SIMON, M.-O. BERGER.*Region-based epipolar and planar geometry estimation in low-textured environments*, in "ICIP 2018 - 25th IEEE International Conference on Image Processing", Athens, Greece, October 2018, https://hal.archives-ouvertes.fr/hal-01802596

[32] N. PADOY, T. BLUM, A. AHMADI, H. FEUSSNER, M.-O. BERGER, N. NAVAB.*Statistical Modeling and Recognition of Surgical Workflow*, in "Medical Image Analysis", 2011, http://hal.inria.fr/inria-00526493/en

[33] J. REDMON, S. K. DIVVALA, R. B. GIRSHICK, A. FARHADI.*You Only Look Once: Unified, Real-Time Object Detection*, in "CoRR", 2015, vol. abs/1506.02640, http://arxiv.org/abs/1506.02640

[34] G. SIMON.*In-Situ 3D Sketching Using a Video Camera as an Interaction and Tracking Device*, in "31st Annual Conference of the European Association for Computer Graphics - Eurographics 2010", Suède Norrkoping, May 2010

Project-Team MFX

Matter From Graphics

IN COLLABORATION WITH: Laboratoire lorrain de recherche en informatique et ses applications (LORIA)

IN PARTNERSHIP WITH:
Université de Lorraine

RESEARCH CENTER
Nancy - Grand Est

THEME
Interaction and visualization

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Project-Team MFX

Creation of the Project-Team: 2019 November 01

Keywords:

Computer Science and Digital Science:
A5.5.1. - Geometrical modeling
A5.5.2. - Rendering
A8.3. - Geometry, Topology

Other Research Topics and Application Domains:
B5.7. - 3D printing

1. Team, Visitors, External Collaborators

Research Scientists
Sylvain Lefebvre [Team leader, Inria, Senior Researcher, HDR]
Samuel Hornus [Inria, Researcher]
Jonàs Martínez Bayona [Inria, Researcher]

Faculty Member
Cédric Zanni [Univ de Lorraine, Associate Professor]

Technical Staff
Jean Baptiste Austruy [Univ de Lorraine, Engineer, from May 2019]
Pierre Bedell [Inria, Engineer]
Pierre-Alexandre Hugron [Univ de Lorraine, Engineer, from Apr 2019]
Yamil Salim Perchy [Inria, Engineer]
Noémie Vennin [Univ de Lorraine, Engineer, until Jun 2019]

PhD Students
Melike Aydinlilar [Univ de Lorraine, from Nov 2019]
Semyon Efremov [Inria]
Jimmy Étienne [CNRS]
Thibault Tricard [Univ de Lorraine]

2. Overall Objectives

2.1. Overall Objectives

Digital fabrication has had a profound impact on most industries. It allows complex products to be modeled in Computer Assisted Design (CAD) software, and then sent to Computer Aided Manufacturing (CAM) devices that physically produce the products. Typical CAM devices are computer controlled lathes and milling machines that are ubiquitous in mass-production chains, along with injection molding and assembly robots. The design of a new product requires a large pool of expertise consisting of highly skilled engineers and technicians at all stages: design, CAD modeling, fabrication and assembly chains.

Within CAM technologies, the advent of additive manufacturing (AM) (i.e., 3D printing) together with powerful and inexpensive computational resources let us envision a different scenario. In particular, these technologies excel where traditional approaches find their limitations:

- Parts with complex geometry can be fabricated in a single production run and the cost has no direct relation with the geometric complexity.
- The cost-per-unit for fabricating an object is constant and significantly lower than that of producing a small series of objects with traditional means. Though it is not competitive on a mass production scale where the cost-per-unit decreases as the number of produced units increases.
- The machine setup is largely independent of the object being fabricated, and thus these technologies can be made available through generic 3D printing companies and online print services. Additionally, the machines are significantly easier to operate than traditional fabrication means to the extent of making them accessible to the general public.

As a consequence, it becomes possible to design and produce parts with short development cycles: physical objects are uniquely and efficiently fabricated from digital models. Each object can be personalized for a specific use or customer. The core difficulty in this context lies in modeling parts, and this remains a major obstacle as functional and manufacturability constraints have to be enforced. By *functional* constraint we refer here to some desired behavior in terms of rigidity, weight, balance, porosity, or other physical properties. This is especially important as AM allows the fabrication of extremely complex shapes, the scales of which vary from a few microns to a few meters. All this moves AM well beyond traditional means of production and enables the concept of *metamaterials*; materials where parameterized microstructures change the behavior of a base shape fabricated from a single material.

Exploiting this capability turns the modeling difficulties into acute challenges. With such a quantity of details modeling becomes intractable and specifying the geometry with standard tools becomes a daunting task, even for experts. In addition, these details have to interact in subtle and specific ways to achieve the final functionality (*e.g.*, flexibility, porosity) while enforcing fabrication constraints. On the process planning side (i.e, the set of computations turning the part into printing instructions), large parts filled with microstructures, porosities and intricate multi-scale details quickly lead to huge data-sets and numerical issues.

Our overall objective is to develop novel approaches enabling experts and practitioners alike to fully exploit the advantages of AM. We aim to achieve this by developing novel algorithms that automatically synthesize or complete designs with functional details. We consider the full chain, from modeling to geometry processing onto the optimization of 3D printer instructions.

3. Research Program

3.1. Research Program

We focus on the computational aspects of shape modeling and processing for digital fabrication: dealing with shape complexity, revisiting design and customization of existing parts in view of the novel possibilities afforded by AM, and providing a stronger integration between modeling and the capabilities of the target processes.
We tackle on the following challenges:

- develop **novel shape synthesis and shape completion algorithms** that can help users model shapes with features in the scale of microns to meters, while following functional, structural, geometric and fabrication requirements;
- propose methodologies to help *expert* designers **describe shapes** and designs that can later be **customized and adapted** to different use cases;

- develop novel algorithms to **adapt and prepare complex designs** for fabrication in a given technology, including the possibility to modify aspects of the design while preserving its functionality;
- develop novel techniques to **unlock the full potential of fabrication processes**, improving their versatility in terms of feasible shapes as well as their capabilities in terms of accuracy and quality of deposition;
- develop **novel shape representations, data-structures, visualization and interaction techniques** to support the integration of our approaches into a single, unified software framework that covers the full chain from modeling to printing instructions;
- **integrate novel capabilities** enabled by advances in additive manufacturing processes and materials **in the modeling and processing chains**, in particular regarding the use of functional materials (*e.g.* piezoelectric, conductive, shrinkable).

Our approach is to cast a holistic view on the aforementioned challenges, by considering modeling and fabrication as a single, unified process. Thus, the modeling techniques we seek to develop will take into account the geometric constraints imposed by the manufacturing processes (minimal thickness, overhang angles, trapped material) as well as the desired object functionality (rigidity, porosity). To allow for the modeling of complex shapes, and to adapt the same initial design to different technologies, we propose to develop techniques that can automatically synthesize functional details within parts. At the same time, we will explore ways to increase the versatility of the manufacturing processes, through algorithms that are capable of exploiting additional degrees of freedom (*e.g.*, curved layering [21]), can introduce new capabilities (*e.g.*, material mixing [22]) and improve part accuracy (*e.g.*, adaptive slicing [20]).

Our research program is organized along three main research directions. The first one focuses on the automatic synthesis of shapes with intricate multi-scale geometries, that conform to the constraints of additive manufacturing technologies. The second direction considers geometric and algorithmic techniques for the actual fabrication of the modeled object. We aim to further improve the capabilities of the manufacturing processes with novel deposition strategies. The third direction focuses on computational design algorithms to help model parts with gradient of properties, as well as to help customizing existing designs for their reuse.

These three research directions interact strongly, and cross-pollinate: *e.g.*, novel possibilities in manufacturing unlock novel possibilities in terms of shapes that can be synthesized. Stronger synthesis methods allow for further customization.

4. Application Domains

4.1. Digital Manufacturing

Our work addresses generic challenges related to fabrication and can thus be applied in a wide variety of contexts. Our aim is first and foremost to develop the algorithms that will allow various industrial sectors to benefit more strongly from the potential of AM. To enable this, we seek collaborations with key industry partners developing software and AM systems for a variety of processes and materials that are of interest to specific sectors (*e.g.*, dental, prosthetic, automotive, aerospace).

4.2. Medical Applications

To allow for faster transfer of our techniques and unlock novel applications, we actively seek to develop applications in the medical sector. In particular, we are involved in a project around the design of orthoses which explores how our research on elasticity control through microstructure geometries can be specifically applied to the medical sector; see §9.1.1.

5. Highlights of the Year

5.1. Highlights of the Year

This year we advanced on all of our main research axes [11], [12], [13], [14], [15], [17]. We would like to highlight two of these results. First, we cast a new view on the Gabor noise – a now well established procedural texturing technique – by reformulating it to enable new controls and properties [17]. This opens interesting possibilities for microstructure synthesis, a direction we are now pursuing. Second, we introduced a novel algorithm for curved 3D printing [11], a long term ongoing effort within the team. This algorithm is the first – to our knowledge – to optimize for curved layers throughout a part, under constraints allowing fabrication on standard 3D printers using thermoplastic filament. This paves the way to more general techniques for 6-DOF 3D printing.

Our software efforts have also intensified, with a clear increase in the use and popularity of our software IceSL (see *software*). We also announced an exciting collaboration with *AddUp*, a leading French company in the field of metal 3D printing.

6. New Software and Platforms

6.1. Chill

Chill, node-based graphical interface for IceSL

KEYWORDS: 3D - Additive manufacturing

SCIENTIFIC DESCRIPTION: ChiLL is an effort to explore visual modeling tools for IceSL. The core idea behind Chill is to propose a node-based modeling interface, which is a popular way to facilitate the design of 3D objects without going directly through code. Our approach creates a bridge between nodes-based editing and scripting, as the syntax for creating a new node is identical to the scripting language used in IceSL.

FUNCTIONAL DESCRIPTION: In Chill a user creates 3D shapes by connecting various nodes arranged in a directed graph. The shape visualization is updated instantly as the graph is modified.

NEWS OF THE YEAR: Chill was publicly released during the summer of 2019. We will broadly communicate about it in 2020.

- Participants: Jimmy Etienne, Pierre Bedell, Thibault Tricard, Yamil Salim Perchy and Sylvain Lefebvre
- Contact: Sylvain Lefebvre

6.2. IceSL

KEYWORD: Additive manufacturing

SCIENTIFIC DESCRIPTION: IceSL is the software developed within MFX, that serves as a research platform, a showcase of our research results, a test bed for comparisons and a vector of collaborations with both academic and industry partners. The software is freely available both as a desktop (Windows/Linux) and an online version.

FUNCTIONAL DESCRIPTION: IceSL allows users to model complex shapes through CSG boolean operations. Objects can be directly prepared and sent to a 3d printer for fabrication, without the need to compute an intermediate 3D mesh.

NEWS OF THE YEAR: In 2019, IceSL has been featured in news, exhibitions and fairs as a well-established tool for 3D printing. Additionally, since its inception, IceSL's community has grown significantly together with the number of new features included in it for slicing and modeling.

Regarding new features and additions to the software in 2019, IceSL has gone through many changes, primarily focused on improving the user experience and scalability/stability of algorithms. The most visible change is the complete rework of the slicing parameters GUI, with the addition of category-icons to allow for a quick access to settings. We can also note the upgrade of the renderer to support wide and high resolution screens, and the possibility to choose an experimental renderer (based on HCSG, published last year).

On the slicing front, we added new features, long requested, from the community: ironing, automatic spiralization, selection of different nozzle diameters, minimum time per layer, etc. A new GUI to customize the supports points was also added to help with the generation of supports.

The social community of IceSL has been growing steadily. Our twitter account has around 338 followers, 187 users frequently interacting in its Google forum (respectively, a progress of 69% and 25% since last year). Downloads have increased by 78% from last year (55K downloads total). In addition, Slicecrafter, the online version, has a cumulative of around 15K sliced objects.

- Participants: Frédéric Claux, Jean Hergel, Jérémie Dumas, Jonas Martinez-Bayona, Samuel Hornus, Sylvain Lefebvre, Pierre Bedell, Cédric Zanni, Noemie Vennin, Thibault Tricard, Jimmy Etienne, Yamil Salim Perchy and Pierre-Alexandre Hugron
- Contact: Sylvain Lefebvre
- URL: https://icesl.loria.fr

6.3. Platforms

Participants: Pierre Bedell, Noémie Vennin, Pierre-Alexandre Hugron.

We continued our active participation within the Creativ'Lab, a common experimental platform funded by Inria, Loria, CNRS and Région Grand Est. We added novel machines (DLP resin printers and large format printers) to explore new problems related to the specificity of each technology. We are also in the process of revisiting some of our techniques in the context of resin 3D printing.

This year we kept developing our custom-made hardware, in particular our color filament 3D printers. In this context we also elaborated our own colored PLA filament (using a filament extrusion device, PLA pellets and pigments). This was instrumental to the success of the corresponding research [15]. Finally, we started the assembly of a 3D printer based on a robotic arm, in the context of our research on curved 3D printing.

We are making these installations available to industrial partners and other research teams.

7. New Results

7.1. Star-shaped Metrics for Mechanical Metamaterial Design

Participants: Jonàs Martínez, Mélina Skouras, Christian Schumacher, Samuel Hornus, Sylvain Lefebvre, Bernhard Thomaszewski.

Digital manufacturing technologies such as 3D printing and laser cutting enable us to fabricate designs with great geometric detail. One particular way of exploiting this capability is to create patterned sheet materials whose geometric structures can be tailored to control their macro-mechanical behavior.

A typical approach to model and analyze structured sheet materials is centered around the concept of a representative element—a tile—which is repeated, transformed, and laid out so as to generate a regular spatial tiling. Changing the shape of the representative tile allows to control macro-mechanical properties such as isotropy or negative Poisson's ratios. Generalizing this material design principle from a single representative tile to *families* of tiles that can be combined in a spatially-varying manner opens the door to structures with progressively-graded material properties.

At SIGGRAPH 2019 we have presented a method for designing mechanical metamaterials [14]. It is based on the novel concept of Voronoi diagrams induced by star-shaped metrics. As one of its central advantages, our approach supports interpolation between arbitrary metrics (see Figure 1). This capability opens up a rich space of tile geometries with interesting aesthetics and a wide range of mechanical properties. They include isotropic, tetragonal, orthotropic, as well as smoothly graded materials. We have validated the mechanical properties predicted by simulation through tensile tests on a set of physical prototypes. An open source C++ implementation of the technique can be found at https://github.com/mfx-inria/starshaped2d

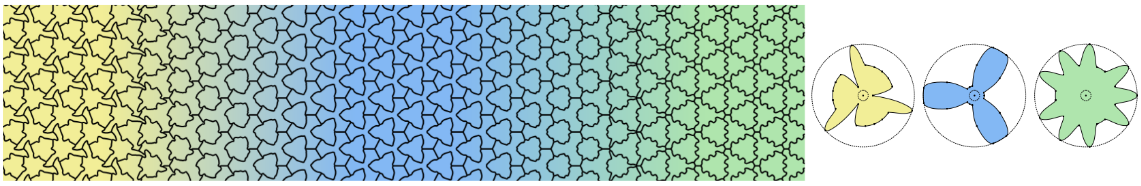

Figure 1. Our method generates a smoothly-graded pattern (left) when interpolating between three star-shaped distance functions (regular) on a regular honeycomb lattice. Each distance function is compactly parameterized with polar coordinates, allowing for simple interpolation in metric space as indicated by color-coding.

7.2. Anisotropic convolution surfaces

Participants: Alvaro Javier Fuentes Suárez, Evelyne Hubert, Cédric Zanni.

Skeletons, as a set of curves and/or surfaces centered inside a shape, provide a compact representation of the shape structure. Due to this property, skeletons have proved useful in many applications that range from shape analysis to 3D modeling and deformation. Convolution surfaces associate radii information to the skeleton and provide a simple way for users to rapidly define a shape. A convolution surface is an implicit surface defined as a level set of a scalar field, the convolution field, that is obtained by integrating a kernel function over the skeleton. This technique allows us to build a complex shape by modeling parts that combine into a smooth surface, independently of the smoothness of the skeleton itself. They also represent a volume with the convolution surface as its boundary and can therefore be combined with other composition operators from implicit modeling frameworks.

We have introduced anisotropic convolution surfaces [12], an extension that increases the modeling freedom by providing ellipse-like normal sections around 1D skeletons. It increases the diversity of shapes that can be generated from 1D skeletons, and reduces the need for 2D skeletons, while it still retains smoothness. We achieve anisotropy not just in the normal sections but also in the tangential direction. This allows sharper and steeper radius variation, and the control of thickness at skeleton endpoints (see Figure 2). The method is applied to skeletons represented by bi-arcs. It allows us to control precisely the orientation of anisotropy thanks to rotation minimizing frames. This work was presented at Shape Modeling International 2019.

7.3. Procedural Phasor Noise

Participants: Thibault Tricard, Semyon Efremov, Cédric Zanni, Fabrice Neyret, Jonàs Martínez, Sylvain Lefebvre.

Procedural pattern synthesis is a fundamental tool of Computer Graphics. In 2019 we introduced a new formulation that generates a wide range of patterns that could not be produced by other techniques. Our procedural *phasor noise* is based on a prior technique called Gabor noise, which creates oscillating patterns with accurate control over their frequency content (power spectrum). Gabor noise achieves this by summing a large number of Gabor kernels — Gaussian weighted sinewaves — distributed pseudo-randomly in space. Unfortunately Gabor noise suffers from local loss of contrast and lacks control over the shape of the oscillations (which always have a sinewave profile).

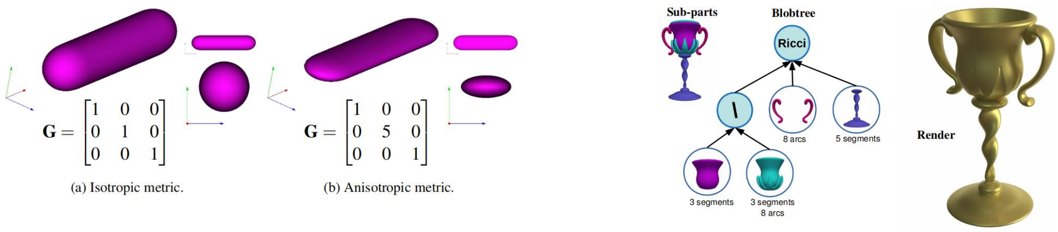

Figure 2. Our method, based on an anisotropic metric, allows us to generate an ellipse-like cross section around 1D skeletons (segments, bi-arcs). The thickness around the skeleton can be controlled precisely both in the orthogonal cross-section and in the tangential direction giving finer control to the user. The density field generated can then be used in a classical implicit modeling framework.

Our method solves these limitations by reformulating Gabor noise to expose its instantaneous phase. Once the phase obtained we can directly remap a periodic profile function onto it, to obtain an oscillating pattern of constant contrast and controlled profile geometry, while retaining all desirable properties of Gabor noise (see Figure 3). This unlocks two main applications. The first is in texture synthesis for computer graphics, to generate color, displacement and normal fields. The second is in additive manufacturing, where our method can be applied in 3D to generate a wide range of microstructures.

This work was done in collaboration with Fabrice Neyret (MAVERICK, Inria) and has been published in ACM Transactions on Graphics, in 2019 [17]. Thibault Tricard and Semyon Efremov did a joint presentation at ACM SIGGRAPH 2019.

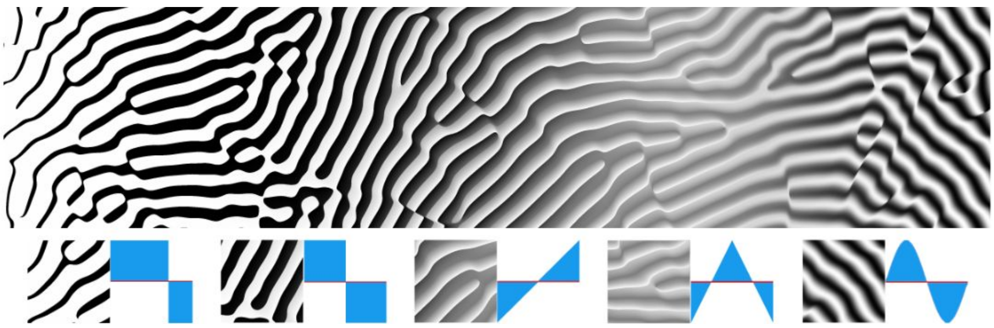

Figure 3. Phasor noise is a novel procedural function generating strongly oriented, coherent stripe patterns. The profiles of the oscillations are controlled (here: square, triangular, sine).

7.4. Ribbed support vaults for 3D printing of hollowed objects

Participants: Thibault Tricard, Frédéric Claux, Sylvain Lefebvre.

In additive manufacturing, and in particular with the popular filament-based fabrication, the printing time remains a major constraint. In a typical print, most of the time is spent filling the interior of the object. Based on this observation we explored how to print an object as empty as possible. The difficulty is that any deposited material has to be supported from below to prevent the object from collapsing.

We developed a simple, yet very efficient, algorithm that generates a lightweight ribbed support vault infill (see Figure 4). Our algorithm sweeps once through the slices from top to bottom, detects non-supported points, and connects them with a segment to the closest already supported points. The endpoints of open segments are eroded from one slice to the next. This process generates hierarchical ribbed support vaults that quickly retract and merge with the enclosing walls, while offering printability guarantees.

Our approach greatly reduces material usage (reaching parts as empty as 98%) and thus strongly reduces print time. Nevertheless it guarantees printability, and scales to very large inputs.

This work originated from the University of Limoges and was the master topic of Thibault Tricard, under the supervision of Frédéric Claux and in collaboration with Sylvain Lefebvre. The work was published in Computer Graphics Forum in June 2019 [16].

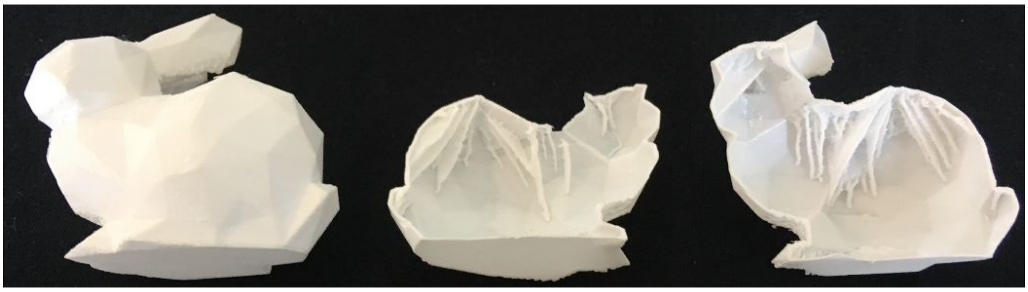

Figure 4. A 3D bunny model printed with our internal ribbed supports. It is mostly empty, with the ribbed vaults providing just enough support to prevent filament to fall during manufacturing.

7.5. CurviSlicer: Slightly curved slicing for 3-axis printers

Participants: Jimmy Étienne, Nicolas Ray, Daniele Panozzo, Samuel Hornus, Charlie C.l. Wang, Jonàs Martínez, Sara Mcmains, Marc Alexa, Brian Wyvill, Sylvain Lefebvre.

Most additive manufacturing processes fabricate objects by stacking planar layers of solidified material. As a result, produced parts exhibit a so-called staircase effect, which results from sampling slanted surfaces with parallel planes. Using thinner slices reduces this effect, but it always remains visible where layers almost align with the input surfaces. In this research we exploit the ability of some additive manufacturing processes to deposit material slightly out of plane to dramatically reduce these artifacts.

We focused in particular on the widespread Fused Filament Fabrication (FFF) technology, since most printers in this category can deposit along slightly curved paths, under deposition slope and thickness constraints. Our algorithm curves the layers, making them either follow the natural slope of the input surface or on the contrary, make them intersect the surfaces at a steeper angle thereby improving the sampling quality.

Rather than directly computing curved layers, our algorithm deforms the input model before slicing it with a standard planar approach. The deformation is optimized for reproduction accuracy. We demonstrate that this approach enables us to encode all fabrication constraints, including the guarantee of generating collision-free toolpaths, in a convex optimization that can be solved using a QP solver.

This work emerged from a problem solving session between its co-authors at the 17th international Bellairs Workshop on Computational Geometry (2018). It was then pursued during 2019 in the context of the PhD thesis of Jimmy Étienne and as a collaboration with Nicolas Ray (PIXEL, Inria). The work was published in ACM Transactions on Graphics in 2019 [11] and presented at ACM SIGGRAPH 2019 by Jimmy Étienne.

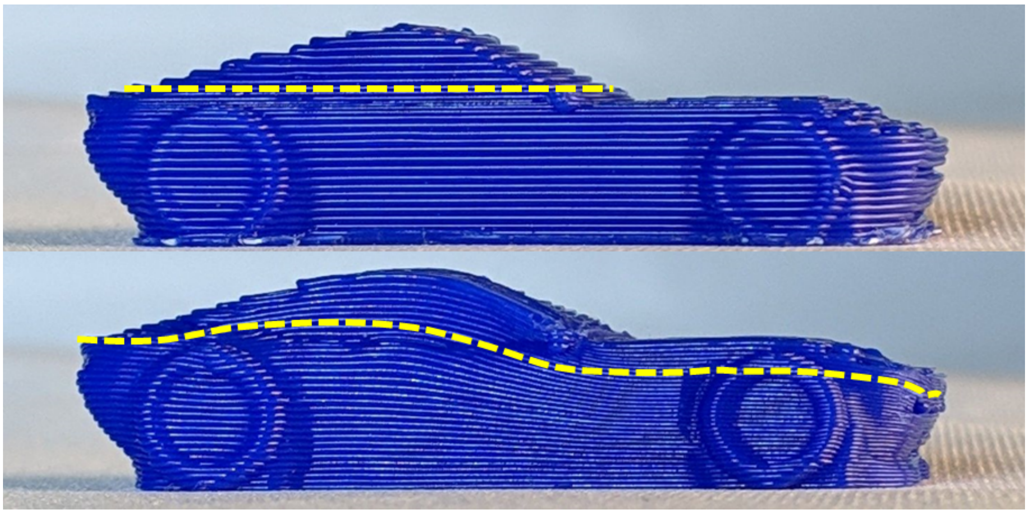

Figure 5. A 3D model printed with our technique. The algorithm automatically generates curved slices (right) to better reproduce the slanted surfaces, removing the staircase defect created by standard planar layers (top-left: standard, bottom-left: curved).

7.6. Extrusion-Based Ceramics Printing with Strictly-Continuous Deposition

Participants: Jean Hergel, Kevin Hinz, Bernhard Thomaszewski, Sylvain Lefebvre.

3D printing with extruded ceramic paste induces constraints that deviate significantly from standard thermoplastic materials. In particular existing path generation methods for thermoplastic materials rely on transfer moves to navigate between different print paths in a given layer. However, when printing with clay, these transfer moves can lead to severe artifacts and failure.

We explored how to eliminate transfer moves altogether by generating deposition paths that are continuous within and across layers. In each layer, we optimize a continuous support path with respect to length, smoothness, and distance to the model. Comparisons to existing path generation methods designed for thermoplastic materials show that our method substantially improves print quality and often makes the difference between success and failure.

This work was primarily done at the University of Montréal in collaboration with Sylvain Lefebvre. It was published in ACM Transactions on Graphics 2019 [13], and presented at SIGGRAPH Asia 2019 by Jean Hergel.

Figure 6. Our technique greatly improves the reliability of 3D printing with extruded clay.

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

8.1.1. Partnership with AddUp

- Company: AddUp.
- Duration: Started in 2019.
- Participants: Sylvain Lefebvre.
- Abstract: AddUp (https://www.addupsolutions.com/en/) is a French manufacturer of metal 3D printers for high-end industrial applications. We announced during FormNext 2019 (November) a partnership towards the creation of new software technologies.

8.1.2. Partnership with Black[Foundry]

- Company: Black[Foundry].
- Duration: January to June 2019.
- Participants: Samuel Hornus, Adrien Tétar.
- Abstract: Black[Foundry] is a company in Paris that specializes in font design. Inria signed a contract with the company to fund an internship on font rasterization on the GPU. An intern, Adrien Tétar, joined our team from January to June, and then spent 3 more weeks at the company offices in Paris. He was supervised by Samuel Hornus and Nicolas Rougier (Inria Bordeaux).

9. Partnerships and Cooperations

9.1. Regional Initiatives

9.1.1. Project Orthosis4D (2019-2022)

- Acronym: Orthosis4D.
- Title: Passive and active 3D printed orthosis: modeling, simulation and applications.
- Duration: 2019-2022.
- Funding: Lorraine Université d'Excellence.
- Coordinator: Sylvain Lefebvre.
- Participants: SylvainLefebvre, ThibaultTricard, Pierre-AlexandreHugron, Jean-BaptisteAustruy
- Other partners: IJL, LRGP, ERPI, IRR and Nancy CHU
- Abstract: The project considers the creation of flexible plates with controlled elasticity for use in medical applications (orthoses, insoles). It exemplifies our approach of doing focused collaborations around application domains of our research, to ensure that our techniques answer actual practical challenges and maximize the chances that they are deployed in the near future. On our side the project funds a PhD student, Thibault Tricard, who started in October 2018, a project manager, Jean-Baptiste Austruy, who started in May 2019 and a design engineer, Pierre-Alexandre Hugron, who started in April 2019.

  The project resulted in several publications this year [17], [11], [14]. We are also actively working with Bernhard Thomaszewski (University of Montréal) and Mélina Skouras (Inria Grenoble) within the scope of this project.

  Pierre-Alexandre Hugron started to interact with the medical partners, following the manufacturing process of orthopedic insoles at the IRR Louis Pierquin as well as producing and discussing 3D printed samples with practitioners to better understand their expectations and requirements. In particular, extensive tests have been conducted on the fabrication of different structures and density samples to mimic the current materials of insoles. Some of these samples are currently reviewed by the CHRU. These tests have resulted in an optimization of our 3D printing processes for a better accuracy and speed.

9.2. National Initiatives

9.2.1. ANR

9.2.1.1. Project MuFFin

- Acronym: MuFFin.
- Title: Procedural Stochastic Microstructures for Functional Fabrication.
- Duration: 2018-2021.
- Funding: ANR JCJC.
- Coordinator: Jonàs Martínez.
- Participants: Jonàs Martínez, Sylvain Lefebvre, Samuel Hornus, Semyon Efremov.
- Abstract:

  MuFFin aims at contributing a unified pipeline for the efficient and scalable synthesis, visualization, and modeling of additively manufactured microstructures with tailored macroscopic physical behavior. In an interdisciplinary effort, MuFFin will blend together computer and material science perspectives to deliver an integrated approach that is both computationally and physically sound.

  We have ongoing interdisciplinary collaborations with researchers in topology optimization (Perle Geoffroy-Donders and Grégoire Allaire at École Polytechnique), material science in the context of aeronautics (Mohamed amin Ben Lassoued, Ahmed Abbad, and Guilhem Michon at ISAE-SUPAREO, Annie Ross at Polytechnique Montréal), and deformable robotics (Félix Vanneste and Olivier Goury in the DEFROST Inria team).

9.2.1.2. Project IMPRIMA

- Acronym: IMPRIMA.
- Title: Implicit modeling for additive manufacturing.
- Duration: 2019-2023.
- Funding: ANR JCJC.
- Coordinator: Cédric Zanni.
- Participants: Cédric Zanni, Sylvain Lefebvre, Melike Aydinlilar.
- Abstract:

  Project IMPRIMA seek to explore novel implicit representations in order to provide a unified approach for the modeling and slicing of both macro geometry, microstructures and gradient of material. Additionally, this research aims at a complete, tight integration of both standard boundary representations and novel implicit volume representations, allowing the best choice of representation for different parts of a design.

  We have hired Melike Aydinlilar as a PhD student, starting from November 2019. We have an ongoing collaboration on skeleton-based implicit surfaces with Évelyne Hubert and Alvaro Fuentes in the AROMATH Inria team.

9.3. International Initiatives

9.3.1. Inria International Partners

9.3.1.1. Informal International Partners

We continued our informal international collaborations, in particular with Bernhard Thomaszewski (University of Montréal) on clay support structures [13] and microstructure design [14].

We are pursuing our joint research effort on slicing and curved 3D printing [11] with Charlie C.L. Wang (The Chinese University of Hong Kong), Sara McMains (University of California Berkeley), Brian Wyvill (University of Victoria), Daniele Panozzo (NYU), and Marc Alexa (TU-Berlin).

We have an ongoing collaboration with Tim Kuipers (TU Delft/Ultimaker) on algorithms for process planning.

9.3.2. Visits of International Scientists

We have invited Tim Kuipers, a developer at Ultimaker in the Netherlands, and a PhD student at TU Delft, to join us on an ongoing project in which Samuel Hornus and Sylvain Lefebvre are involved together with the GAMBLE team of Inria Nancy. Tim visited us in Nancy for 3 weeks in September.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events: Selection

10.1.1.1. Chair of Conference Program Committees

- Sylvain Lefebvre was a program co-chair for the SGP 2019 graduate school.

10.1.1.2. Member of the Conference Program Committees

- Jonàs Martínez was on the full papers program committee of EUROGRAPHICS 2020.
- Sylvain Lefebvre was a conflict of interest coordinator for ACM SIGGRAPH 2019.
- Sylvain Lefebvre was on the paper advisory board of EUROGRAPHICS 2020.
- Sylvain Lefebvre was on the papers program committee of SMI 2019.

10.1.1.3. Reviewer

- Jonàs Martínez was reviewer for ACM SIGGRAPH, Pacific Graphics, and the Symposium on Solid and Physical Modeling (SPM).
- Sylvain Lefebvre was a reviewer for ACM SIGGRAPH and ACM SIGGRAPH Asia.
- Samuel Hornus was a reviewer for ACM SIGGRAPH 2019, SPM 2019 (Symposium on Physical Modeling), HPG 2019 (High Performance Graphics) and EUROGRAPHICS 2020.

10.1.2. Journal

10.1.2.1. Reviewer - Reviewing Activities

- Jonàs Martínez was a reviewer for the ACM Transactions on Graphics journal and the SV–Journal of Mechanical Engineering.
- Cédric Zanni was a reviewer for the Elsevier Computer and Graphics journal and the Elsevier Graphical Models journal.
- Sylvain Lefebvre was a reviewer for the ACM Transactions on Graphics journal and the Computer Aided Geometric Design journal.
- Samuel Hornus was a reviewer for the Computer Graphics Forum journal.

10.1.3. Invited Talks

Jonàs Martínez gave an invited talk at Journées Matériaux Numériques 2019 entitled “Generalized Voronoi Diagrams for Metamaterial Design”.

Sylvain Lefebvre gave a keynote at SCF 2019 (Pitsburg, USA), at the IS2M annual meeting (Mulhouse, France) and at the JGA 2019 (La Bresse, France).

10.1.4. Research Administration

Jonàs Martínez is the scientific correspondent for Europe (Inria Nancy Grand-Est). Samuel Hornus is the chair of the CDT (Commission de dévelopement technologique) of Inria Nancy Grand-Est.

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Master : Jonàs Martínez, Introduction to data parallelism, 14 ETD, Université de Lorraine, France.

Master : Jonàs Martínez, Geometric modelling for additive manufacturing, 10 ETD, ENSEM Nancy, France.

Master: Cédric Zanni, Software Engineering, 13.5h ETD, M1, École des Mines de Nancy, France.

Master: Cédric Zanni, Operating System, 12h ETD, M1, École des Mines de Nancy, France.

Master: Cédric Zanni, Introduction to C/C++, 27h ETD, M1, École des Mines de Nancy, France.

Master: Cédric Zanni, Techniques for video game programming, 54h ETD, M1, École des Mines de Nancy, France.

Master: Sylvain Lefebvre, Additive manufacturing for soft robotics, 6h ETD, École Polytechnique, Saclay, France.

Master: Sylvain Lefebvre, Introduction to parallel programming, 9h ETD, ENSG Nancy, France.

Master: Sylvain Lefebvre, Introduction to additive manufacturing, 9h ETD, ENSEM Nancy, France.

License : Cédric Zanni, Computer science, 11h ETD, École des Mines de Nancy, France.

License : Cédric Zanni, Introduction to Computer Science, 13.5h ETD, École des Mines de Nancy, France.

License : Samuel Hornus, Mathematics for Computer Science, 64h ETD, Télécom Nancy, France. (responsible of class series for 2019-2020, 2020-2021.)

IUT: Thibault Tricard, Data structures, data bases, 40h ETD.

IUT: Jimmy Étienne, Introduction to programming, 64h ETD.

10.2.2. Supervision

- PhD in progress : Thibault Tricard, Procedural synthesis of structured patterns, started October 2018, advisors: Sylvain Lefebvre, Dider Rouxel (IJL).
- PhD in progress : Jimmy Étienne, Curved slicing for additive manufacturing, started September 2018, advisors: Sylvain Lefebvre, Cédric Zanni
- PhD in progress : Semyon Efremov, procedural microstructures for additive manufacturing, started October 2018, advisors: Jonàs Martínez, Sylvain Lefebvre
- PhD in progress : Melike Aydinlilar, Implicit modeling for additive manufacturing, started November 2019, advisors: Cédric Zanni, Sylvain Lefebvre.

10.2.3. Juries

Sylvain Lefebvre was reviewer (*rapporteur)* on the PhD thesis of Geoffroy Guingo (University of Strasbourg) and participated in the thesis mid-term committees of Nicolas Lutz et Pascal Guehl (University of Strasbourg).

Sylvain Lefebvre was a member of the jury for the Young Researcher Fellow EGFR, which awards every year a young French researcher with outstanding research and community contributions in the field of Computer Graphics.

10.3. Popularization

10.3.1. Articles and contents

Sylvain Lefebvre co-authored a position paper for NEM on Creative AI [18], and appeared in a short movie on the Creativ'Lab's shared fabrication space and MFX's research.

10.3.2. Interventions

In March 2019, IceSL was presented at the **Maker Faire Lille**, with a focus on color printing, printing big parts using cavities and polyfoams (all results from prior years now available in IceSL). IceSL was presented during an **Inria Tech Talk at Station-F** in Paris, along with a display of best prints [0].

In April 2019, IceSL was presented to an audience of designers for the second part of **Affinité Design** (http://www.affinitedesign.com/), with a discussion about the transition from 3D printing to "4D printing", in a joint talk with Sylvain Lefebvre, Jean-Claude André and Samuel Kenzari (http://www.nancy.archi.fr/fr/biennale-du-design-grand-est-2019_-e.html). In October 2019, Pierre Bedell and Pierre-Alexandre Hugron presented IceSL at **OctoberMAKE**, a meeting organised by the French FabLabs network (http://www.fablab.fr/octobermake/). Sylvain Lefebvre gave an IceSL tutorial at the **Soft Robotics days** in Lille (https://jrs2019.sciencesconf.org/). Sylvain Lefebvre created quick tutorial videos on Youtube (channel *icesl-fr*), to help introduce new users to IceSL.

Sylvain Lefebvre gave a presentation at **Grand-Est Numerique** 2019, geared towards start-ups, presenting results from MFX.

10.3.3. Internal action

The team actively participated to the inauguration of the Creativ'Lab space in December 2019.

11. Bibliography

Major publications by the team in recent years

[1] M. ALEXA, K. HILDEBRAND, S. LEFEBVRE.*Optimal discrete slicing*, in "ACM Transactions on Graphics", February 2017, vol. 36, n^o^ 1, p. 1 - 16 [*DOI :* 10.1145/2999536], https://hal.inria.fr/hal-01660773

[2] J. DUMAS, J. HERGEL, S. LEFEBVRE.*Bridging the Gap: Automated Steady Scaffoldings for 3D Printing*, in "ACM Transactions on Graphics", July 2014, vol. 33, n^o^ 4, p. 98:1 - 98:10 [*DOI :* 10.1145/2601097.2601153], https://hal.inria.fr/hal-01100737

[3] I. GARCÍA, S. LEFEBVRE, S. HORNUS, A. LASRAM.*Coherent Parallel Hashing*, in "ACM Transactions on Graphics", December 2011, vol. 30, n^o^ 6, https://hal.inria.fr/inria-00624777

[4] S. LEFEBVRE, S. HORNUS, A. LASRAM.*By-example Synthesis of Architectural Textures*, in "ACM Transactions on Graphics", July 2010, vol. 29, n^o^ 4, p. 84:1-8 [*DOI :* 10.1145/1778765.1778821], https://hal.inria.fr/inria-00547754

[5] A. LU, S. LEFEBVRE, J. DUMAS, J. WU, C. DICK.*By-example synthesis of structurally sound patterns*, in "ACM Transactions on Graphics", 2015 [*DOI :* 10.1145/2766984], https://hal.inria.fr/hal-01240392

[6] J. MARTÍNEZ, J. DUMAS, S. LEFEBVRE.*Procedural Voronoi Foams for Additive Manufacturing*, in "ACM Transactions on Graphics", 2016, vol. 35, p. 1 - 12 [*DOI :* 10.1145/2897824.2925922], https://hal.archives-ouvertes.fr/hal-01393741

[7] J. MARTÍNEZ, J. DUMAS, S. LEFEBVRE, L.-Y. WEI.*Structure and appearance optimization for controllable shape design*, in "ACM Transactions on Graphics", November 2015, vol. 34, n^o^ 6, 12 [*DOI :* 10.1145/2816795.2818101], https://hal.inria.fr/hal-01240642

[0] https://french-tech-central.com/events/du-modele-3d-a-la-piece-fabriquee-utilisez-icesl-pour-vos-prototypages/

[8] J. MARTÍNEZ, H. SONG, J. DUMAS, S. LEFEBVRE.*Orthotropic k-nearest foams for additive manufacturing*, in "ACM Transactions on Graphics", July 2017, vol. 36, n^o 4, p. 121:1–121:12 [*DOI :* 10.1145/3072959.3073638], https://hal.archives-ouvertes.fr/hal-01577859

[9] J. MARTÍNEZ, S. HORNUS, H. SONG, S. LEFEBVRE.*Polyhedral Voronoi diagrams for additive manufacturing*, in "ACM Transactions on Graphics", August 2018, vol. 37, n^o 4, 15 [*DOI :* 10.1145/3197517.3201343], https://hal.inria.fr/hal-01697103

[10] R. PRÉVOST, E. WHITING, S. LEFEBVRE, O. SORKINE-HORNUNG.*Make It Stand: Balancing Shapes for 3D Fabrication*, in "ACM Transactions on Graphics", 2013, vol. 32, n^o 4, Article No. 81 [*DOI :* 10.1145/2461912.2461957], https://hal.inria.fr/hal-00926855

Publications of the year

Articles in International Peer-Reviewed Journal

[11] J. ETIENNE, N. RAY, D. PANOZZO, S. HORNUS, C. C. WANG, J. MARTÍNEZ, S. MCMAINS, M. ALEXA, B. WYVILL, S. LEFEBVRE.*CurviSlicer: Slightly curved slicing for 3-axis printers*, in "ACM Transactions on Graphics", 2019, vol. 38, forthcoming [*DOI :* 10.1145/3306346.3323022], https://hal.archives-ouvertes.fr/hal-02120033

[12] A. J. FUENTES SUÁREZ, E. HUBERT, C. ZANNI.*Anisotropic convolution surfaces*, in "Computers and Graphics", 2019, vol. 82, p. 106-116 [*DOI :* 10.1016/J.CAG.2019.05.018], https://hal.inria.fr/hal-02137325

[13] J. HERGEL, K. HINZ, S. LEFEBVRE, B. THOMASZEWSKI.*Extrusion-Based Ceramics Printing with Strictly-Continuous Deposition*, in "ACM Transactions on Graphics", November 2019 [*DOI :* 10.1145/3355089.3356509], https://hal.inria.fr/hal-02363424

[14] J. MARTÍNEZ, M. SKOURAS, C. SCHUMACHER, S. HORNUS, S. LEFEBVRE, B. THOMASZEWSKI.*Star-Shaped Metrics for Mechanical Metamaterial Design*, in "ACM Transactions on Graphics", July 2019, vol. 38, n^o 4, p. Article No. 82 :1-13, Special issue, SIGGRAPH 2019 [*DOI :* 10.1145/3306346.3322989], https://hal.inria.fr/hal-02118846

[15] H. SONG, J. MARTÍNEZ, P. BEDELL, N. VENNIN, S. LEFEBVRE.*Colored fused filament fabrication*, in "ACM Transactions on Graphics", June 2019, vol. 38, n^o 5, p. 1-11 [*DOI :* 10.1145/3183793], https://hal.inria.fr/hal-01660621

[16] T. TRICARD, F. CLAUX, S. LEFEBVRE.*Ribbed support vaults for 3D printing of hollowed objects*, in "Computer Graphics Forum", June 2019 [*DOI :* 10.1111/CGF.13750], https://hal.archives-ouvertes.fr/hal-02155929

[17] T. TRICARD, S. EFREMOV, C. ZANNI, F. NEYRET, J. MARTÍNEZ, S. LEFEBVRE.*Procedural Phasor Noise*, in "ACM Transactions on Graphics", July 2019, vol. 38, n^o 4, p. Article No. 57:1-13 [*DOI :* 10.1145/3306346.3322990], https://hal.archives-ouvertes.fr/hal-02118508

Research Reports

[18] B. CARAMIAUX, F. LOTTE, J. GEURTS, G. AMATO, M. BEHRMANN, F. BIMBOT, F. FALCHI, A. GARCIA, J. GIBERT, G. GRAVIER, H. HOLKEN, H. KOENITZ, S. LEFEBVRE, A. LIUTKUS, A. PERKIS, R.

REDONDO, E. TURRIN, T. VIÉVILLE, E. VINCENT.*AI in the media and creative industries*, New European Media (NEM), April 2019, p. 1-35, https://arxiv.org/abs/1905.04175 , https://hal.inria.fr/hal-02125504

[19] S. LEFEBVRE.*Efficient Direct Slicing Of Dilated And Eroded 3d Models For Additive Manufacturing: Technical Report*, Inria Nancy - Grand Est, November 2019, https://arxiv.org/abs/1911.05992 , https://hal.inria.fr/hal-02360401

References in notes

[20] M. ALEXA, K. HILDEBRAND, S. LEFEBVRE.*Optimal discrete slicing*, in "ACM Transactions on Graphics", February 2017, vol. 36, n^{o} 1, p. 1 - 16 [*DOI :* 10.1145/2999536], https://hal.inria.fr/hal-01660773

[21] C. DAI, C. C. WANG, C. WU, S. LEFEBVRE, G. FANG, Y.-J. LIU.*Support-free volume printing by multi-axis motion*, in "ACM Transactions on Graphics", July 2018, vol. 37, n^{o} 4, p. 1 - 14 [*DOI :* 10.1145/3197517.3201342], https://hal.inria.fr/hal-01887571

[22] H. SONG, S. LEFEBVRE.*Colored fused filament fabrication*, December 2017, working paper or preprint, https://hal.inria.fr/hal-01660621

Team MIMESIS

Computational Anatomy and Simulation for Medicine

Inria teams are typically groups of researchers working on the definition of a common project, and objectives, with the goal to arrive at the creation of a project-team. Such project-teams may include other partners (universities or research institutions).

RESEARCH CENTER
Nancy - Grand Est

THEME
Computational Neuroscience and Medicine

Table of contents

Team MIMESIS

Creation of the Team: 2015 July 01

Keywords:

Computer Science and Digital Science:

A2.5. - Software engineering
A3.1.1. - Modeling, representation
A3.1.4. - Uncertain data
A3.2.2. - Knowledge extraction, cleaning
A5.1. - Human-Computer Interaction
A5.3.4. - Registration
A5.4.4. - 3D and spatio-temporal reconstruction
A5.4.5. - Object tracking and motion analysis
A5.6. - Virtual reality, augmented reality
A6.1.1. - Continuous Modeling (PDE, ODE)
A6.1.5. - Multiphysics modeling
A6.2.8. - Computational geometry and meshes
A6.3.1. - Inverse problems
A6.3.2. - Data assimilation
A6.3.4. - Model reduction
A9.2. - Machine learning
A9.10. - Hybrid approaches for AI

Other Research Topics and Application Domains:

B2.4. - Therapies
B2.4.3. - Surgery
B2.6. - Biological and medical imaging
B2.7. - Medical devices
B2.7.1. - Surgical devices

1. Team, Visitors, External Collaborators

Research Scientists

Stéphane Cotin [Team leader, Inria, Senior Researcher, HDR]
Hadrien Courtecuisse [CNRS, Researcher]
Axel Hutt [Inria, Senior Researcher, from Nov 2019, HDR]
Igor Peterlik [Inria, Researcher, until Jul 2019]

External Collaborators

Rémi Bessard Duparc [IHU Strasbourg, from Oct 2019]
David Cazier [Univ de Strasbourg, HDR]
Julia Coste Marin [Univ de Strasbourg, from Sep 2019]

Technical Staff

Rémi Bessard Duparc [Univ de Strasbourg, Engineer, until Sep 2019]
Mohamed Omar Boukhris [Inria, Engineer, from Feb 2019]

Frederick Roy [Univ de Strasbourg, Engineer, until Jun 2019]

PhD Students

Paul Baksic [Univ de Strasbourg, PhD Student]
Jean-Nicolas Brunet [Inria, PhD Student]
Jaime Garcia Guevara [Inria, PhD Student, until Mar 2019]
Andréa Mendizabal [Univ de Strasbourg, PhD Student]
Guillaume Mestdagh [Univ de Strasbourg, PhD Student, from Oct 2019]
Sergei Nikolaev [Inria, PhD Student]
Alban Odot [Inria, PhD Student, from Oct 2019]
Raffaella Trivisonne [Inria, PhD Student, until Jun 2019]
Ziqiu Zeng [Univ de Strasbourg, PhD Student, from Jul 2019]

Post-Doctoral Fellows

Nava Schulmann [Politecnico di Milano, PostDoc, from November 2019]
Mohamed Ryadh Haferssas [Inria, Post-Doctoral Fellow]
Antoine Petit [Inria, Post-Doctoral Fellow, until May 2019]

Visiting Scientist

Eleonora Tagliabue [Verona University, PhD Student, from May 2019 until Jun 2019]

Administrative Assistant

Ouiza Herbi [Inria, Administrative Assistant]

2. Overall Objectives

2.1. Team Overview

The MIMESIS team is developing **advanced numerical simulations** in the context of **surgical training, planning and per-operative guidance** (see Fig. 1). The underlying objectives include **patient-specific biophysical modeling**, novel **numerical techniques for real-time computation**, data assimilation using Bayesian methods and more generally **data-driven simulation**. This last topic is a transverse research theme which raises several open problems, related to the field of machine learning. To pursue these directions we have assembled a team with a multidisciplinary background, and have established close collaborations with academic and clinical partners, in particular the IHU institute in Strasbourg. We also continue the development of the SOFA framework through the creation of a consortium, to better support the increasingly large community of users.

2.2. Challenges

Image-guided therapy has revolutionized medicine, in its ability to provide care that is both efficient and effective. However, images acquired during an intervention are either incomplete, under-exploited or can induce adverse outcomes. This can be due, for instance, to the lack of dimensionality of X ray images and the associated radiation exposure for the patient. We believe that by combining our expertise in real-time numerical simulation (of soft tissues, flexible medical devices, and complex interactions) with data extracted from intra-operative images, we could **provide efficient per-operative guidance**. To reach these objectives we need to solve challenges that lie at the intersection of several scientific domains. They include the **development of novel numerical strategies** (to enable real-time computation even with the increase in complexity of future models), and **data-driven simulation** (to link simulation with real world data).

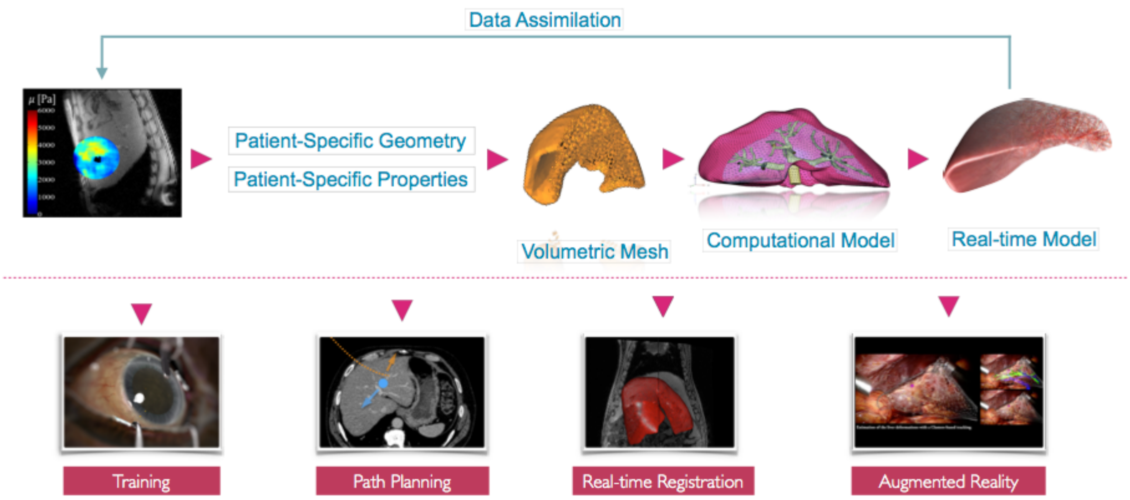

Figure 1. Data-driven simulations: from surgical training to patient-specific intra-operative computer-aided intervention.

3. Research Program

3.1. Real-time computational models for interactive applications

The principal objective of this challenge is to improve, at the numerical level, the efficiency, robustness, and quality of the simulations (see Fig. 2). An important part of our research is dedicated to the development of computational models that remain compatible with real-time computation, i.e., which allow immediate visual or haptic feedback. This typically requires computation times below $50ms$ and in some cases around $1ms$. Such advanced models can not only increase the realism of future training systems, but also act as a bridge toward the development of patient-specific solutions for computer-aided interventions. Additionally, such simulations should run on (high-end) consumer level computers (i.e. with a single multi-core CPU and a dedicated GPU). To reach these goals, we are investigating novel finite element techniques able to cope with complex, potentially ill-defined input data. After developing Smoothed FEM for real-time simulations, we are developing meshless techniques and immersed boundary methods. The first one is well suited for topological changes, which we sometimes need to account for in our simulations. The second is expected to lead to more stable, and numerically efficient, formulations of the finite element method. We are also developing numerical techniques to compute the complex interactions that can take place between anatomical structures or between medical devices and organs. Boundary conditions are known to also play an important role in the solution of such problems. Therefore we are investigating solutions to both identify and model the interactions that take place between the structure of interest and its anatomical environment.

3.2. Data-driven simulations

Data-driven simulation has been a recent area of research in our team (see Fig. 3). We have demonstrated that it has the potential to bridge the gap between medical imaging and clinical routine by adapting pre-operative data to the time of the procedure. In the areas of non-rigid registration and augmented reality during surgery, we have demonstrated the benefit of our physics-based approaches with several key publications in major conferences (MICCAI, CVPR, IPCAI, ISMAR).

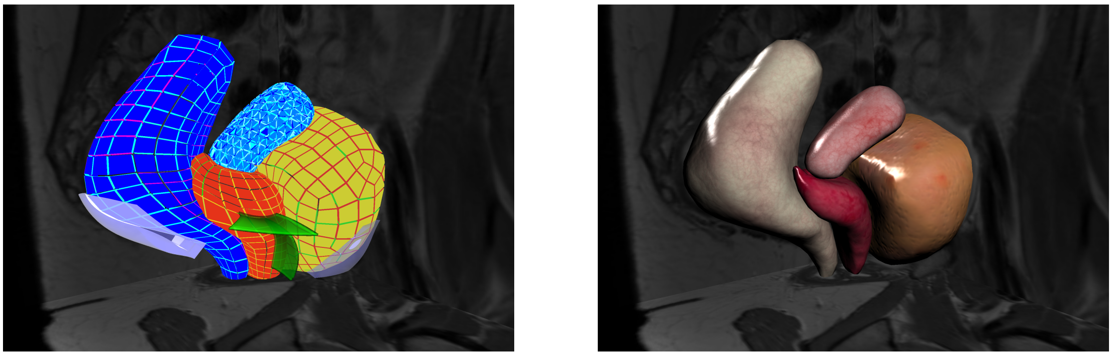

Figure 2. Model of the pelvis with (left) the finite element models of different anatomical structures and (right) their visual representations. Complex interactions take place between these deformable structures. The simulation is computed at interactive rates

We have continued this work with an **emphasis on robustness to uncertainty and outliers** in the information extracted in real-time from image data, as well as real-time parameter estimation. This is currently done by **combining Bayesian methods with advanced physics-based methods** to handle uncertainties in image-driven simulations (MICCAI 2017, CVCS 2018).

Finally, Bayesian or similar methods require to perform a large amount of simulations to sample the domain space, even when using efficient methods such as Reduced Order Unscented Kalman Filters. For this reason, we are investigating the use of neural networks to perform predictions instead of using full numerical simulations. Our latest paper [22] at MICCAI 2019 shows it is possible to **teach a neural network from numerical simulations** and **predict**, with good accuracy, **the deformation of an organ**.

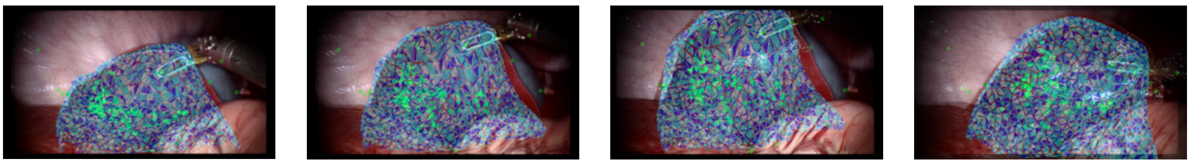

Figure 3. Real-time deformation of a virtual liver according to tissue motion tracked in laparoscopic images.

4. Application Domains

4.1. Surgical training

Virtual training helps medical students to get familiar with surgical procedures before manipulation of real patients. The development of simulation used for medical training usually requires important computational power, since realistic behaviors are key to deliver a high-fidelity experience to the trainee. Further, the quality of interaction with the simulator (usually via visual and haptic rendering) is also of paramount importance. All these constraints make the development of training systems time-consuming, thus limiting the deployment of virtual simulators in standard medical curriculum.

4.2. Pre-operative planning

Beyond training, clinicians ask for innovative tools that can assist them in the pre-operative planning of an intervention. Using the patient information acquired before the operation, physics-based simulations allow to simulate the effect of therapy with no risk to the patient. The clinicians can thus virtually assess different strategies and select the optimal procedure. Compared to a training simulation, a planning system requires a high accuracy to ensure reliability. Constrained by the time elapsed between the preoperative acquisition and the intervention, the computation must also be efficient.

4.3. Intra-operative guidance

Besides the surgery training and planning, another major need from clinicians is surgical guidance. While the clinician is performing the operation, a guidance system provides enriched visual feedback. This is especially useful with the emergence of minimally invasive surgery (MIS) where the visual information is often strongly limited. It can be used for example to avoid critical areas such as vessels or to highlight the position of a tumor during its resection. In the MIS technique, the clinician does not interact with organs directly as in the open surgery, but manipulates instruments inserted through trocars placed in small incisions in the wall of the abdominal cavity. The surgeon can observe these instruments on a display showing a video stream captured by an endoscopic camera inserted through the navel. The main advantage of the method resides in reducing pain and time recovery, in addition to reducing bleeding and risks of infection. However, from a surgical standpoint, the procedure is quite complex since the field of view is considerably reduced and the direct manipulation of organs is not possible.

5. Highlights of the Year

5.1. Highlights of the Year

- Our paper entitled "Physics-based Deep Neural Network for Augmented Reality during Liver Surgery" was selected for oral presentation at the MICCAI conference in Shenzhen China and presented to more than 2,000 attendees [22]. In this work we demonstrated that it is possible to combine a neural network with physics-based simulation to reproduce the deformation of a complex organ.
- SOFA, our open source simulation software, continues to grow and attract scientists and companies. New results were presented during the SOFA week in November at Station F in Paris. Three start-ups created by former SOFA engineers or researchers, were among the attendees.

6. New Software and Platforms

6.1. SOFA

Simulation Open Framework Architecture

KEYWORDS: Real time - Multi-physics simulation - Medical applications

FUNCTIONAL DESCRIPTION: SOFA is an Open Source framework primarily targeted at real-time simulation, with an emphasis on medical simulation. It is mostly intended for the research community to help develop new algorithms, but can also be used as an efficient prototyping tool. Based on an advanced software architecture, it allows : the creation of complex and evolving simulations by combining new algorithms with algorithms already included in SOFA, the modification of most parameters of the simulation (deformable behavior, surface representation, solver, constraints, collision algorithm, etc.) by simply editing an XML file, the building of complex models from simpler ones using a scene-graph description, the efficient simulation of the dynamics of interacting objects using abstract equation solvers, the reuse and easy comparison of a variety of available methods.

- Participants: Christian Duriez, François Faure, Hervé Delingette and Stéphane Cotin
- Partner: IGG
- Contact: Hugo Talbot
- URL: http://www.sofa-framework.org

6.2. SofaNeedleInsertion

Needle Insertion Plugin

KEYWORD: Simulation

FUNCTIONAL DESCRIPTION: This plugin contains needle/tissue interaction models for real-time simulations of needle insertion in deformable objects using the open-source sofa frame-work. This allows for modeling the different forces playing a role during the insertion process (penetration forces, friction along the shaft...) using a constrained-based formulation. This formulation provides a fast and stable solution for the simulation of complex insertions (and reinsertion) of the needle in deformations Finite Element models

- Contact: Hadrien Courtecuisse

6.3. SOFA Optimus

Optimization methods in SOFA: stochastic filtering and data assimilation.

KEYWORDS: Data assimilation - Kalman filter - Stochastic optimization

FUNCTIONAL DESCRIPTION: Optimus is a plugin to work with advanced methods of state estimation and parameter identification. It was created to provide a testing environment for data-driven physics-based modeling (typically finite elements). While currently the plugin implements only stochastic methods based on Kalman filtering, its architecture allows for the implementation of generic prediction–correction schemes where the model is employed as a predictor and correction is performed using given observation data.

- Contact: Stéphane Cotin
- URL: https://gitlab.inria.fr/mimesis/Optimus

7. New Results

7.1. Real-time simulation of hyperelastic materials using Deep Learning

Participants: Andrea Mendizabal, Pablo Márquez-Neila, Stéphane Cotin.

The finite element method (FEM) is among the most commonly used numerical methods for solving engineering problems. Due to its computational cost, various ideas have been introduced to reduce computation times, such as domain decomposition, parallel computing, adaptive meshing, and model order reduction. In this work we propose the U-Mesh: a data-driven method based on a U-Net architecture that approximates the non-linear relation between a contact force and the displacement field computed by FE algorithm. We show that deep learning, one of the latest machine learning methods based on artificial neural networks, can enhance computational mechanics through its ability to encode highly non-linear models in a compact form. Our method is applied to three benchmark examples: a cantilever beam, an L-shape and a liver model subject to moving punctual loads. A comparison between our method and proper orthogonal decomposition (POD) is done. The results show that U-Mesh can perform very fast simulations on various geometries and topologies, mesh resolutions and number of input forces with very small errors. results were published in the Journal of Medical Image Analysis [23] (impact factor 8.5).

7.2. FEM-based confidence assessment of non-rigid registration

Participants: Paul Baksic, Hadrien Courtecuisse, Matthieu Chabanas, Bernard Bayle.

Non-rigid registration is often used for 3D representations during surgical procedures. It needs to provide good precision in order to guide the surgeon properly. We proposed in [25] a method that allows the computation of a local upper bound of the registration confidence over the whole organ volume. Using a bio-mechanical model, we apply tearing forces over the whole organ to compute the upper bound of the degrees of freedom left by the registrations constraints. Confrontation of our method with experimental data shows promising results to estimate the registration confidence. Indeed, the computed maximum error appears to be a real upper bound(see figure 4). A more advanced method was submitted at IPCAI 2020.

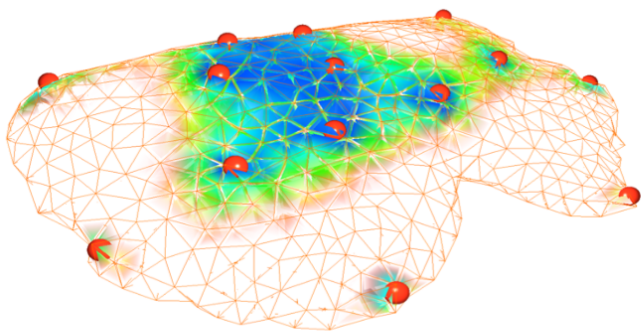

Figure 4. This is an example of confidence map given by our method on a registration of a lamb liver. The red dots are the registration constraint given by sensors. High confidence area are presented in blue. The area where the confidence is below the one needed for the surgery appears transparent.

7.3. Physics-based Deep Neural Network for Augmented Reality

Participants: Jean-Nicolas Brunet, Andrea Mendizabal, Antoine Petit, Nicolas Golse, Eric Vibert, Stéphane Cotin.

We propose an approach combining a finite element method and a deep neural network to learn complex elastic deformations with the objective of providing augmented reality during hepatic surgery. Derived from the U-Net architecture, our network is built entirely from physics-based simulations of a preoperative segmentation of the organ (see figure 5). These simulations are performed using an immersed-boundary method, which offers several numerical and practical benefits, such as not requiring boundary-conforming volume elements. We perform a quantitative assessment of the method using synthetic and *ex vivo* patient data. Results show that the network is capable of solving the deformed state of the organ using only a sparse partial surface displacement data and achieve similar accuracy as a FEM solution, while being about 100x faster. When applied to an *ex vivo* liver example, we achieve the registration in only $3\,ms$ with a mean target registration error (TRE) of $2.9\,mm$. This results were presented at MICCAI 2019 [22].

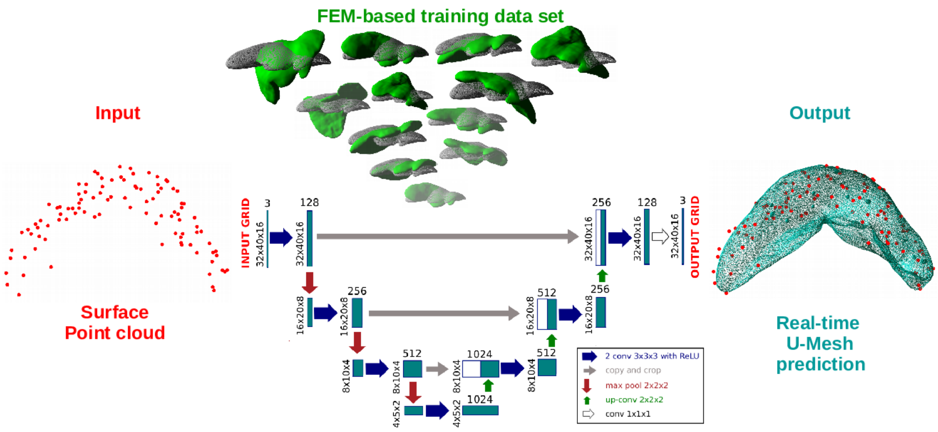

Figure 5. The U-Mesh framework allows for extremely fast simulations of soft tissues accounting for large non linear deformations.

7.4. Estimation of boundary conditions for patient-specific liver simulation during augmented surgery

Participants: Sergei Nikolaev, Stéphane Cotin.

Augmented liver surgery is an active research area that aims at improving the surgical outcome by enhancing the view of internal structures. However, to precisely estimate the position of these, an accurate model of the liver is required. While researchers have focused on proposing new models, algorithms for real-time computation or estimation of the tissue properties, very few have addressed the question of boundary conditions. Yet, they play a key role in the computation of the deformation. Boundary conditions mainly result from ligaments connecting the liver to its surrounding anatomy and limiting its motion. Unfortunately, ligaments' shapes and properties cannot be identified with preoperative imaging. We propose to estimate both the location and stiffness of ligaments by using a combination of a statistical atlas, numerical simulation, and Bayesian inference (fig. 6). Ligaments are modeled as polynomial springs connected to a liver finite element model. Their original location on the liver is based on an anatomical atlas, and their initial stiffness is taken from the literature. These characteristics are then corrected using a reduced order unscented Kalman filter based on observations taken from the laparoscopic image stream. Our approach is evaluated using synthetic data and phantom data. Results show that our estimation of the boundary conditions improves the accuracy of the simulation by 75% when compared to typical methods involving Dirichlet boundary conditions. The results were submitted for a presentation at IPCAI 2020

7.5. Corotated meshless implicit dynamics for deformable bodies

Participants: Jean-Nicolas Brunet, Vincent Magnoux, Benoît Ozell, Stéphane Cotin.

We proposed a fast, stable and accurate meshless method to simulate geometrically non-linear elastic behaviors. To address the inherent limitations of finite element (FE) models, the discretization of the domain is simplified by removing the need to create polyhedral elements. The volumetric locking effect exhibited by incompressible materials in some linear FE models is also completely avoided. Our approach merely requires that the volume of the object be filled with a cloud of points (see figure 7). To minimize numerical errors, we constructed a corotational formulation around the quadrature positions that is well suited for large displacements containing small deformations. The equations of motion was integrated in time following an implicit

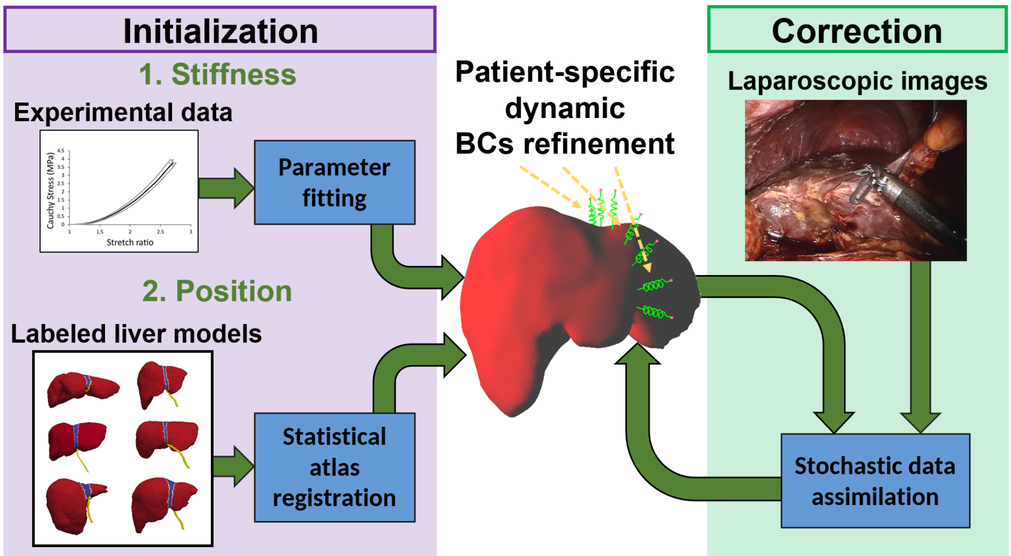

Figure 6. Overview of the boundary condition identification process. It contains two main steps. 1 - Initial approximation based on statistics from the processed model database and experimental data. 2 - Identification based on intraoperative patient-specific images.

scheme. The convergence rate and accuracy were validated through both stretching and bending case studies. Finally, results were presented using a set of examples that show how we can easily build a realistic physical model of various deformable bodies with little effort spent on the discretization of the domain. We presented our work at WSCG 2019 [21]. (Fig. 7).

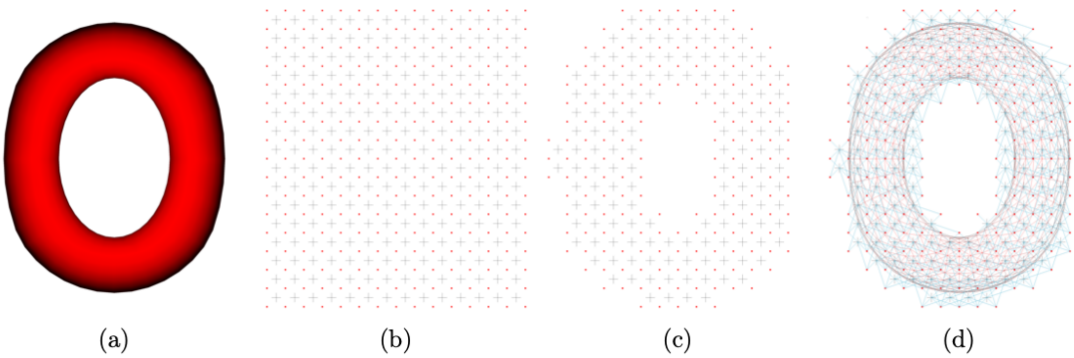

Figure 7. Volumetric discretizations of a 3D surface. (a) Surface mesh provided by the user. (b) Background grid where the grid's cubes are used to place the DOFs(degrees of freedom) and the integration points. (c) DOFs and integration points are cropped to fit the surface mesh. (d) A neighborhood of the closest particles is built around each integration point.

7.6. The effect of discretization on parameter identification. Application to patient-specific simulations

Participants: Nava Schulmann, Igor Peterlik, Stéphane Cotin.

Identifying the elastic parameters of a finite element model from a dynamically acquired set of observations is a fundamental challenge in many data-driven medical applications, from soft surgical robotics to image-guided per-operative simulations. While various strategies exist to tackle the parameter-identification inverse problem [29], the effect of sub-optimal discretization, as often required in real-time applications, is largely overlooked. Indeed, the need to tune the parameter values in order to account for discretization-induced stiffening in specific models is reported in different works (e.g. [Chen et al., 2015, Anna et al., 2018]). However, to the best of our knowledge, no systematic study of this phenomenon exists to date, nor has any strategy to select optimal effective values been developed. Our work addresses the issue of parameter identification in coarsened meshes with special attention to the dynamical nature of the identification. We focus on the estimation of Young's moduli in simplified systems and show that the estimated stiffnesses are underestimated in a systematic manner when reducing the number of degrees of freedom. We also show that the effective stiffness of a given coarse mesh, when associated with an undersampled mesh discretization, is not constant but strongly depends on the prescribed deformations. These results show that the estimated parameters should not be considered as the true parameter value of the organ or tissue but instead are model-dependent values. We argue that Bayesian methods present a clear advantage w.r.t. classical minimization methods by their ability to efficiently adapt the local parameter values. The results were presented at CMBBE 2019 [26].

7.7. Elastic registration based on biomechanical graph matching

Participants: Jaime Garcia Guevara, Igor Peterlik, Marie-Odile Berger, Stéphane Cotin.

An automatic elastic registration method suited for vascularized organs is proposed. The vasculature in both the preoperative and intra-operative images is represented as a graph. A typical application of this method is the fusion of pre-operative information onto the organ during surgery, to compensate for the limited details provided by the intra-operative imaging modality (e.g. CBCT) and to cope with changes in the shape of the organ. Due differences in image modalities and organ deformation, each graph has a different topology and shape. The Adaptive Compliance Graph Matching (ACGM) method presented does not require any manual initialization, handles intra-operative nonrigid deformations of up to 65 mm and computes a complete displacement field over the organ from only the matched vasculature. ACGM is better than the previous Biomechanical Graph Matching method [3] (BGM) because it uses an efficient biomechanical vascularized liver model to compute the organ's transformation and compliance of vessel bifurcations. It allows to efficiently find the best graph matches with a novel compliance-based adaptive search. These contributions are evaluated on ten realistic synthetic and two real porcine automatically segmented datasets. ACGM obtains better target registration error (TRE) than BGM, with an average TRE in the real datasets of 4.2 mm compared to 6.5 mm, respectively. It also is up to one order of magnitude faster, less dependent on the parameters used and more robust to noise. Figure 8 depicts the large deformation and the registered porcine CBCT and CTA data. Results were published in Annals of Biomedical Engineering (2019) [4].

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

- **Siemens:** A global leader in healthcare industry. Via IHU, we collaborate with Siemens in the context of the IHU project CIOS Alpha Fusion dealing with augmentation of the intra-operative image provided by a fluoroscopic imaging modality with pre-operative data.
- **Naviworks:** A South Korean company specialized in ICT convergence simulation/IoT smart controlling. We collaborate on simulation and visualization in the context of interventional radiology.

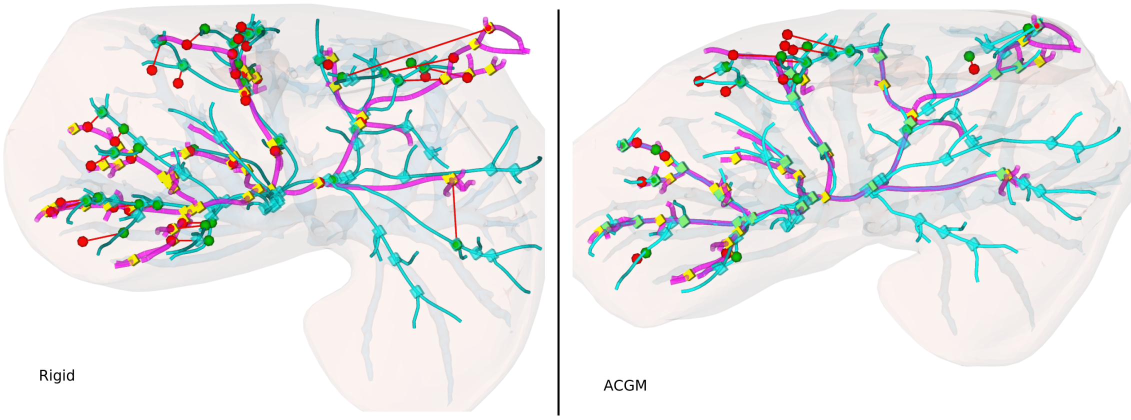

Figure 8. Registration between CTA and CBCT images. The target CBCT (in pink) and source CTA (in cyan) portal vein graphs are rendered with tubular structures. The graph nodes (bifurcations) are shown as cubic markers (in yellow for the target, cyan for the source and green for the matched). The augmented hepatic vein, which was only visible in the CTA image, is in transparent blue behind the portal veins graphs. The 37 target evaluation landmarks (red spheres) and their corresponding connected source landmarks (green spheres) and the liver structures are rigidly aligned and show the large intra-operative deformation (left image). The result of the registration process (right) shows the 16 registered landmarks.

- **Marion surgical**: we have continued our interactions with the start-up Marion Surgical based in Canada through the transfer of our technology related to the simulation of needle insertion.

9. Partnerships and Cooperations

9.1. Regional Initiatives

At the regional level, the MIMESIS team collaborates with

9.1.1. ICube Automatique Vision et Robotique (AVR)

We have been collaborating with the medical robotics team on percutaneous procedures, in particular robotized needle insertion (with Prof. Bernard Bayle), and needle tracking in medical images (with Elodie Breton). We are also collaborating with Jonathan Vappou on elastography.

9.1.2. ICube Informatique Géométrique et Graphique

MIMESIS joined the IGG team to collaborate in the domain of dynamic topologies, mainly through the use of the CGoGN framework. CGoGN is a C++ library for the manipulation of meshes. It implements combinatorial maps and their multiresolution extensions and has been used in various high level application like the simulation of crowds of autonomous agents and the simulation of cuts, tears and fractures in the context of surgical simulations.

9.1.3. Institute of Image-Guided Surgery (IHU)

We have several active projects and collaborations with IHU Strasbourg in order to collect and use medical images (such as MRI, CT, Fluoroscopy and Ultrasound) before, during and after minimally-invasive surgical procedures (percutaneous, endovascular and laparoscopic). Such images represent an essential support for the development of numerical simulations for intra-operative assistance through augmented and virtual reality. We also collaborate in the field of elastic registration with X-ray images and surgical training for flexible endoscopy.

9.2. National Initiatives

9.2.1. ADT (Action de Développement Technologique)

MIMESIS received a support for the development of the project **LOSAR: Liver Open Surgery with Augmented Reality** that aims at developing tools for a per-operative usage of registration algorithms developed in the team. Our goal is to be able to repeatedly test our method for one or more important publications in medical conferences. This type of publication requires to methodically repeat our solution on several patients. However, the steps are still insufficiently automated and the algorithm needs to be improved for greater reliability. These essential elements lie outside traditional research missions and require significant development and engineering effort. Indeed, an effort of automation and ergonomics will have to be made to make the use of the software sufficiently simple to be used in the operating room. Furthermore, the accuracy of the deformed model (anatomical distances modeled versus actual anatomical relationships) must also be verified and validated through experimentation. This project is done in collaboration with Paul Brousse Hospital in Paris.

9.2.2. ANR (Agence Nationale de la Recherche)

MIMESIS coordinates the ANR project entitled **SPERRY: SuPervisEd Robotic suRgerY** - application to needle insertion. Percutaneous medical procedures (using surgical needles) are among the least invasive approaches to accessing deep internal structures of organs without damaging surrounding tissues. Today, many surgical procedures rely on the use of needles allowing for complex interventions such as curie-therapies or thermo-ablations of tumors (cryoablation, radio frequencies). Unlike traditional open surgery, these approaches only affect a localized area around the needle, reducing trauma and risks of complications. These treatments also offer new solutions for tumors or for metastases for which traditional methods may be contraindicated due to the age of the patient and the extent or location of the disease. In this project, we want to develop new solutions for the control of medical robots interacting with soft tissues. This work is motivated by recent advances in the field of medical simulation achieving a sufficient level of realism to help surgeons during the operation. The maturity of these techniques now suggests the ability to use a simulation intra-operatively to control the motion of a robotic system for needle insertion. This is really a challenge, because in general, few information can be extracted in real time from images during an intervention. We believe that even minimal knowledge of the mechanical behavior of structures, associated with the use of images can make it possible and allow a robot to reach a pre-identified target during a planning stage, without human intervention.

9.2.3. Inria Collaborations

MIMESIS is closely connected to the SOFA Consortium, created by Inria in November 2015 with the objective to support the SOFA community and encourage contributions from new SOFA users. The consortium should also be a way to better answer to the needs of academic or industrial partners. MIMESIS actively participates at the development of SOFA and contributes to the evolution of the framework. Moreover, MIMESIS also participates in an initiative aiming at verification and validation of codes and algorithms of SOFA. Further, MIMESIS actively collaborates with the following Inria teams:

MAGRIT: The team at Inria Grand-Est focuses on research in computer vision and is also actively involved in computer-based solutions for the planning or the simulation of interventional radiology procedures. Currently, two PhD are co-supervised by researcher from Magrit: Jaime Garcia and Guevara Raffaella Trivisonne.

DEFROST: The team conducts research in soft robotics. We continue mutual interaction with DEFROST mainly in the context of contact modeling.

9.2.4. National Collaborations

At the national level, the MIMESIS team collaborates with:

The LML laboratory(*Laboratoire de Mécanique de Lille)*: a French research laboratory (UMR CNRS 8107) part of the Carnot institute ARTS. With more than two hundred researchers, LML focuses on the following research areas: mechanical reliability and tribology, fluid mechanics, civil engineering and soil mechanics.

Hôpital Paul-Brousse a hospital in South Paris. We collaborate with *Centre Hépato-Biliaire* via the co-supervision of the Ph.D. thesis of Nicolas Golse, MD, who is a surgeon specialized in hepatic surgery.

IRMA Research Institut on Advanced Mathematics, a research laboratory at Strasbourg university. A collaboration started in the fields of shape optimisation methods via the co-supervision of the PhD of Guillaume Mestdagh.

9.3. European Initiatives

9.3.1. FP7 & H2020 Projects

- **HiPerNav** is an Innovative Training Network (ITN) funded through a Marie Skłodowska-Curie grant. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 722068. There is 14 fully funded and 2 partially funded PhD working on the project. The project aims to improve soft tissue navigation through research and development, to improve several bottleneck areas:
  - Creating effective pre-operative model(s) and planning
  - Faster and more accurate intra-operative model updates
  - Faster and more accurate model-to-patient registration
  - More intuitive user-interaction and effective workflow
  - Usage of high performance computing (e.g. GPU)

  From these 14 PhD students, two of them are from the Mimesis team: **Jean-Nicolas Brunet** and **Sergei Nikolaev**
- **Driven** The overall aim of the DRIVEN project is to boost the scientific excellence and innovation capacity in data-driven simulation of the University of Luxembourg (UL) and partners (Inria, University of Limerick, and University of Texas at Austin). To boost their scientific excellence and technology transfer capacity in data-driven simulation, the partners will implement a research and innovation strategy focused on three sub-topics:
  - Mathematical foundations for data-driven simulations – UL with UT Austin,
  - Data-driven simulations for computer-assisted therapy – UL with Inria,
  - Data-driven simulations for functional composite materials –UL with ULIM.

9.4. International Initiatives

9.4.1. Informal International Partners

- **CAMERA group, University of Bath, UK:** Collaboration on non-rigid registration using **RGB-D** sensors
- **PRISMA Lab, University of Naples, Italy:** Collaboration on soft object robotic manipulation, along with DEFROST team at Inria Lille, and collaboration on visual perception for robotic surgery.

- **University of Twente, Netherlands:** we collaborate with Prof. Stefano Stramigioli, head of a group in Robotics and Mechatronics laboratory, on the development of a low-cost training system for flexible endoscopy.
- **Verona University, Italy:** we collaborate with the ALTAIR Robotics Lab on computer-aided ultrasound guidance using real-time registration. This resulted in 2 publications this year: [19] and [23].
- **Faculty of Informatics, Masaryk University, Czech Republic:** We collaborate on simulation of living cells in fluorescent microscopy.
- **Team Legato, University of Luxembourg:** We have an active collaboration with Prof. Stéphane Bordas on error estimation in real-time simulations of deformable objects.
- **ARTORG Center for Biomedical Engineering Research, Bern, Switzerland:** Collaboration in the projects related to deep learning.
- **CIMIT and Harvard Medical School:** we collaborate with members of the Center for Minimally Invasite Therapy and faculty from HMS on the development of a training system for Resuscitative endovascular balloon occlusion of the aorta (REBOA).

9.5. International Research Visitors

Eleonora Tagliabue, PhD student at the robotics laboratory of Verona University, visited the team from April to June 2019. During her stay we collaboration of the comparison of different physics-based approaches to model soft tissues. This led to a publication in the International Journal of Computer Assisted Radiology and Surgery. We also applied our deep physics network to the problem od registration of breast model onto ultrasound data. This was presented at the MICCAI workshop on Computational Biomechanics in September 2019.

9.5.1. Visits to International Teams

Jean-Nicolas Brunet and Sergei Nikolaev spent 2 weeks in Forchheim (Germany) to visit Siemens R&D and product development groups, as part of the H2020 HiPerNav project.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Reviewer - Reviewing Activities

Members of the teams regularly provide reviews for:

- International conferences and journals on Image Processing and Computer-Assisted Interventions (MICCAI, IPCAI, IJCARS, Medical Image Analysis, Transactions on Medical Imaging)
- International conferences and journals on Computer Graphics and Physics-based modeling (Eurographics, VRIPHYS)
- International conferences on Robotics (IROS, ICRA, EuroHaptics)

10.1.2. Invited Talks

- **Nava Schulmann**: talk on "Bayesian data assimilation" at the Data-driven computational mechanics workshop, New York (USA), February 2019.
- **Hadrien Courtecuisse**: Next Generation Intelligent Surgical Systems workshop, Verona (Italy), November 2019
- **Stéphane Cotin**: Next Generation Intelligent Surgical Systems workshop, Verona (Italy), November 2019
- **Stéphane Cotin**: International Conference on Nonlinear Solid Mechanics, Roma (Italy), June 2019.
- **Stéphane Cotin**: talk on "Digital Twin for medicine" at the Data-driven computational mechanics workshop, Luxembourg, September 2019
- **Stéphane Cotin**: talk on "Patient-specific simulation in medicine" at the Data-driven computational mechanics workshop, February 2019.

10.1.3. Scientific Expertise

Stéphane Cotin provides scientific expertise for Insimo (www.insimo.com).

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

- Master: Igor Peterlik, Modélisation des systèmes vivants, 17h, M2, University of Strasbourg
- Master: Igor Peterlik, Visualisation des données et simulation, 10h, M1, University of Strasbourg
- Master: Hadrien Courtecuisse, Real time simulation, 30h, M2, University of Strasbourg
- Master: Hadrien Courtecuisse, Visualisation des données et simulation, 10h, M2, University of Strasbourg
- Master: Hadrien Courtecuisse, Visualisation des données et simulation, 10h, M1, University of Strasbourg

10.2.2. Supervision

PhD : Jaime Garcia Guevara, Augmented ultrasound imaging for hepatic surgery, supervised by Stéphane Cotin, Marie-Odile Berger. Defended on Dec 2nd 2019.

PhD in progress: Raffaella Trivisonne, Computer-aided vascular interventions, started 01/09/2015, supervised by Stéphane Cotin and Erwan Kerrien.

PhD in progress: Nicolas Golse, Navigation using the augmented reality during hepatic surgery, started 01/09/2016, supervised by Stéphane Cotin.

PhD in progress: Sergei Nikolaev, Characterization of boundary conditions for biomechanical modeling of liver, started 01/05/2017, supervised by Stéphane Cotin, co-supervised by Igor Peterlik and Hadrien Courtecuisse.

PhD in progress: Jean-Nicolas Brunet, Characterization of boundary conditions for biomechanical modeling of liver, started 01/09/2017, supervised by Stéphane Cotin.

PhD in progress: Andrea Mendizabal, Numerical simulation of soft tissues and machine learning, 01/09/2017, supervised by Stéphane Cotin.

PhD in progress: Paul Baksic, Robotic assistance for percutaneous surgical interventions in deformable structures – Application to radiofrequency ablation, started 01/10/2018, supervised by Hadrien Courtecuisse.

PhD in progress: Ziqiu Zeng started 01/07/2019, SPERRY - Supervised Robotic Surgery - Application to needle insertion, supervised by Hadrien Courtecuisse.

PhD in progress: Guillaume Mestdagh, started 01/09/2019, Real-Time Tumor Tracking as an Optimization Problem, co-supervised by Stéphane Cotin.

10.2.3. Juries

Stephane Cotin was president of the Ph.D. committee for Lorenzo Sala (September 27, 2019). Mathematics laboratory, Strasbourg

Stephane Cotin was in the Ph.D. committee for Jaime Guevara (December 2, 2019). LORIA, Nancy.

10.3. Popularization

10.3.1. Articles and contents

Stephane Cotin wrote a chapter for the book entitled "Virtual Reality and Augmented Reality - Myths and Realities", which is an easy access book on the usages and developments of Virtual Reality and Augmented Reality for various domains. ISBN 978-1-78630-105-5.

10.3.2. Education

We are developing a training system dedicated to flexible endoscopy, used in university diplomas and masters programs for clinicians.

11. Bibliography

Major publications by the team in recent years

[1] H. P. Bui, S. Tomar, H. Courtecuisse, M. Audette, S. Cotin, S. P. A. Bordas.*Controlling the error on target motion through real-time mesh adaptation: applications to Deep Brain Stimulation*, in "International Journal for Numerical Methods in Biomedical Engineering", December 2017, p. 1-26 [*DOI :* 10.1002/cnm.2958], https://hal.archives-ouvertes.fr/hal-01672962

[2] H. Courtecuisse, J. Allard, K. Pierre, S. P.-A. Bordas, S. Cotin, C. Duriez.*Real-time simulation of contact and cutting of heterogeneous soft-tissues*, in "Medical Image Analysis", February 2014, 20, https://hal.inria.fr/hal-01097108

[3] J. Garcia Guevara, I. Peterlik, M.-O. Berger, S. Cotin.*Biomechanics-based graph matching for augmented CT-CBCT*, in "IJCARS", Apr 2018, https://doi.org/10.1007/s11548-018-1755-1

[4] J. Garcia Guevara, I. Peterlik, M.-O. Berger, S. Cotin.*Elastic Registration Based on Compliance Analysis and Biomechanical Graph Matching*, in "Annals of Biomedical Engineering", 2019, p. 1–16

[5] N. Haouchine, W. Kuang, S. Cotin, M. Yip.*Vision-based Force Feedback Estimation for Robot-assisted Surgery using Instrument-constrained Biomechanical 3D Maps*, in "IEEE Robotics and Automation Letters", February 2018, Proceedings of International Conference on Robotics and Automation ICRA 2018 [*DOI :* 10.1109/LRA.2018.2810948], https://hal.inria.fr/hal-01720259

[6] E. Kerrien, A. Yureidini, J. Dequidt, C. Duriez, R. Anxionnat, S. Cotin.*Blood vessel modeling for interactive simulation of interventional neuroradiology procedures*, in "Medical Image Analysis", January 2017, vol. 35, p. 685 - 698 [*DOI :* 10.1016/j.media.2016.10.003], https://hal.inria.fr/hal-01390923

[7] A. MENDIZABAL, T. FOUNTOUKIDOU, J. HERMANN, R. SZNITMAN, S. COTIN.*A Combined Simulation & Machine Learning Approach for Image-based Force Classification during Robotized Intravitreal Injections*, in "MICCAI 2018 - 21st International Conference on Medical Image Computing and Computer Assisted Intervention", Granada, Spain, September 2018, https://hal.archives-ouvertes.fr/hal-01878682

[8] F. MORIN, H. COURTECUISSE, I. REINERTSEN, F. LE LANN, O. PALOMBI, Y. PAYAN, M. CHABANAS.*Brain-shift compensation using intraoperative ultrasound and constraint-based biomechanical simulation*, in "Medical Image Analysis", 2017, vol. 40, p. 133 - 153 [*DOI :* 10.1016/J.MEDIA.2017.06.003], https://hal.archives-ouvertes.fr/hal-01560157

[9] I. PETERLIK, H. COURTECUISSE, R. ROHLING, P. ABOLMAESUMI, C. NGUAN, S. COTIN, S. E. SALCUDEAN.*Fast Elastic Registration of Soft Tissues under Large Deformations*, in "Medical Image Analysis", 2017, https://hal.inria.fr/hal-01613757

[10] A. PETIT, S. COTIN, V. LIPPIELLO, B. SICILIANO.*Capturing Deformations of Interacting Non-rigid Objects Using RGB-D Data*, in "IROS 2018 - IEEE/RSJ International Conference on Intelligent Robots and Systems", Madrid, Spain, October 2018, https://hal.inria.fr/hal-01889771

[11] D. V. SOROKIN, I. PETERLIK, V. V. ULMAN, D. SVOBODA, T. NEČASOVÁ, K. MORGAENKO, L. EISELLOVÁ, L. TESAŘOVÁ, M. MAŠKA.*FiloGen: A Model-Based Generator of Synthetic 3D Time-Lapse Sequences of Single Motile Cells with Growing and Branching Filopodia*, in "IEEE Transactions on Medical Imaging", June 2018, p. 1-12 [*DOI :* 10.1109/TMI.2018.2845884], https://hal.inria.fr/hal-01821338

[12] H. TALBOT, F. SPADONI, C. DURIEZ, M. SERMESANT, M. O'NEILL, P. JAÏS, S. COTIN, H. DELINGETTE.*Interactive training system for interventional electrocardiology procedures*, in "Medical image analysis", 2017, vol. 35, p. 225–237

Publications of the year

Doctoral Dissertations and Habilitation Theses

[13] J. GARCIA GUEVARA.*Biomechanical graph matching for hepatic intra-operative image registration*, Universite de Lorraine, Inria, Nancy, France, December 2019, https://hal.archives-ouvertes.fr/tel-02408339

Articles in International Peer-Reviewed Journal

[14] Y. ADAGOLODJO, L. GOFFIN, M. DE MATHELIN, H. COURTECUISSE.*Robotic Insertion of Flexible Needle in Deformable Structures Using Inverse Finite-Element Simulation*, in "IEEE Transactions on Robotics", March 2019, p. 1-12 [*DOI :* 10.1109/TRO.2019.2897858], https://hal.inria.fr/hal-02144487

[15] J. GARCIA GUEVARA, I. PETERLIK, M.-O. BERGER, S. COTIN.*Elastic registration based on compliance analysis and biomechanical graph matching*, in "Annals of Biomedical Engineering", September 2019, https://arxiv.org/abs/1912.06353 [*DOI :* 10.1007/S10439-019-02364-4], https://hal.archives-ouvertes.fr/hal-02401280

[16] S. HINDS, H. A. JAEGER, R. BURKE, B. O'SULLIVAN, J. KEANE, F. TRAUZETTEL, B. MARQUES, S. COTIN, B. BIRD, H. LEIRA, T. LANGØ, P. CANTILLON-MURPHY.*Electromagnetic Tracking for Deep Liver Targets: A preliminary feasibility study*, in "International Journal of Computer Assisted Radiology and Surgery", April 2019 [*DOI :* 10.1007/S11548-019-01983-5], https://hal.inria.fr/hal-02121900

[17] A. MENDIZABAL, P. MÁRQUEZ-NEILA, S. COTIN.*Simulation of hyperelastic materials in real-time using deep learning*, in "Medical Image Analysis", 2019, vol. 59, 101569 [*DOI :* 10.1016/J.MEDIA.2019.101569], https://hal.inria.fr/hal-02097119

[18] A. MENDIZABAL, R. SZNITMAN, S. COTIN.*Force classification during robotic interventions through simulation-trained neural networks*, in "International Journal of Computer Assisted Radiology and Surgery", July 2019 [*DOI :* 10.1007/S11548-019-02048-3], https://hal.inria.fr/hal-02268782

[19] E. TAGLIABUE, D. DALL'ALBA, E. MAGNABOSCO, C. TENGA, I. PETERLIK, P. FIORINI.*Position-based modeling of lesion displacement in Ultrasound-guided breast biopsy*, in "International Journal of Computer Assisted Radiology and Surgery", 2019, vol. 14, n^{o} 8, p. 1329-1339 [*DOI :* 10.1007/S11548-019-01997-Z], https://hal.archives-ouvertes.fr/hal-02276090

[20] Z. ZHANG, A. PETIT, J. DEQUIDT, C. DURIEZ.*Calibration and External Force Sensing for Soft Robots using an RGB-D Camera*, in "IEEE Robotics and Automation Letters", March 2019, vol. 4, n^{o} 3, p. 2356 - 2363 [*DOI :* 10.1109/LRA.2019.2903356], https://hal.archives-ouvertes.fr/hal-02060976

International Conferences with Proceedings

[21] J.-N. BRUNET, V. MAGNOUX, B. OZELL, S. COTIN.*Corotated meshless implicit dynamics for deformable bodies*, in "WSCG 2019 - 27th International Conference on Computer Graphics, Visualization and Computer Vision", Pilsen, Czech Republic, Západočeská univerzita, May 2019 [*DOI :* 10.24132/CSRN.2019.2901.1.11], https://hal.inria.fr/hal-02119414

[22] J.-N. BRUNET, A. MENDIZABAL, A. PETIT, N. GOLSE, E. VIBERT, S. COTIN.*Physics-based Deep Neural Network for Augmented Reality during Liver Surgery*, in "Medical Image Computing and Computer Assisted Intervention 2019, 22nd International Conference", Shenzhen, China, October 2019, vol. 11768, n^{o} 137-145, 8 [*DOI :* 10.1007/978-3-030-32254-0_16], https://hal.inria.fr/hal-02158862

[23] A. MENDIZABAL, E. TAGLIABUE, J.-N. BRUNET, D. DALL'ALBA, P. FIORINI, S. COTIN.*Physics-based Deep Neural Network for Real-Time Lesion Tracking in Ultrasound-guided Breast Biopsy*, in "Computational Biomechanics for Medicine XIV", Shenzhen, China, 2019, https://hal.inria.fr/hal-02311277

[24] A. PETIT, N. HAOUCHINE, F. ROY, D. B. GOLDMAN, S. COTIN.*Deformed Reality*, in "Computer Graphics & Visual Computing (Eurographics)", Bangor, United Kingdom, September 2019, https://hal.inria.fr/hal-02320444

Conferences without Proceedings

[25] P. BAKSIC, H. COURTECUISSE, M. CHABANAS, B. BAYLE.*FEM-based confidence assessment of non-rigid registration*, in "Surgetica 2019", Rennes, France, June 2019, https://hal.archives-ouvertes.fr/hal-02238974

[26] N. W. SCHULMANN, S. COTIN, I. PETERLIK.*The effect of discretization on parameter identification. Application to patient-specific simulations*, in "CMBBE 2019 - 16th International Symposium on Computer Methods in Biomechanics and Biomedical Engineering", New York (NY), United States, August 2019, https://hal.archives-ouvertes.fr/hal-02276130

Other Publications

[27] R. HAFERSSAS, P.-H. TOURNIER, F. NATAF, S. COTIN.*Simulation of soft tissue deformation in real-time using domain decomposition*, December 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-02400982

[28] R. TRIVISONNE, E. KERRIEN, S. COTIN.*Constrained Stochastic State Estimation for 3D Shape Reconstruction of Catheters and Guidewires in Fluoroscopic Images*, April 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-02072386

References in notes

[29] R. C. ASTER, B. BORCHERS, C. H. THURBER.*Parameter estimation and inverse problems*, Elsevier, 2018

Team MOCQUA

Designing the Future of Computational Models

Inria teams are typically groups of researchers working on the definition of a common project, and objectives, with the goal to arrive at the creation of a project-team. Such project-teams may include other partners (universities or research institutions).

RESEARCH CENTER
Nancy - Grand Est

THEME
Proofs and Verification

Table of contents

Team MOCQUA

Creation of the Project-Team: 2020 March 01

Keywords:

Computer Science and Digital Science:

A2.3.2. - Cyber-physical systems
A2.4.1. - Analysis
A6.5. - Mathematical modeling for physical sciences
A7.1.4. - Quantum algorithms
A7.2. - Logic in Computer Science
A7.3. - Calculability and computability
A8.1. - Discrete mathematics, combinatorics
A8.3. - Geometry, Topology
A8.6. - Information theory

Other Research Topics and Application Domains:

B9.5.1. - Computer science
B9.5.2. - Mathematics
B9.5.3. - Physics

1. Team, Visitors, External Collaborators

Research Scientists

Frédéric Dupont Dupuis [CNRS, Researcher, until Sep 2019]
Nazim Fatès [Inria, Researcher]
Isabelle Gnaedig [Deputy team leader, Inria, Researcher]
Mathieu Hoyrup [Inria, Researcher]
Simon Perdrix [CNRS, Researcher, HDR]

Faculty Members

Emmanuel Jeandel [Team leader, Univ de Lorraine, Professor, HDR]
Emmanuel Hainry [Univ de Lorraine, Associate Professor]
Irène Marcovici [Univ de Lorraine, Associate Professor]
Romain Péchoux [Univ de Lorraine, Associate Professor, Délég. Inria, 2018-2019]

PhD Students

Agustin Borgna [CNRS, from Oct 2019]
Titouan Carette [Univ de Lorraine]
Alexandre Clement [Univ de Lorraine, from Sep 2019]
Pierre Mercuriali [Univ de Lorraine]
Margarita Veshchezerova [EDF, from Oct 2019]
Renaud Vilmart [Univ de Lorraine, until Sep 2019]

Post-Doctoral Fellows

Francesco Arzani [CNRS, until Oct 2019]
Donald Stull [Inria, until Aug 2019]
Vladimir Zamdzhiev [CNRS]

Visiting Scientists

Alonso Herrera [Univ Andress Bello, from Apr 2019 until Jul 2019]

Victor Selivanov [Ershov Institute of Informatics, Sep 2019]
Kihara Takayuki [Nagoya Univ, Sep 2019]

Administrative Assistants
Sophie Drouot [Inria]
Sylvie Hilbert [CNRS, from Jun 2018]

2. Overall Objectives

2.1. Designing the future of computational models

The goal of the Mocqua team is to tackle challenges coming from the emergence of new or future computational models. The landscape of computational models has indeed changed drastically in the last few years: the complexity of digital systems is continually growing, which leads to the introduction of new paradigms, while new problems arise due to this larger scale (tolerance to faulty behaviors, asynchronicity) and constraints of the present world (energy limitations). In parallel, new models based on physical considerations have appeared. There is thus a real need to accompany these changes, and we intend to investigate these new models and try to solve their intrinsic problems by computational and algorithmic methods.

While the bit remains undeniably the building block of computer architecture and software, it is fundamental for the development of new paradigms to investigate computations and programs working with inputs that cannot be reduced to finite strings of 0's and 1's. Our team will focus on a few instances of this phenomenon: programs working with qubits (quantum computing), programs working with functions as inputs (higher-order computation) and programs working in infinite precision (real numbers, infinite sequences, streams, coinductive data, ...).

3. Research Program

3.1. Quantum Computing

While it can be argued that the quantum revolution has already happened in cryptography [39] or in optics [38], quantum computers are far from becoming a common commodity, with only a few teams around the world working on a practical implementation. In fact, one of the most commonly known examples of a quantum computer, the D-Wave 2X System, defies the usual definition of a computer: it is not general-purpose, and can only solve (approximately) a very specific hardwired problem.

Most current prototypes of a quantum computer differ fundamentally on the hardware substrate, and it is quite hard to predict which solution will finally be adopted. The landscape of quantum programming languages is also constantly evolving. Comparably to compiler design, the foundation of quantum software therefore relies on an intermediate representation that is suitable for manipulation, easy to produce from software and easily encodable into hardware. The language of choice for this is the ZX-calculus.

Regardless of the actual model that will be accepted by the industry, it is becoming clear that some of the hurdles into scaling up quantum computers from a few qubits to very large arrays will remain. As an example, current implementations of quantum computers working on hundreds of qubits indeed are not able to form and maintain all possible forms of entanglement between qubits. This raises two questions. First, does this restrict the computational power, and the supposed advantage of the quantum computer over the classical computer? Second, how to ensure that a quantum program that was designed for a theoretical quantum computer will work on the practical implementations? This will be investigated, in particular by providing static analysis methods for evaluating a priori how much entanglement a quantum program needs.

3.2. Higher-Order Computing

While programs often operate on natural numbers or finite structures such as graphs or finite strings, they can also take functions as input. In that case, the program is said to perform higher-order computations, or to compute a higher-order functional. Functional programming or object-oriented programming are important paradigms allowing higher-order computations.

While the theory of computation is well developed for first-order programs, difficulties arise when dealing with higher-order programs. There are many non-equivalent ways of presenting inputs to such programs: an input function can be presented as a black-box, encoded in an infinite binary sequence, or sometimes by a finite description. Comparing those representations is an important problem. A particularly useful application of higher-order computations is to compute with infinite objects that can be represented by functions or symbolic sequences. The theory works well in many cases (to be precise, when these objects live in a topological space with a countable basis [42]), but is not well understood in other interesting cases. For instance, when the inputs are the second-order functionals (of type $(\mathbb{N} \to \mathbb{N}) \to (\mathbb{N} \to \mathbb{N})$), the classical theory does not apply and many problems are still open.

3.3. Dynamical Systems

The most natural example of a computation with infinite precision is the simulation of a dynamical system. The underlying space might be $\mathbb{R}^n$ in the case of the simulation of physical systems, or the Cantor space $\{0,1\}^{\mathbb{Z}}$ in the case of discrete dynamical systems.

From the point of view of computation, the main point of interest is the link between the long-term behavior of a system and its initial configuration. There are two questions here: (a) predict the behavior, (b) design dynamical systems with some prescribed behavior. The first will be mainly examined through the angle of reachability and more generally control theory for hybrid systems.

The model of cellular automata will be of particular interest. This computational model is relevant for simulating complex global phenomena which emerge from simple interactions between simple components. It is widely used in various natural sciences (physics, biology, etc.) and in computer science, as it is an appropriate model to reason about errors that occur in systems with a great number of components.

The simulation of a physical dynamical system on a computer is made difficult by various aspects. First, the parameters of the dynamical systems are seldom exactly known. Secondly, the simulation is usually non exact: real numbers are usually represented by floating-point numbers, and simulations of cellular automata only simulate the behavior of finite or periodic configurations. For some chaotic systems, this means that the simulation can be completely irrelevant.

4. Application Domains

4.1. Quantum Computing

Quantum Computing is currently the most promising technology to extend Moore's law, whose end is expected with the engraving at 7 nm, in less than 5 years. Thanks to the exponential computational power it will bring, it will represent a decisive competitive advantage for those who will control it.

Quantum Computing is also a major security issue, since it allows us to break today's asymmetric cryptography. Hence, mastering quantum computing is also of the highest importance for national security concerns. Recent scientific and technical advances suggest that the construction of the first quantum computers will be possible in the coming years.

As a result, the major US players in the IT industry have embarked on a dramatic race, mobilizing huge resources: IBM, Microsoft, Google and Intel have each invested between 20 and 50 million euros, and are devoting significant budgets to attract and hire the best scientists on the planet. Some states have launched ambitious national programs, including Great Britain, the Netherlands, Canada, China, Australia, Singapore, and very recently Europe, with the upcoming 10-year FET Flagship program in Quantum Engineering.

While a large part of these resources are going towards R-&-D in quantum hardware, there is still an important need and real opportunities for leadership in the field of quantum software.

The Mocqua team contributes to the computer science approach to quantum computing, aka the quantum software approach. We aim at a better understanding of the power and limitations of the quantum computer, and therefore of its impact on society. We also contribute to ease the development of the quantum computer by filling the gap between the theoretical results on quantum algorithms and complexity and the recent progresses in quantum hardware.

4.2. Higher-Order Computing

The idea of considering functions as first-class citizens and allowing programs to take functions as inputs has emerged since the very beginning of theoretical computer science through Church's λ-calculus and is nowadays at the core of functional programming, a paradigm that is used in modern software and by digital companies (Google, Facebook, ...). In the meantime higher-order computing has been explored in many ways in the fields of logic and semantics of programming languages.

One of the central problems is to design programming languages that capture most of, if not all, the possible ways of computing with functions as inputs. There is no Church thesis in higher-order computing and many ways of taking a function as input can be considered: allowing parallel or only sequential computations, querying the input as a black-box or via an interactive dialog, and so on.

The Kleene-Kreisel computable functionals are arguably the broadest class of higher-order continuous functionals that could be computed by a machine. However their complexity is such that no current programming language can capture all of them. Better understanding this class of functions is therefore fundamental in order to identify the features that a programming language should implement to make the full power of higher-order computation expressible in such a language.

4.3. Simulation of Dynamical Systems by Cellular Automata

We aim at developing various tools to simulate and analyse the dynamics of spatially-extended discrete dynamical systems such as cellular automata. The emphasis of our approach is on the evaluation of the robustness of the models under study, that is, their capacity to resist various perturbations.

In the framework of pure computational questions, various examples of such systems have already been proposed for solving complex problems with a simple bio-inspired approach (e.g. the decentralized gathering problem [40]). We are now working on their transposition to various real-world situations. For example when one needs to understand the behaviour of large-scale networks of connected components such as wireless sensor networks. In this direction of research, a first work has been presented on how to achieve a decentralized diagnosis of networks made of simple interacting components and the results are rather encouraging [5]. Nevertheless, there are various points that remain to be studied in order to complete this model for its integration in a real network.

We have also tackled the question of the evaluation of the robustness of a swarming model proposed by A. Deutsch to mimic the self-organization process observed in various natural systems (birds, fishes, bacteria, etc.) [2]. We now wish to develop our simulation tools to apply them to various biological phenomena where a great number of agents are implied.

We are also currently extending the range of applications of these techniques to the field of economy. We have started a collaboration with Massimo Amato, a professor in economy at the Bocconi University in Milan. Our aim is to examine how to propose a decentralized view of a business-to-business market and propose agent-oriented and totally decentralized models of such markets. Various banks and large businesses have already expressed their interest in such modelling approaches.

5. Highlights of the Year

5.1. Highlights of the Year

The ZX-calculus is a powerful diagrammatic language which can be used to reason on quantum computing. The ZX-calculus is also an essential tool for the development of the quantum computer allowing for instance optimisation of quantum programs. Indeed the ZX-calculus is equipped with an equational theory which allows one to transform and optimize quantum programs. A few years ago, we have proved the first completeness result of the ZX-calculus [41] [28], guaranteeing that two equivalent evolutions can be transformed one into the other thanks to the equational theory. Its completeness gives to the ZX-calculus a competitive advantage compared to the other models of quantum computation, like the quantum circuits, for which no complete equational theory is known.

In [31], Renaud Vilmart introduced a new, simple, and meaningful equational theory for the ZX-calculus, based on the famous Euler angle decomposition. Renaud participated to the various previous results of the team on this subject during his PhD thesis in the Mocqua team, and culminated with this sole author paper published at LICS for which he obtained the best student paper award.

5.1.1. Awards

Best student paper award at LICS'19 for Renaud Vilmart. [31].

6. New Software and Platforms

6.1. FiatLux

KEYWORDS: Cellular automaton - Multi-agent - Distributed systems

SCIENTIFIC DESCRIPTION: FiatLux is a discrete dynamical systems simulator that allows the user to experiment with various models and to perturb them. It includes 1D and 2D cellular automata, moving agents, interacting particle systems, etc. Its main feature is to allow users to change the type of updating, for example from a deterministic parallel updating to an asynchronous random updating. FiatLux has a Graphical User Interface and can also be launched in a batch mode for the experiments that require statistics.

FUNCTIONAL DESCRIPTION: FiatLux is a cellular automata simulator in Java specially designed for the study of the robustness of the models. Its main distinctive features is to allow to perturb the updating of the system (synchrony rate) and to perturb the topology of the grid.

- Participants: Nazim Fatès and Olivier Boure
- Partners: ENS Lyon - Université de Lorraine
- Contact: Nazim Fatès
- URL: http://fiatlux.loria.fr/

6.2. ComplexityParser

KEYWORDS: Complexity - Static typing - Parsing

FUNCTIONAL DESCRIPTION: ComplexityParser is a static complexity analyzer of Java programs written in Java (approximatively 5000 lines of code). The program consists in a type inference and checking program based on the data tiering principle. It allows the program to certify that the typed program has a polynomial time complexity.

- Participants: Olivier Zeyen, Emmanuel Hainry, Romain Péchoux and Emmanuel Jeandel
- Contact: Emmanuel Hainry

7. New Results

7.1. Semicomputable points in Euclidean spaces

- Participants: Mathieu Hoyrup, Donald Stull

Many natural problems/objects from theoretical computer science and logic are not decidable/computable, but semidecidable/semicomputable only: the halting problem, provability, domino problem, attractors of dynamical systems, etc. We pursue our program to study semicomputable objects in a systematic way. In this work, we focus on objects that can be described by finitely many real numbers, in particular polynomials and disks in the plane. Such objects can be identified with points of Euclidean spaces. We therefore introduce and study a notion of semicomputable point in Euclidean spaces, providing a multi-dimensional analog of a well-known unidimensional notion. The study involves ideas from linear algebra, convex analysis and computability. This work was presented at MFCS 2019 [27].

7.2. Computability on quasi-Polish spaces

- Participants: Mathieu Hoyrup, Cristobal Rojas, Victor Selivanov, Donald Stull

Descriptive Set Theory (DST) is a branch of topology which interacts very nicely with computability and logic. Indeed, these three theories involve measuring the complexity of describing objects in different ways (respectively as combinations of open sets, by programs, by formulae), which are intimately related. However, DST is traditionally developed on spaces relevant to mathematical analysis (Polish spaces), but not to theoretical computer science. The recently introduced quasi-Polish spaces are a much broader class of spaces including for instance Scott domains, important in functional programming. However, how to compute in such spaces is still not well-understood. In particular, quasi-Polish spaces can be characterized in many ways, so one has to choose the right definition to start with. We compare the computable versions of some of them, proving their non-equivalence, and focus on one of them, providing evidence that this notion is probably the right one. This work was presented at DCFS 2019 [26].

7.3. Degree spectra of Polish spaces

- Participants: Mathieu Hoyrup, Takayuki Kihara, Victor Selivanov

Mathematical objects can encode information. An obvious example is given by subsets of the plane: a text printed on a sheet of paper is a subset of the plane conveying information. However, when the object is submitted to deformations, what information can still be conveyed? What information is invariant under such deformations?

It is the core question in computable structure theory: for instance, what can be encoded in an infinite graph, which can be decoded from the structure itself and not from a particular presentation of the graph? Mathematically, what information is robust under graph isomorphism? It happens that much information can be encoded, for instance by using the lengths of the cycles in the graph.

Albegraic structures have been thoroughly studied from this perspective. However, the study of topological structures is almost inexistant, and more difficult (they are continuous while algebraic structures are often discrete). For instance, what information can be encoded in a subset of the plane, which is stable under continuous deformations (homeomorphisms)?

We have tackled this question during the visit of Takayuki Kihara and Victor Selivanov, and obtained many interesting results. For instance, we have proved that no direct information can be encoded (for instance, no infinite binary sequence can be extracted by an algorithm, unless the sequence is already computable). However, limit information can be encoded (for instance, a binary sequence can be encoded in such a way that a double-sequence converging to it can be extracted from the object by an algorithm). It is still open whether a single limit is possible.

A paper is still in preparation.

7.4. Computable SFTs

- Participants: Emmanuel Jeandel and Pascal Vanier

Previous works by the two participants have shown that there is a striking similarity between subshifts of finite type (tilings, coloring of the plane that do not contain a given set of patterns) and finitely presented groups (finitely generated groups with a finite number of equations).

This analogy can be described intuitively as follows: colors in subshifts corresponds to the generators of the groups, forbidden patterns correspond to the equations. Finite type is the same as finite presentation, and minimal subshifts correspond to simple groups.

The article [29] develops this analogy to computable objects: It is well known by the Higman-Thompson theorem that a finitely generated group is computable iff it is a subgroup of a simple group which is itself a subgroup of a finitely presented group. In this article, we give an equivalent for subshifts : a subshift is computable iff it is the restriction of a minimal subshift which is itself the restriction of a subshift of finie type.

7.5. Probabilistic cellular automata for problem solving

- Participants: Nazim Fatès, Irène Marcovici

Directly related to the theme exposed in Sec. 4.3, we examined the problem of self-stabilisation, as introduced by Dijkstra in the 1970's, in the context of cellular automata [33]. More precisely, we examined how to stabilise k-colourings, that is, infinite grids which are coloured with k distinct colours in such a way that adjacent cells have different colours. The idea is that if, for any reason (e.g., noise, previous usage, tampering by an adversary), the colours of a finite number of cells in a valid k-colouring are modified, thus introducing errors, we can correct the system into a valid k-colouring by using local rules only. In other words, we designed cellular automaton rules which, starting from any finite perturbation of a valid k-colouring, reach a valid k-colouring in finite time. We discussed the different cases depending on the number of colours k, and propose some deterministic and probabilistic rules which solve the problem for $k \neq 3$. We also explained why the case $k = 3$ is more delicate. Finally, we proposed some insights on the more general setting of this problem, passing from k-colourings to other tilings (subshifts of finite type).

In the same spirit, we addressed the problem of detecting failures in a distributed network [30]. Our question is: if some components can break down over time, how can we detect that the failure rate has exceeded a given threshold without any central authority? We want to estimate the global state of the network, only through local interactions of components with their neighbours. In particular, we wish to reach a consensus on an alert state when the failure rate exceeds a given threshold. We used a cellular automaton in order to propose solutions in the case of a network with a grid structure. We compared three methods of self-organisation that are partly inspired by physical and biological phenomena. As an application, we envisioned sensor networks or any type of decentralised system with a great number of components.

Concerning the fundamental properties of asynchronous cellular automata, we presented a tutorial on the convergence properties of the 256 Elementary Cellular Automata under the fully asynchronous updating, that is, when only one cell is updated at each time step. We regrouped the results which have been presented in different articles and exposed a full analysis of the behaviour of finite systems with periodic boundary conditions. Our classification relies on the scaling properties of the average convergence time to a fixed point. We presented the different scaling laws that can be found, which fall in one of the following classes: logarithmic, linear, quadratic, exponential and non-converging. The techniques for quantifying this behaviour rely mainly on Markov chain theory and martingales. Most behaviours can be studied analytically but there are still many rules for which obtaining a formal characterisation of their convergence properties is still an open problem.

Our article on the global synchronisation problem was finally published [21]. In this problem, one is asked to find a cellular automaton which has the property that every initial condition evolves into a homogeneous blinking state. We studied this simple inverse problem for the case of one-dimensional systems with periodic boundary conditions. Two paradoxical observations were made: (a) despite the apparent simplicity of finding rules with good statistical results, there exist no perfect deterministic solutions to this problem, (b) if we allow the use of randomness in the local rule, constructing “perfect” stochastic solutions is easy. For the stochastic case, we give some rules for which the mean time of synchronisation varies quadratically with the number of cells and ask if this result can be improved. To explore more deeply the deterministic rules, we code our problem as a SAT problem and use SAT solvers to find rules that synchronise a large set of initial conditions.

7.6. Diagrammatic quantum computing

- Participants: Titouan Carette, Dominic Horsman, Emmanuel Jeandel, Simon Perdrix, Renaud Vilmart.

This year, we have contributed in several ways to the foundations and the applications of the ZX-calculus, a diagrammatic language for quantum computing.

Emmanuel Jeandel, Simon Perdrix, and Renaud Vilmart have introduced a general normal form for ZX-diagrams implying completeness results for various (almost all) fragments of quantum mechanics [28]. Renaud Vilmart has also introduced the simple, meaningful axiomatisation of the full ZX-calculus [31]. This two papers have been published at LICS’19.

Titouan Carette, Emmanuel Jeandel, Simon Perdrix, and Renaud Vilmart, have introduced a new simple categorical construction allowing to deal with non pure quantum evolutions (i.e. involving quantum measurements, discard of quantum systems, and probability mixtures). Wen this new construction coincides with the existing constructions, it provides simpler axiomatisation. For instance, this construction provides a complete equational theory for an extension of the ZX-calculus for arbitrary (non necessary pure) quantum evolutions. This result has been published at ICALP’19 [24].

Titouan Carette, Dominic Horsman (form LIG Grenoble) and Simon Perdrix have provided an axiomatisation for a scalable ZX-calculus where each wire represents a register of qubits, instead of a single qubit in the standard ZX-calculus. The scalable ZX-calculus allows compact representation of quantum algorithms, protocols and quantum codes. This result has been published at MFCS’19 [23]

7.7. Causal Graph Dynamics

- Participants: Pablo Arrighi, Simon Martiel, Simon Perdrix.

Causal Graph Dynamics extend Cellular Automata to arbitrary time-varying graphs of bounded degree. The whole graph evolves in discrete time steps, and this global evolution is required to have a number of symmetries: shift-invariance (it acts everywhere the same) and causality (information has a bounded speed of propagation). Pablo Arrighi (LIS, Marseille), Simon Martiel (Atos-Bull) and Simon Perdrix have considered a natural physics-like symmetry, namely reversibility. In particular, they extended two fundamental results on reversible cellular automata, by proving that the inverse of a causal graph dynamics is a causal graph dynamics, and that these reversible causal graph dynamics can be represented as finite-depth circuits of local reversible gates. These results have been published in the journal Natural Computing [16].

7.8. Contextuality in multipartite pseudo-telepathy graph games

- Participants: Anurag Anshu, Peter Høyer, Mehdi Mhalla, and Simon Perdrix.

Analyzing pseudo-telepathy graph games, Anurag Anshu, Peter Høyer, Mehdi Mhalla, and Simon Perdrix proposed a way to build contextuality scenarios exhibiting the quantum advantage using graph states. A new tool, called multipartiteness width, is introduced to investigate which scenarios are hard to decompose and to show that there exist graphs generating scenarios with a linear multipartiteness width. These results have been published in the Journal of Computer and System Science [15].

8. Partnerships and Cooperations

8.1. National Initiatives

8.1.1. ANR

- Project acronym: ANR PRCE SoftQPro (ANR-17-CE25-0009)
  Project title: Solutions logicielles pour l'optimisation des programmes et ressources quantiques.
  Duration: Dec. 2017 - Dec. 2022
  Coordinator: Simon Perdrix
  Other partners: Atos-Bull, LRI, CEA-Saclay.
  Participants: Simon Perdrix, Emmanuel Jeandel, Emmanuel Hainry, and Romain Péchoux
  Abstract: Quantum computers can theoretically solve problems out of reach of classical computers. We aim at easing the crucial back and forth interactions between the theoretical approach to quantum computing and the technological efforts made to implement the quantum computer. Our software-based quantum program and resource optimisation (SoftQPRO) project consists in developing high level techniques based on static analysis, certification, transformations of quantum graphical languages, and optimisation techniques to obtain a compilation suite for quantum programming languages. We will target various computational model back-ends (e.g. QRAM, measurement-based quantum computations) as well as classical simulation. Classical simulation is central in the development of the quantum computer, on both ends: as a way to test quantum programs but also as a way to test quantum computer prototypes. For this reason we aim at designing sophisticated simulation techniques on classical high-performance computers (HPC).
- Project acronym: ANR PRCI VanQuTe (ANR-17-CE24-0035)
  Project title: Validation of near-future quantum technologies.
  Duration: Fev. 2018 - Jan. 2022
  Coordinator: Damian Markham (Laboratoire d'informatique de Paris 6)
  Other partners: NTU (Nanyang Technological University), SUTD (Singapore University of Technology and Design), NUS (Nationl University of Singapore), LIP6 (Laboratoire d'informatique de Paris 6)
  Participants: Simon Perdrix, Emmanuel Jeandel
  Abstract: In the last few years we have seen unprecedented advances in quantum information technologies. Already quantum key distribution systems are available commercially. In the near future we will see waves of new quantum devices, offering unparalleled benefits for security, communication, computation and sensing. A key question to the success of this technology is their verification and validation.

  Quantum technologies encounter an acute verification and validation problem: On one hand, since classical computations cannot scale-up to the computational power of quantum mechanics, verifying the correctness of a quantum-mediated computation is challenging. On the other hand, the underlying quantum structure resists classical certification analysis. Members of our consortium have shown, as a proof-of-principle, that one can bootstrap a small quantum device to test a larger one. The aim of VanQuTe is to adapt our generic techniques to the specific applications and constraints of photonic systems being developed within our consortium. Our ultimate goal is to develop techniques to unambiguously verify the presence of a quantum advantage in near future quantum technologies.

8.1.2. Other initiatives

- Quantex. Project acronym: PIA-GDN/Quantex. (initially an ITEA3 project finally funded by the *Grands défis du Numérique / Programme d'investissements d'avenir*).
  Project title: Simulation/Emulation of Quantum Computation.
  Duration: Feb. 2018 - Jan 2021.
  Coordinator: Huy-Nam Nguyen (Atos Bull).
  Other partners: Atos-Bull, LRI, CEA Grenoble.
  Participants: Simon Perdrix (WP leader), Emmanuel Jeandel
  Abstract: The lack of quantum computers leads to the development of a variety of software-based simulators to assist in the research and development of quantum algorithms. This proposal focuses on the development of a combined software-based and hardware-accelerated toolbox for quantum computation. A quantum computing stack including specification language, libraries and optimisation/execution tools will be built upon a well-defined mathematical framework mixing classical and quantum computation. Such an environment will be dedicated to support the expression of quantum algorithms for the purpose of investigation and verification.

8.2. European Initiatives

8.2.1. FP7 & H2020 Projects

Mathieu Hoyrup participates in the Marie-Curie RISE project Computing with Infinite Data coordinated by Dieter Spreen (Univ. Siegen) that has started in April 2017.

8.3. International Initiatives

8.3.1. Participation in Other International Programs

ECOS-Sud A17C03 QuCa - 01/2018 - 12/2020. **Quantum Calculi**. Funded by MinCyT and ECOS France.
Argentine Director: A. Díaz-Caro (UNQ/CONICET), French Director: G. Dowek (Inria, LSV, ENS Paris-Saclay)
Permanent members: P. Arrighi (Aix-Marseille) - J.-Y. Marion (LORIA) - P. E. Martínez López (UNQ) - S. Perdrix - B. Valiron (CentraleSupélec).

8.4. International Research Visitors

8.4.1. Visits of International Scientists

- Alonso Herrera: Universidad Andrés Bello, Chile.
- Takayuki Kihara : Nagoya University, Japan.
- Damiano Mazza, CNRS, LIPN.
- Victor Selivanov: Ershov Institute of Informatics Systems, Novosibirsk, Russia.

8.4.2. Visits to International Teams

8.4.2.1. Research Stays Abroad

Simon Perdrix visited Universita Buenos Aires, Universita de Quilmes and Conicet for two weeks in November 2019. The visit was part of the QuCa Ecos Sud project and was partially funded by LIA SINFIN.

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. Scientific Events: Organisation

9.1.1.1. General Chair, Scientific Chair

- Mathieu Hoyrup was chair and organizer of the workshop MLA 2019.
- Jointly with Andreas Deutsch (TU Dresden, Germany), Nazim Fatès was chair and organizer of SOLSTICE 2019, Summer Solstice Conference on Discrete Models of Complex Systems.

9.1.1.2. Member of the Conference Program Committees

- Mathieu Hoyrup was member of the PC of CiE 2019.
- Romain Péchoux was member of the PC of DICE and FOPARA 2019.
- Nazim Fatès was member of the PC of AUTOMATA 2019.
- Simon Perdrix was member of the PC of QPL'19.

9.1.1.3. Reviewer

Romain Péchoux was reviewer for DICE and FOPARA 2019, FOSSACS 2019, ICALP 2019, and ISMVL 2019.

9.1.2. Journal

9.1.2.1. Member of the Editorial Boards

- Emmanuel Jeandel is member of the Editorial Board of RAIRO-ITA.
- Nazim Fatès is a member of the Editorial board of the *Journal of cellular automata*.

9.1.2.2. Reviewer - Reviewing Activities

- Romain Péchoux was reviewer for Information Processing Letters and Journal of Automated Reasoning.
- Nazim Fatès served as a reviewer for the *SIAM Journal on Discrete Mathematics* (SIDMA) and for *Informatica*.

9.1.3. Invited Talks

Romain Péchoux gave an invited talk at Shonan seminar #151 on higher order complexity theory and its applications.

9.1.4. Leadership within the Scientific Community

- Romain Péchoux is guest coeditor of the Theoretical Computer Science, special issue on Implicit Computational Complexity, DICE 2016-2018.
- Nazim Fatès is the vice-president of the IFIP WG 1.5 on Cellular Automata and Discrete Complex Systems. He is a guest coeditor of a special issue of *Natural computing* on the theme "Discrete Models of Complex Systems: recent trends and analytical challenges". This call for papers follows the SOLSTICE 2019 conference (Dresden, Germany, July 2019).

9.1.5. Scientific Expertise

- Romain Péchoux is Rapporteur and Expert for the Marie Curie IF call of the European Commission, ERA.
- Nazim Fatès was an evaluator for a funding project of the CONICYT, the Chilean *Comisión Nacional de Investigación Científica y Tecnológica*.
- Simon Perdrix was member of the HCERES evaluation committee of G-SCOP.

- Simon Perdrix was member of the committee "La Recherche" award (Prix du Magazine La Recherche) 2019.

9.1.6. Research Administration

- Emmanuel Hainry was member of the CNU (Conseil National des Universités), Section 27 until 2019, nov 18th.
- Simon Perdrix is elected member and scientific secretary of the CNRS section 6.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

- Licence
  - Isabelle Gnaedig:
    - To the limits of the computable, 6 hours, Opening course-conference of the collegium “Lorraine INP”, Université de Lorraine, Nancy, France.
  - Emmanuel Hainry:
    - Operating Systems, 30h, L1, IUT Nancy Brabois, Université de Lorraine, Nancy, France.
    - Algorithmics, 40h, L1, IUT Nancy Brabois.
    - Dynamic Web, 60h, L1, IUT Nancy Brabois.
    - Databases, 30h, L1, IUT Nancy Brabois.
    - Object Oriented Languages, 16h, L2, IUT Nancy Brabois.
    - Complexity, 30h, L2, IUT Nancy Brabois.
  - Emmanuel Jeandel:
    - Algorithmics and Programming 1, 60h, L1 Maths-Info, Université de Lorraine, Nancy, France.
    - Algorithmics and Programming 4, 30h, L3 Informatique.
    - Modeling Using Graph Theory, 30h, L3 Informatique.
    - Networking, 15h, L3 Informatique.
    - Formal Languages, 30h, L2-L3 Informatique.
  - Romain Péchoux had an Inria delegation (2018-2019).
- Master
  - Isabelle Gnaedig:
    - Rule-based Programming, 24 hours, M2, Telecom-Nancy, Université de Lorraine, Nancy, France.
  - Emmanuel Hainry:
    - Mathematics for Computer Science, 15h, M1 TAL, Institut des Sciences du Digital: Management et Cognition, Université de Lorraine, Nancy, France.
  - Mathieu Hoyrup:
    - Mathematics for Computer Science, 15h, M1 TAL, Institut des Sciences du Digital: Management et Cognition, Université de Lorraine, Nancy, France.
  - Emmanuel Jeandel:
    - Algorithmics and Complexity, 30h, M1 Informatique, Université de Lorraine, Nancy, France.
    - Quantum Computing, 15h, M1 Informatique.

- Nazim Fatès:
  - Systèmes distribués adaptatifs, 10h, Master 2, informatique, Université de Lorraine, Nancy, France.
  - Agents intelligents et collectifs, 15h, Master 1, sciences cognitives.
  - Modèles de calcul, 12h, Master 2, informatique.

9.2.2. Supervision

- Mathieu Hoyrup supervised the L3 internship of Antonin Callard (ENS Paris Saclay), about descriptive set theory on represented spaces.
- Emmanuel Hainry and Romain Péchoux supervised the L3 internship of Olivier Zeyen (FST, Université de Lorraine), on implementing a complexity parser for Java.
- Nazim Fatès supervised the internship of Karim Boutamine and Maxime Thaon, students of Master 1 in Cognitive Sciences (Université de Lorraine) and the internship of Baptiste Collet, student of Licence 3 at École normale supérieure de Paris.
- PhD: Renaud Vilmart, “Langages graphiques pour calculer et raisonner en quantique”, defended september 2019, Advisors: Emmanuel Jeandel and Simon Perdrix.
- PhD in progress: Titouan Carette, “Langage diagrammatique pour l’ordinateur quantique”, Start: October 2018, Advisors: Emmanuel Jeandel and Simon Perdrix.
- PhD in progress: Pierre Mercuriali, “Calcul à base de médiane et structures médianes pour la classification”, Start: October 2016, Advisors: Miguel Couceiro and Romain Péchoux.
- PhD in progress: Robert Booth, “Formalismes pour la vérification de technologies quantiques”, Start: November 2018, Advisors: Damian Markham and Simon Perdrix.
- PhD in progress: Alexandre Clément, “Graphical Languages for Quantum Control”, Start: September 2019, Advisors: Emmanuel Jeandel and Simon Perdrix.
- PhD in progress: Margarita Veshchezerova, “Quantum Computing for Combinatorial Optimisation”, Start: October 2019, Advisors: Emmanuel Jeandel and Simon Perdrix, joint supervision with Marc Porcheron at EDF (CIFRE).

9.2.3. Juries

- Emmanuel Jeandel participated in the PhD defense of Florian Bridoux (Université d’Aix-Marseille), François Pirot (Université de Lorraine and Rahdboud University) and Alexandre Talon (ENS Lyon).
- Emmanuel Jeandel reviewed the PhD thesis of Paulina Cecchi (University of Santiago and Université Paris-Diderot) and Ilya Galanov (Université de Villetaneuse).
- Nazim Fatès reviewed the PhD of Adam Dzedzej (University of Gdańsk, Poland) and served a the main external examiner during the PhD defense.
- Simon Perdrix was external reviewer for the PhD thesis of Kang Feng Ng (Oxford University), March 2019.
- Simon Perdrix was reviewer for the PhD thesis of Matthew Amy (University of Waterloo, Canada), January 2019.
- Simon Perdrix reviewed the PhD thesis of Ghazal Kachigar (University of Bordeaux), December 2019.

9.3. Popularization

9.3.1. Articles and contents

- The scientific magazine *La Recherche* re-published an article by Nazim Fatès and Irène Marcovici, with the title “Les automates cellulaires jouent le jeu”, in a Special issue devoted to the theme "Les maths et le réel" (September 2019) [34]. The original article "Automates cellulaires : la complexité dans les règles de l’art" (2018), was modified with minor changes for this special issue.

- Interviews of Simon Perdrix about the Google's result on quantum advantage. La tribune (online article) ; Sciences et Avenir (November 2019 - paper journal and online articles), We demain (online article).

9.3.2. Education

Nazim Fatès participated to a workshop destined to the high-school teachers which were training on the « Information et sciences du numérique » module.
In the lycée Saint-Exupéry de Saint-Dizier: he gave three one-hour conferences destined to students, related to the film *Imitation game* on Alan Turing (March 18).

9.3.3. Interventions

Nazim Fatès was invited to give various talks on the question of artificial intelligence:

- With the European parliamentary association (APE), he was invited to talk to European MP's on the the theme « Is Europe ready for artificial intelligence? » (Strasbourg, February 13).
- In the « Sciences et société » cycle of IUT Charlemagne (September 26).
- With the association « Jardin des sciences », cycle « intelligences » destined to a wide public, University of Strasbourg (October 10).
- With the association Femmes responsables (November 20).

10. Bibliography

Major publications by the team in recent years

[1] O. BOURNEZ, D. GRAÇA, E. HAINRY.*Computation with perturbed dynamical systems*, in "Journal of Computer and System Sciences", August 2013, vol. 79, n^{o} 5, p. 714-724 [*DOI :* 10.1016/J.JCSS.2013.01.025], http://hal.inria.fr/hal-00861041

[2] N. FATÈS, V. CHEVRIER, O. BOURÉ.*Is there a trade-off between simplicity and robustness? Illustration on a lattice-gas model of swarming*, in "Probabilistic Cellular Automata", P.-Y. LOUIS, F. R. NARDI (editors), Emergence, Complexity and Computation, Springer, 2018 [*DOI :* 10.1007/978-3-319-65558-1_16], https://hal.inria.fr/hal-01230145

[3] N. FATÈS, I. MARCOVICI, S. TAATI.*Two-dimensional traffic rules and the density classification problem*, in "International Workshop on Cellular Automata and Discrete Complex Systems, AUTOMATA 2016", Zürich, France, Lecture Notes of Computer Science, June 2016, vol. 9664 [*DOI :* 10.1007/978-3-319-39300-1_11], https://hal.inria.fr/hal-01290290

[4] H. FÉRÉE, E. HAINRY, M. HOYRUP, R. PÉCHOUX.*Characterizing polynomial time complexity of stream programs using interpretations*, in "Journal of Theoretical Computer Science (TCS)", January 2015, vol. 585, p. 41-54 [*DOI :* 10.1016/J.TCS.2015.03.008], https://hal.inria.fr/hal-01112160

[5] N. GAUVILLE.*Système robuste de diagnostic décentralisé à l'aide d'automates cellulaires simples*, Université de Lorraine (Nancy), September 2018, https://hal.inria.fr/hal-01894581

[6] I. GNAEDIG, H. KIRCHNER.*Proving Weak Properties of Rewriting*, in "Theoretical Computer Science", 2011, vol. 412, p. 4405-4438 [*DOI :* 10.1016/J.TCS.2011.04.028], http://hal.inria.fr/inria-00592271/en

[7] E. HAINRY, R. PÉCHOUX.*Objects in Polynomial Time*, in "APLAS 2015", Pohang, South Korea, X. FENG, S. PARK (editors), Lecture Notes in Computer Science, Springer, November 2015, vol. 9458, p. 387–404 [*DOI :* 10.1007/978-3-319-26529-2_21], https://hal.inria.fr/hal-01206161

[8] M. HOYRUP, W. GOMAA.*On the extension of computable real functions*, in "32nd Annual ACM/IEEE Symposium on Logic in Computer Science, LICS 2017, Reykjavik, Iceland, June 20-23, 2017", IEEE Computer Society, 2017, p. 1–12, https://doi.org/10.1109/LICS.2017.8005067

[9] M. HOYRUP.*The decidable properties of subrecursive functions*, in "International Colloquium on Automata, Languages, and Programming (ICALP) 2016", Rome, Italy, 43rd International Colloquium on Automata, Languages, and Programming, ICALP 2016, July 12-15, 2016, Rome, Italy, July 2016 [*DOI :* 10.4230/LIPICS.ICALP.2016.108], https://hal.inria.fr/hal-01308224

[10] E. JEANDEL.*Computability of the entropy of one-tape Turing Machines*, in "STACS - Symposium on Theoretical Aspects of Computer Science", Lyon, France, E. MAYR, N. PORTIER (editors), LIPCS, March 2014, vol. 25, p. 421-432, First version [*DOI :* 10.4230/LIPICS.STACS.2014.421], https://hal.inria.fr/hal-00785232

[11] E. JEANDEL, P. VANIER.*Hardness of Conjugacy, Embedding and Factorization of multidimensional Subshifts of Finite Type*, in "STACS - 30th International Symposium on Theoretical Aspects of Computer Science", Kiel, Germany, N. PORTIER, T. WILKE (editors), Leibniz International Proceedings in Informatics (LIPIcs), Schloss Dagstuhl–Leibniz-Zentrum fuer Informatik, February 2013, vol. 20, p. 490–501 [*DOI :* 10.4230/LIPICS.STACS.2013.490], http://hal.inria.fr/hal-00840384

[12] S. PERDRIX, Q. WANG.*Supplementarity is Necessary for Quantum Diagram Reasoning **, in "41st International Symposium on Mathematical Foundations of Computer Science (MFCS 2016)", Krakow, Poland, Leibniz International Proceedings in Informatics (LIPIcs), August 2016, vol. 58, p. 76:1–76:14 [*DOI :* 10.4230/LIPICS.MFCS.2016.76], https://hal.archives-ouvertes.fr/hal-01361419

Publications of the year

Doctoral Dissertations and Habilitation Theses

[13] S. PERDRIX.*Approches Graphiques en Informatique Quantique*, Université de Lorraine, September 2019, Habilitation à diriger des recherches, https://hal.archives-ouvertes.fr/tel-02400128

[14] R. VILMART.*ZX-Calculi for Quantum Computing and their Completeness*, Université de Lorraine, September 2019, https://hal.archives-ouvertes.fr/tel-02395443

Articles in International Peer-Reviewed Journal

[15] A. ANSHU, P. HØYER, M. MHALLA, S. PERDRIX.*Contextuality in multipartite pseudo-telepathy graph games*, in "Journal of Computer and System Sciences", February 2020, vol. 107, p. 156-165 [*DOI :* 10.1016/J.JCSS.2019.06.005], https://hal.archives-ouvertes.fr/hal-02400051

[16] P. ARRIGHI, S. MARTIEL, S. PERDRIX.*Reversible causal graph dynamics: invertibility, block representation, vertex-preservation*, in "Natural Computing", October 2019 [*DOI :* 10.1007/S11047-019-09768-0], https://hal.archives-ouvertes.fr/hal-02400095

[17] T. CARETTE, M. LAURIÈRE, F. MAGNIEZ.*Extended Learning Graphs for Triangle Finding*, in "Algorithmica", 2019, forthcoming [*DOI :* 10.1007/S00453-019-00627-Z], https://hal-cnrs.archives-ouvertes.fr/hal-02349981

[18] M. COUCEIRO, E. LEHTONEN, P. MERCURIALI, R. PÉCHOUX.*On the efficiency of normal form systems for representing Boolean functions*, in "Theoretical Computer Science", 2019, forthcoming, https://hal.inria.fr/hal-02153506

[19] M. COUCEIRO, P. MERCURIALI, R. PÉCHOUX, A. SAFFIDINE.*On the complexity of minimizing median normal forms of monotone Boolean functions and lattice polynomials*, in "Journal of Multiple-Valued Logic and Soft Computing", 2019, vol. 33, n^{o} 3, p. 197-218, forthcoming, https://hal.inria.fr/hal-01905491

[20] N. FATÈS.*A tutorial on Elementary cellular automata with fully asynchronous updating -General properties and convergence dynamics*, in "Natural Computing", 2019, forthcoming, https://hal.inria.fr/hal-02400792

[21] N. FATÈS.*Remarks on the cellular automaton global synchronisation problem – deterministic vs. stochastic models*, in "Natural Computing", September 2019, vol. 18, n^{o} 3, p. 429-424 [*DOI :* 10.1007/S11047-018-9683-0], https://hal.inria.fr/hal-01653631

[22] E. JEANDEL, E. MOUTOT, P. VANIER.*Slopes of multidimensional subshifts*, in "Theory of Computing Systems", 2019, forthcoming [*DOI :* 10.1007/S00224-019-09931-1], https://hal.inria.fr/hal-02158012

International Conferences with Proceedings

[23] T. CARETTE, D. HORSMAN, S. PERDRIX.*SZX-calculus: Scalable Graphical Quantum Reasoning*, in "44th International Symposium on Mathematical Foundations of Computer Science (MFCS 2019)", Aachen, Germany, Leibniz International Proceedings in Informatics (LIPIcs), August 2019, vol. 138, p. 55:1–55:15, https://arxiv.org/abs/1905.00041 [*DOI :* 10.4230/LIPICS.MFCS.2019.55], https://hal.archives-ouvertes.fr/hal-02400070

[24] T. CARETTE, S. PERDRIX, R. VILMART, E. JEANDEL.*Completeness of Graphical Languages for Mixed States Quantum Mechanics*, in "ICALP", Patras, Greece, LIPICS, 2019, vol. 132 [*DOI :* 10.4230/LIPICS.ICALP.2019.108], https://hal.archives-ouvertes.fr/hal-02025720

[25] P. GUILLON, E. JEANDEL, J. KARI, P. VANIER.*Undecidable word problem in subshift automorphism groups*, in "Computer Science in Russia 2019", Novosibirsk, Russia, R. VAN BEVERN (editor), Lecture Notes in Computer Science, Springer, July 2019, https://arxiv.org/abs/1808.09194 , https://hal.archives-ouvertes.fr/hal-01862896

[26] M. HOYRUP, C. ROJAS, V. SELIVANOV, D. M. STULL.*Computability on quasi-Polish spaces*, in "DCFS 2019 - 21st International Conference on Descriptional Complexity of Formal Systems", Kosice, Slovakia, M. HOSPODÁR, G. JIRÁSKOVÁ, S. KONSTANTINIDIS (editors), Descriptional Complexity of Formal Systems, Springer International Publishing, July 2019, vol. LNCS-11612, p. 171-183, https://hal.inria.fr/hal-02118947

[27] M. HOYRUP, D. M. STULL.*Semicomputable points in Euclidean spaces*, in "MFCS 2019: 44th International Symposium on Mathematical Foundations of Computer Science", Aachen, Germany, August 2019 [*DOI :* 10.4230/LIPICS.MFCS.2019.63], https://hal.inria.fr/hal-02154825

[28] E. JEANDEL, S. PERDRIX, R. VILMART.*A Generic Normal Form for ZX-Diagrams and Application to the Rational Angle Completeness*, in "34th Annual ACM/IEEE Symposium on Logic in Computer Science (LICS)", Vancouver, Canada, June 2019 [*DOI :* 10.1109/LICS.2019.8785754], https://hal.archives-ouvertes.fr/hal-01791791

[29] E. JEANDEL, P. VANIER.*A Characterization of Subshifts with Computable Language*, in "STACS 2019 - 36th International Symposium on Theoretical Aspects of Computer Science", Berlin, Germany, March 2019, https://hal.archives-ouvertes.fr/hal-02133469

National Conferences with Proceeding

[30] N. GAUVILLE, N. FATÈS, I. MARCOVICI.*Diagnostic décentralisé à l'aide d'automates cellulaires*, in "JFSMA 2019 - 27emes Journées Francophones sur les Systèmes Multi-Agents", Toulouse, France, Cépaduès, July 2019, ISBN 9782364937192, https://hal.inria.fr/hal-02195799

Conferences without Proceedings

[31] R. VILMART.*A Near-Minimal Axiomatisation of ZX-Calculus for Pure Qubit Quantum Mechanics*, in "34th Annual ACM/IEEE Symposium on Logic in Computer Science (LICS)", Vancouver, Canada, June 2019 [*DOI :* 10.1109/LICS.2019.8785765], https://hal.archives-ouvertes.fr/hal-01963426

[32] N. DE BEAUDRAP, R. DUNCAN, D. HORSMAN, S. PERDRIX.*Pauli Fusion: a computational model to realise quantum transformations from ZX terms*, in "QPL'19 : International Conference on Quantum Physics and Logic", Los Angeles, United States, June 2019, https://arxiv.org/abs/1904.12817 - 12 pages + appendices, https://hal.archives-ouvertes.fr/hal-02413388

Scientific Books (or Scientific Book chapters)

[33] N. FATÈS, I. MARCOVICI, S. TAATI.*Cellular automata for the self-stabilisation of colourings and tilings*, in "Proceedings of RP 2019 (International Conference on Reachability Problems)", September 2019, p. 121-136 [*DOI :* 10.1007/978-3-030-30806-3_10], https://hal.inria.fr/hal-02159155

Scientific Popularization

[34] N. FATÈS, I. MARCOVICI.*Les automates cellulaires jouent le jeu*, in "La Recherche : l'actualité des sciences", September 2019, n^{o} Numéro spécial 31, Réédition après changements mineurs de l'article " Automates cellulaires : la complexité dans les règles de l'art" https://hal.inria.fr/hal-01847663, https://hal.inria.fr/hal-02381102

Other Publications

[35] A. CALLARD, M. HOYRUP.*Descriptive complexity on non-Polish spaces*, January 2020, working paper or preprint [*DOI :* 10.4230/LIPIcs.STACS.2020.4], https://hal.inria.fr/hal-02298815

[36] T. CARETTE, M. LAURIÈRE, F. MAGNIEZ.*Extended Learning Graphs for Triangle Finding*, April 2019, https://arxiv.org/abs/1609.07786 - Fixing few typos in references, https://hal.archives-ouvertes.fr/hal-02107535

[37] E. JEANDEL, S. PERDRIX, R. VILMART.*Completeness of the ZX-Calculus*, December 2019, https://arxiv.org/abs/1903.06035 - Contains an appendix. arXiv admin note: text overlap with arXiv:1801.10142, https://hal.archives-ouvertes.fr/hal-02400081

References in notes

[38] A. ASPECT, P. GRANGIER, G. ROGER.*Experimental tests of realistic local theories via Bell's theorem*, in "Phys. Rev. Lett.", 1981, vol. 47, 460

[39] C. H. BENNETT, G. BRASSARD.*Quantum cryptography: Public key distribution and coin tossing*, in "Proceedings of IEEE international Conference on Computers, Systems and Signal Processing, Bangalore, India", New York, IEEE Press, 1984, 175

[40] N. FATÈS.*Solving the decentralised gathering problem with a reaction-diffusion-chemotaxis scheme - Social amoebae as a source of inspiration*, in "Swarm Intelligence", 2010, vol. 4, n^{o} 2, p. 91–115, http://dx.doi.org/10.1007/s11721-010-0038-4

[41] E. JEANDEL, S. PERDRIX, R. VILMART.*A Complete Axiomatisation of the ZX-Calculus for Clifford+T Quantum Mechanics*, in "The 33rd Annual ACM/IEEE Symposium on Logic in Computer Science, LICS 2018", Oxford, United Kingdom, Proceedings of the 33rd Annual ACM/IEEE Symposium on Logic in Computer Science, July 2018, p. 559–568 [*DOI :* 10.1145/3209108.3209131], https://hal.archives-ouvertes.fr/hal-01529623

[42] K. WEIHRAUCH.*Computable Analysis*, Springer, 2000

Project-Team MULTISPEECH

Speech Modeling for Facilitating Oral-Based Communication

IN COLLABORATION WITH: Laboratoire lorrain de recherche en informatique et ses applications (LORIA)

IN PARTNERSHIP WITH:
CNRS

Université de Lorraine

RESEARCH CENTER
Nancy - Grand Est

THEME
Language, Speech and Audio

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Project-Team MULTISPEECH

Creation of the Team: 2014 July 01, updated into Project-Team: 2015 July 01

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A3.5. - Social networks
A4.8. - Privacy-enhancing technologies
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A5.7.1. - Sound
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A5.9.1. - Sampling, acquisition
A5.9.2. - Estimation, modeling
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Other Research Topics and Application Domains:

B8.1.2. - Sensor networks for smart buildings
B8.4. - Security and personal assistance
B9.1.1. - E-learning, MOOC
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B9.5.2. - Mathematics
B9.5.6. - Data science
B9.6.8. - Linguistics
B9.6.10. - Digital humanities

1. Team, Visitors, External Collaborators

Research Scientists

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Antoine Deleforge [Inria, Researcher]
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Emmanuel Vincent [Inria, Senior Researcher, HDR]
Md Sahidullah [Inria, Starting Research Position]

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Adrien Dufraux [Facebook AI Research]
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Mathieu Fontaine [Inria, until Jun 2019, granted by ANR & Région Lorraine]
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Mohamed Amine Menacer [Univ de Lorraine]
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Lauréline Perotin [Orange Labs, until Nov 2019]
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Nicolas Zampieri [Inria, from Nov 2019, partially granted by Région Grand-Est]
Georgios Zervakis [Inria, from Nov 2019]

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Delphine Hubert [Univ de Lorraine]
Martine Kuhlmann [CNRS, until Apr 2019]
Anne-Marie Messaoudi [CNRS, since May 2019]

2. Overall Objectives

2.1. Overall Objectives

The goal of the project is the modeling of speech for facilitating oral-based communication. The name MULTISPEECH comes from the following aspects that are particularly considered.

- **Multisource aspects** - which means dealing with speech signals originating from several sources, such as speaker plus noise, or overlapping speech signals resulting from multiple speakers; sounds captured from several microphones are also considered.
- **Multilingual aspects** - which means dealing with speech in a multilingual context, as for example for computer assisted language learning, where the pronunciations of words in a foreign language (i.e., non-native speech) is strongly influenced by the mother tongue.
- **Multimodal aspects** - which means considering simultaneously the various modalities of speech signals, acoustic and visual, in particular for the expressive synthesis of audio-visual speech.

Our objectives are structured in three research axes, which have evolved compared to the project proposal finalized in 2014. Indeed, due to the ubiquitous use of deep learning, the distinction between 'explicit modeling' and 'statistical modeling' is not relevant anymore and the fundamental issues raised by deep learning have grown into a new research axis 'beyond black-box supervised learning'. The three research axes are now the following.

- **Beyond black-box supervised learning** This research axis focuses on fundamental, domain-agnostic challenges relating to deep learning, such as the integration of domain knowledge, data efficiency, or privacy preservation. The results of this axis naturally apply in the various domains studied in the two other research axes.
- **Speech production and perception** This research axis covers the topics of the research axis on 'Explicit modeling of speech production and perception' of the project proposal, but now includes a wide use of deep learning approaches. It also includes topics around prosody that were previously in the research axis on 'Uncertainty estimation and exploitation in speech processing' in the project proposal.
- **Speech in its environment** The themes covered by this research axis mainly correspond to those of the axis on 'Statistical modeling of speech' in the project proposal, plus the acoustic modeling topic that was previously in the research axis on 'Uncertainty estimation and exploitation in speech processing' in the project proposal.

A large part of the research is conducted on French and English speech data; German and Arabic languages are also considered either in speech recognition experiments or in language learning. Adaptation to other languages of the machine learning based approaches is possible, depending on the availability of speech corpora.

3. Research Program

3.1. Beyond black-box supervised learning

This research axis focuses on fundamental, domain-agnostic challenges relating to deep learning, such as the integration of domain knowledge, data efficiency, or privacy preservation. The results of this axis naturally apply in the domains studied in the two other research axes.

3.1.1. Integrating domain knowledge

State-of-the-art methods in speech and audio are based on neural networks trained for the targeted task. This paradigm faces major limitations: lack of interpretability and of guarantees, large data requirements, and inability to generalize to unseen classes or tasks. We intend to research **deep generative models** as a way to learn task-agnostic probabilistic models of audio signals and design inference methods to combine and reuse them for a variety of tasks. We will pursue our investigation of hybrid methods that combine the representational power of deep learning with **statistical signal processing** expertise by leveraging recent optimization techniques for non-convex, non-linear inverse problems. We will also explore the integration of deep learning and **symbolic reasoning** to increase the generalization ability of deep models and to empower researchers/engineers to improve them.

3.1.2. Learning from little/no labeled data

While fully labeled data are costly, unlabeled data are cheap but provide intrinsically less information. **Weakly supervised learning** based on not-so-expensive incomplete and/or noisy labels is a promising middle ground. This entails modeling label noise and leveraging it for unbiased training. Models may depend on the labeler, the spoken context (voice command), or the temporal structure (ambient sound analysis). We will also keep studying **transfer learning** to adapt an expressive (audiovisual) speech synthesizer trained on a given speaker to another speaker for which only neutral voice data has been collected.

3.1.3. Preserving privacy

Some voice technology companies process users' voices in the cloud and store them for training purposes, which raises privacy concerns. We aim to **hide speaker identity** and (some) speaker states and traits from the speech signal, and evaluate the resulting automatic speech/speaker recognition accuracy and subjective quality/intelligibility/identifiability, possibly after removing private words from the training data. We will also explore **semi-decentralized learning** methods for model personalization, and seek to obtain statistical guarantees.

3.2. Speech production and perception

This research axis covers topics related to the production of speech through articulatory modeling and multi-modal expressive speech synthesis, and topics related to the perception of speech through the categorization of sounds and prosody in native and in non-native speech.

3.2.1. Articulatory modeling

Articulatory speech synthesis will rely on further 2D and 3D modeling of the vocal tract as well as of the **dynamics of the vocal tract** from real-time MRI data. The prediction of glottis opening will also be considered so as to produce better quality acoustic events for consonants. The **coarticulation model** developed to handle the animation of the visible articulators will be extended to control the face and the tongue. This will help characterize links between the vocal tract and the face, and illustrate inner mouth articulation to learners. The suspension of articulatory movements in stuttering speech will also be studied.

3.2.2. Multimodal expressive speech

The dynamic realism of the animation of the talking head, which has a direct impact on audiovisual intelligibility, will continue to be our goal. Both the **animation** of the lower part of the face relating to speech and of the upper part relating to the facial expression will be considered, and development will continue towards a multilingual talking head. We will investigate further the modeling of **expressivity** both for audio-only and for audiovisual speech synthesis. We will also evaluate the benefit of the talking head in various use cases, including children with language and learning disabilities or deaf people.

3.2.3. Categorization of sounds and prosody

Reading and speaking are basic skills that need to be mastered. Further analysis of schooling experience will allow a better understanding of reading acquisition, especially for children with some language impairment. With respect to L1/L2 language interference [0] , a special focus will be set on the impact of L2 prosody on segmental realizations. Prosody will also be considered for its implication on the structuration of speech communication, including on discourse particles. Moreover, we will experiment the usage of speech technologies for computer assisted language learning in middle and high schools, and, hopefully, also for helping children learning to read.

3.3. Speech in its environment

The themes covered by this research axis correspond to the acoustic environment analysis, to speech enhancement and noise robustness, and to linguistic and semantic processing.

3.3.1. Acoustic environment analysis

Audio scene analysis is key to characterize the environment in which spoken communication may take place. We will investigate audio event detection methods that exploit both strongly/weakly labeled and unlabeled data, operate in real-world conditions, can discover novel events, and provide a semantic interpretation. We will keep working on source localization in the presence of nearby acoustic reflectors. We will also pursue our effort at the interface of **room acoustics** to blindly estimate room properties and develop acoustics-aware signal processing methods. Beyond spoken communication, this has many applications to surveillance, robot audition, building acoustics, and augmented reality.

3.3.2. Speech enhancement and noise robustness

We will pursue **speech enhancement** methods targeting several distortions (echo, reverberation, noise, overlapping speech) for both speech and speaker recognition applications, and extend them to ad-hoc arrays made of the microphones available in our daily life using multi-view learning. We will also continue to explore statistical signal models **beyond the usual zero-mean complex Gaussian model** in the time-frequency domain, e.g., deep generative models of the signal phase. **Robust acoustic modeling** will be achieved by learning domain-invariant representations or performing unsupervised domain adaptation on the one hand, and by extending our uncertainty-aware approach to more advanced (e.g., nongaussian) uncertainty models and accounting for the additional uncertainty due to short utterances on the other hand, with application to speaker and language recognition “in the wild”.

3.3.3. Linguistic and semantic processing

We will seek to address robust speech recognition by exploiting word/sentence embeddings carrying **semantic information** and combining them with acoustical uncertainty to rescore the recognizer outputs. We will also combine semantic content analysis with text obfuscation models (similar to the label noise models to be investigated for weakly supervised training of speech recognition) for the task of detecting and classifying (hateful, aggressive, insulting, ironic, neutral, etc.) **hate speech** in social media.

[0] L1 refers to the speaker’s native language, and L2 to a speaker’s second language, usually learned later as a foreign language

4. Application Domains

4.1. Introduction

Approaches and models developed in the MULTISPEECH project are intended to be used for facilitating oral communication in various situations through enhancements of communication channels, either directly via automatic speech recognition or speech production technologies, or indirectly, thanks to computer assisted language learning. Applications also include the usage of speech technologies for helping people in handicapped situations or for improving their autonomy. Foreseen application domains are related to multimodal computer interaction, annotation and processing of spoken documents, health and autonomy (more precisely aided communication and monitoring), and computer assisted learning.

4.2. Multimodal Computer Interactions

Speech synthesis has tremendous applications in facilitating communication in a human-machine interaction context to make machines more accessible. For example, it started to be widely common to use acoustic speech synthesis in smartphones to make possible the uttering of all the information. This is valuable in particular in the case of handicap, as for blind people. Audiovisual speech synthesis, when used in an application such as a talking head, i.e., virtual 3D animated face synchronized with acoustic speech, is beneficial in particular for hard-of-hearing individuals. This requires an audiovisual synthesis that is intelligible, both acoustically and visually. A talking head could be an intermediate between two persons communicating remotely when their video information is not available, and can also be used in language learning applications as vocabulary tutoring or pronunciation training tool. Expressive acoustic synthesis is of interest for the reading of a story, such as an audiobook, as well as for better human-machine interactions.

4.3. Annotation and Processing of Spoken Documents and Audio Archives

A first type of annotation consists in transcribing a spoken document in order to get the corresponding sequences of words, with possibly some complementary information, such as the structure (punctuation) or the modality (affirmation/question) of the utterances to make the reading and understanding easier. Typical applications of the automatic transcription of radio or TV shows, or of any other spoken document, include making possible their access by deaf people, as well as by text-based indexing tools.

A second type of annotation is related to speech-text alignment, which aims at determining the starting and ending times of the words, and possibly of the sounds (phonemes). This is of interest in several cases such as for annotating speech corpora for linguistic studies, and for synchronizing lip movements with speech sounds (for example, for avatar-based communications). Although good results are currently achieved on clean data, automatic speech-text alignment needs to be improved for properly processing noisy spontaneous speech data and needs to be extended to handle overlapping speech.

Finally, there is also a need for speech signal processing techniques in the field of multimedia content creation and rendering. Relevant techniques include speech and music separation, speech equalization, speech enhancement, prosody modification, and speaker conversion.

4.4. Aided Communication and Monitoring

Source separation techniques should help for locating and monitoring people through the detection of sound events inside apartments, and speech enhancement is mandatory for hands-free vocal interactions. A foreseen application aims at improving the autonomy of elderly or disabled people, and also fits with smartroom applications. In a longer perspective, adapting speech recognition technologies to the voice of elderly people should also be useful for such applications, but this requires the recording of adequate databases. Sound monitoring in other application fields (security, environmental monitoring) can also be envisaged.

4.5. Computer Assisted Learning

Although speaking seems quite natural, learning foreign languages, or learning the mother tongue for people with language deficiencies, represents critical cognitive stages. Hence, many scientific activities have been devoted to these issues either from a production or a perception point of view. The general guiding principle with respect to computer assisted mother or foreign language learning is to combine modalities or to augment speech to make learning easier. Based upon an analysis of the learner's production, automatic diagnoses can be considered. However, making a reliable diagnosis on each individual utterance is still a challenge, which is dependent on the precision and quality of the segmentation of the speech utterance into phones, and of the computed prosodic parameters.

5. Highlights of the Year

5.1. Highlights of the Year

We developed the first deep learning-based multichannel speech enhancement algorithm that jointly reduces acoustic echo, reverberation, and background noise [57].

E. Vincent gave a keynote at the Voice Tech Paris 2019 trade fair [18].

A. Deleforge organized the IEEE Signal Processing Cup 2019 on "Search & Rescue with Drone-Embedded Sound Source Localization", to which 20 teams of undergraduate students from 18 universities in 11 countries participated, for a total of 132 participants [5]. The final took place on May the 13th at the international conference ICASSP in Brighton. The associated DREGON dataset, which was made publicly available afterwards, has received over 1,000 file downloads as of December 2019.

5.1.1. Awards

L. Perotin obtained the Best Poster Award of the 2019 IEEE Workshop on Applications of Signal Processing to Audio and Acoustics (WASPAA) .
BEST PAPERS AWARDS :
[43]
L. PEROTIN, A. DÉFOSSEZ, E. VINCENT, R. SERIZEL, A. GUÉRIN.*Regression versus classification for neural network based audio source localization*, in "WASPAA 2019 - IEEE Workshop on Applications of Signal Processing to Audio and Acoustics", New Paltz, United States, IEEE, October 2019, https://hal.inria.fr/hal-02125985

6. New Software and Platforms

6.1. dnnsep

Multichannel audio source separation with deep neural networks

KEYWORDS: Audio - Source Separation - Deep learning

SCIENTIFIC DESCRIPTION: dnnsep is the only source separation software relying on multichannel Wiener filtering based on deep learning. Deep neural networks are used to initialize and reestimate the power spectrum of the sources at every iteration of an expectation-maximization (EM) algorithm.

FUNCTIONAL DESCRIPTION: Combines deep neural networks and multichannel signal processing for speech enhancement and separation of musical recordings.

NEWS OF THE YEAR: Version 1.1 was slightly modified in order to issue a test license to the French Ministry of Interior.

- Participants: Aditya Nugraha, Emmanuel Vincent and Antoine Liutkus
- Contact: Emmanuel Vincent

6.2. KATS

Kaldi-based Automatic Transcription System

KEYWORD: Speech recognition

FUNCTIONAL DESCRIPTION: KATS is a multipass system for transcribing audio data, and in particular radio or TV shows in French, English or Arabic. It is based on the Kaldi speech recognition tools. It relies on Deep Neural Network (DNN) modeling for speech detection and acoustic modeling of the phones (speech sounds). Higher order statistical language models and recurrent neural network language models can be used for improving performance through rescoring of multiple hypotheses.

NEWS OF THE YEAR: New models have been trained for German, as well as two bilingual models: one combining French and German phones, and one combining French and English phones. Also, a web server has been set up for on line real-time speech recognition.

- Participants: Dominique Fohr, Odile Mella, Mathieu Hu, Denis Jouvet and Irina Illina
- Contact: Dominique Fohr

6.3. SOJA

Speech Synthesis platform in JAva

KEYWORDS: Speech Synthesis - Audio

SCIENTIFIC DESCRIPTION: SOJA relies on a non-uniform unit selection algorithm. Phonetic and linguistic features are extracted and computed from the text to drive the selection of speech units in a recorded corpus. The selected units are concatenated to obtain the speech signal corresponding to the input text.

FUNCTIONAL DESCRIPTION: SOJA is a software for Text-To-Speech synthesis (TTS). It performs all steps from text input to speech signal output. A set of associated tools is available for elaborating a corpus for a TTS system (transcription, alignment, etc.). Currently, the corpus contains about 3 hours of speech recorded by a female speaker. Most of the modules are in Java, some are in C. The SOJA software runs under Windows and Linux. It can be launched with a graphical user interface or directly integrated in a Java code or by following the client-server paradigm.

RELEASE FUNCTIONAL DESCRIPTION: Version 3.0 integrates a phonetization based on a deep learning algorithm. In addition, the phonetization step is managed by API REST (client/server mode). The NLP part provides an output of descriptors in the format that can be used by HTS and Merlin systems.

NEWS OF THE YEAR: The latest version can use the LORIA-PHON deep learning based grapheme-to-phoneme converter through a web API.

- Participants: Alexandre Lafosse and Vincent Colotte
- Contact: Vincent Colotte

6.4. LORIA-PHON

LORIA grapheme-to-phoneme converter

KEYWORDS: Grapheme-to-phoneme converter - Neural networks

FUNCTIONAL DESCRIPTION: LORIA-PHON is a deep-learning based software for grapheme-to-phoneme conversion. It currently works for French. A web API is available for using it in a client/server mode. It properly interfaces with the SOJA software used for speech synthesis.

NEWS OF THE YEAR: new software

- Participants: Mathieu Hu, Denis Jouvet, Vincent Colotte and Louis Delebecque
- Contact: Vincent Colotte

6.5. Dynalips-Player

High realistic lip synchronization for 3d animated characters

KEYWORDS: 3D animation - Graphics - Speech Synthesis

FUNCTIONAL DESCRIPTION: Dynalips provides a solution to synchronize precisely and automatically the movements of the lips of a 3D character with speech (we address 3D animation movies and video games). We have developed a demonstrator that illustrates the whole process: from audio + text to the generation of the animation trajectory, and controlling the animation of a 3D model (e.g. an avatar). The demonstrator is composed mainly by the player developed in Unity 3D (but can be used with any other system) and plays the animation synchronously with speech in realtime. It is possible to generate an animation for Autodesk Maya 3D.

NEWS OF THE YEAR: The player has been extended to be multilingual thanks to two developments within two projects. In fact, within the METAL project, a lipsync for German has been developed. In addition, within the ATT Dynalips, we have built a lipsync for English.

- Partners: Université de Lorraine - Sayens (SATT Grand Est)
- Contact: Slim Ouni
- URL: http://www.dynalips.com

6.6. VisArtico

Visualization of multimodal speech data

KEYWORDS: Data visualization - 3D movement - Speech processing - Videos

SCIENTIFIC DESCRIPTION: VisArtico is a visualization software of multimodal data. It is possible to visualize the positions of real or virtual sensors and to animate them simultaneously with acoustics. This software can be useful for researchers in speech production, audiovisual speech synthesis or articulatory speech analysis.

FUNCTIONAL DESCRIPTION: VisArtico is a user-friendly software which allows visualizing multimodal data acquired by several systems: an articulograph, motion capture system, depth camera. This visualization software has been designed so that it can directly use the data provided by the different systems to display the spatial and temporal positions of the sensors (real and virtual). Moreover, VisArtico allows viewing the sensors augmented with visual information by indicating graphically the data for the tongue, lips and jaw.

RELEASE FUNCTIONAL DESCRIPTION: The current version allows the user to manage different modalities (articulatory, gestural, acoustic and video). It is possible to do automatic alignment, or even speech recognition. Several spatial data processing tools have been added (referential change, head movement suppression, merging data from multiple sources, ...).

NEWS OF THE YEAR: The software has undergone several improvements. Mainly, several branches have been merged in order to have as many features as possible available within the master branch.

- Participants: Ilef Ben Farhat, Loïc Mangeonjean, Slim Ouni and Louis Abel
- Partners: CNRS - Université de Lorraine
- Contact: Slim Ouni
- Publication: VisArtico: a visualization tool for articulatory data
- URL: http://visartico.loria.fr

6.7. Xarticulators

KEYWORDS: Medical imaging - Natural language processing

FUNCTIONAL DESCRIPTION: The Xarticulators software is intended to delineate contours of speech articulators in X-ray and MR images, construct articulatory models and synthesize speech from X-ray films. This software provides tools to track contours automatically, semi-automatically or by hand, to make the visibility of contours easier, to add anatomical landmarks to speech articulators and to synchronize images with the sound. In addition we also added the possibility of processing digitized manual delineation results made on sheets of papers when no software is available. Xarticulators also enables the construction of adaptable linear articulatory models from the X-ray or MR images and incorporates acoustic simulation tools to synthesize speech signals from the vocal tract shape. Recent work was on the possibility of synthesizing speech from 2D-MRI films, and on the construction of better articulatory models for the velum, lips and epiglottis.

RELEASE FUNCTIONAL DESCRIPTION: The new version allows MRI films to be processed and, above all, it offers a better transition from the shape of the vocal tract to the area function, which corresponds to an approximation of the vocal tract using a series of elementary tubes from the glottis to the lips.

NEWS OF THE YEAR: This year we completed the software to evaluate the articulatory model built from static images on dynamic images and we added a module to monitor the contour of the language using deep learning.

- Contact: Yves Laprie
- Publication: Articulatory model of the epiglottis

6.8. DCASE 2019 baseline

Baseline system for the task 4 of DCASE 2019 Challenge

KEYWORDS: Audio signal processing - Audio source classification - Machine learning - Smart home

FUNCTIONAL DESCRIPTION: This is the baseline system for the task 4 of the challenge on Detection and Classification of Acoustic Scenes and Events (DCASE) 2019. The algorithm performs sound events detection and classification. From an audio recording, the target of the system is to provide not only the event class but also the event time boundaries given that multiple events can be present in an audio recording. The baseline approach relies on convolutionnal and recurrent neural networks (CRNN) and a mean-teacher model to exploit a large amount of unbalanced and unlabeled training data together with a small weakly annotated (without timestamps) training set and a strongly annotated (with timestamps) synthetic set to improve system performance.

RELEASE FUNCTIONAL DESCRIPTION: This version includes a mean teacher model to exploit the various training sets with that have different levels of annotations, as provided in the task 4 of the DCASE 2019 challenge.

- Participants: Nicolas Turpault and Romain Serizel
- Contact: Nicolas Turpault
- Publication: Sound event detection in domestic environments with weakly labeled data and soundscape synthesis
- URL: https://github.com/turpaultn/DCASE2019_task4/tree/public/baseline

7. New Results

7.1. Beyond black-box supervised learning

Participants: Emmanuel Vincent, Denis Jouvet, Antoine Deleforge, Vincent Colotte, Irène Illina, Romain Serizel, Imran Sheikh, Pierre Champion, Adrien Dufraux, Ajinkya Kulkarni, Manuel Pariente, Georgios Zervakis, Zaineb Chelly Dagdia, Mehmet Ali Tugtekin Turan, Brij Mohan Lal Srivastava.

This year marked a significant increase in our research activities on domain-agnostic challenges relating to deep learning, such as the integration of domain knowledge, data efficiency, or privacy preservation. Our vision was illustrated by a keynote [18] and several talks [19], [17] on the key challenges and solutions.

7.1.1. Integrating domain knowledge

7.1.1.1. Integration of signal processing knowledge

State-of-the-art methods for single-channel speech enhancement or separation are based on end-to-end neural networks including learned real-valued filterbanks. We tackled two limitations of this approach. First, to ensure that the representation properly encodes phase properties as the short time Fourier transform and other conventional time-frequency transforms, we designed complex-valued analytic learned filterbanks and defined corresponding representations and masking strategies which outperformed the popular ConvTasNet algorithm [59]. Second, in order to allow generalization to mixtures of sources not seen together in training, we explored the modeling of speech spectra by variational autoencoders (VAEs), which are a variant of the probabilistic generative models classically used in source separation before the deep learning era. The VAEs are trained separately for each source and used to infer the source signals underlying a given mixture. Compared with existing iterative inference algorithms involving Gibbs sampling or gradient descent, we proposed a computationally efficient variational inference method based on an analytical derivation in which the encoder of the pre-learned VAE can be used to estimate the variational approximation of the true posterior [42], [55].

7.1.2. Learning from little/no labeled data

7.1.2.1. Learning from noisy labels

ASR systems are typically trained in a supervised fashion using manually labeled data. This labeling process incurs a high cost. Classical semi-supervised learning and transfer learning approaches to reduce the transcription cost achieve limited performance because the amount of knowledge that can be inferred from unlabeled data is intrinsically lower. We explored the middle ground where the training data are neither accurately labeled nor unlabeled but a not-so-expensive “noisy” transcription is available instead. We proposed a method to learn an end-to-end ASR model given a noise model and a single noisy transcription per utterance by adapting the auto segmentation criterion (ASG) loss to account for several possible transcriptions. Because the computation of this loss is intractable, we used a differentiable beam search algorithm that samples only the best alignments of the best transcriptions [32].

7.1.2.2. Transfer learning

We worked on the disentanglement of speaker, emotion and content in the acoustic domain for transferring expressivity information from one speaker to another one, particularly when only neutral speech data is available for the latter. In [36], we proposed to transfer the expressive characteristics through layer adaptation during the learning step. The obtained results highlighted that there is a difficult trade-off between speaker’s identity to remove and the expressivity to transfer. We are now working on an approach relying on multiclass N-pair based deep metric learning in recurrent conditional variational autoencoder (RCVAE) for implementing a multispeaker expressive text-to-speech (TTS) system. The proposed approach conditions the text-to-speech system on speaker embeddings, and leads to a clustering with respect to emotion in a latent space. The deep metric learning helps to reduce the intra-class variance and increase the inter-class variance. We transfer the expressivity by using the latent variables for each emotion to generate expressive speech in the voice of a different speaker for which no expressive speech is available. The performance measured shows the model’s capability to transfer the expressivity while preserving the speaker’s voice in synthesized speech.

7.1.3. Preserving privacy

Speech signals involve a lot of private information. With a few minutes of data, the speaker identity can be modeled for malicious purposes like voice cloning, spoofing, etc. To reduce this risk, we investigated speaker anonymization strategies based on voice conversion. In contrast to prior evaluations, we argue that different types of attackers can be defined depending on the extent of their knowledge. We compared three conversion methods in three attack scenarios, and showed that these methods fail to protect against an attacker that has extensive knowledge of the type of conversion and how it has been applied, but may provide some protection against less knowledgeable attackers [64]. As an alternative, we proposed an adversarial approach to learn representations that perform well for ASR while hiding speaker identity. Our results demonstrate that adversarial training dramatically reduces the closed-set speaker classification accuracy, but this does not translate into increased open-set speaker verification error [45]. We are currently organizing the 1st Voice Privacy Challenge in which these and other approaches will be further assessed and compared.

7.2. Speech production and perception

7.2.1. Articulatory modeling

Participants: Denis Jouvet, Anne Bonneau, Dominique Fohr, Yves Laprie, Vincent Colotte, Slim Ouni, Agnes Piquard-Kipffer, Elodie Gauthier, Manfred Pastatter, Théo Biasutto-Lervat, Sara Dahmani, Ioannis Douros, Amal Houidhek, Lou Lee, Shakeel Ahmad Sheikh, Anastasiia Tsukanova, Louis Delebecque, Valérian Girard, Thomas Girod, Seyed Ahmad Hosseini, Mathieu Hu, Leon Rohrbacher, Imene Zangar.

7.2.1.1. Articulatory speech synthesis

A number of simplifying assumptions have to be made in articulatory synthesis to enable the speech signal to be generated in a reasonable time. They mainly consist of approximating the propagation of the sound in the vocal tract as a plane wave and approximating the 3D vocal tract shape from the mid-sagittal shape [30], and also simplifying the vocal tract topology by removing small cavities [29]. The posture of the subject in the MRI machine was also investigated [31]. Vocal tract resonances were evaluated from the 3D acoustic simulation computed with the K-wave Matlab package from the complete 3D vocal tract shape recovered from MRI and compared to those of real speech [27].

We also developed an approach for using articulatory features for speech synthesis. The approach is based on a deep feed-forward neural network-based speech synthesizer trained with the standard recipe of Merlin on the audio recorded during real-time MRI (RT-MRI) acquisitions: denoised (and yet containing a residual noise of the MRI machine) speech in French and force-aligned state labels encoding phonetic and linguistic information [26]. The synthesizer was augmented with eight parameters representing articulatory information (lips opening and protrusion, distances between the tongue and the velum, between the velum and the pharyngeal wall, and between the tongue and the pharyngeal wall) that were automatically extracted from the captures and aligned with the audio signal and the linguistic specification.

7.2.1.2. Dynamics of vocal tract and glottal opening

The problem of creating a 3D dynamic atlas of the vocal tract that captures the dynamics of the articulators in all three dimensions has been addressed [28]. The core steps of the method are using 2D real time MRI in several sagittal planes and, after temporal alignment, combine them using adaptive kernel regression. As a preprocessing step, a reference space was created to be used in order to remove anatomical information of the speakers and keep only the variability in speech production for the construction of the atlas. Using adaptive kernel regression makes the choice of atlas time points independent of the time points of the frames that are used as an input for the atlas construction.

We started the development of a database of realistic glottal gestures which will be used to design the glottal opening dynamics in articulatory synthesis paradigms. Experimental measurements of glottal opening dynamics in VCV and VCCV sequences uttered by real subjects have been achieved thanks to a specifically designed external photoglottographic device (ePGG) [33]. The existence of different patterns of glottal opening is evidenced according to the class of the consonant articulated.

7.2.1.3. Multimodal coarticulation modeling

We have investigated labial coarticulation to animate a virtual face from speech. We experimented a sequential deep learning model, bidirectional gated recurrent networks, that have been used successfully in addressing the articulatory inversion problem. We have used phonetic information as input to ensure speaker independence. The initialization of the last layers of the network has greatly eased the training and helped to handle coarticulation. It relies on dimensionality reduction strategies, allowing injecting knowledge of useful latent representation of the visual data into the network. We have trained and evaluated the model with a corpus consisting of 4 hours of French speech, and we got a good average RMSE (Root Mean Square Error) close to 1.3 mm [21].

7.2.1.4. Identifying disfluency in stuttered speech

Within the ANR project BENEPHIDIRE, the goal is to automatically identify typical kinds of stuttering disfluency using acoustic and visual cues for their automatic detection. This year, we started analyzing existing stuttering acoustic speech datasets to characterize the kind of data.

7.2.2. Multimodal expressive speech

7.2.2.1. Arabic speech synthesis

We have continued working on Modern Standard Arabic speech synthesis with ENIT (École Nationale d'Ingénieurs de Tunis, Tunisia), using HMM and NN based approaches. This year we investigated the modeling of the fundamental frequency for Arabic speech synthesis with feedforward and recurrent DNN, and using specific linguistic features for Arabic like vowel quantity and gemination [50].

7.2.2.2. Expressive audiovisual synthesis

After acquiring a high quality expressive audio-visual corpus based on fine linguistic analysis, motion capture, and naturalistic acting techniques, we have analyzed, processed, and phonetically aligned it with speech. We used conditional variational autoencoders (CVAE) to generate the duration, acoustic and visual aspects of speech without using emotion labels. Perceptual experiments have confirmed the capacity of our system to generate recognizable emotions. Moreover, the generative nature of the CVAE allowed us to generate well-perceived nuances of the six emotions and to blend different emotions together [23].

7.2.2.3. Lipsync - synchronization of lips movements with speech

In the ATT Dynalips-2, we have developed an English version of the system which allows us having a full multilingual lipsync system. During this ATT, we also worked on the business aspects (business plan, funding, investment, search for clients, etc.) with the goal of creating a startup, spinoff of the laboratory, during 2020.

7.2.3. Categorization of sounds and prosody

7.2.3.1. Non-native speech production

We analysed voicing in sequences of obstruents with French as L1 and German as L2, that is languages characterized by strong differences in the voicing dimension, including assimilation direction. To that purpose, we studied the realizations of two sequences of obstruents, where the first consonant, in final position, was fortis, and the second consonant, in initial position, was either a lenis stop or a lenis fricative. These sequences lead to a possible anticipation of voicing in French, a direction not allowed in German given German phonetics and phonology. Highly variable realizations were observed: progressive and regressive assimilation, and absence of assimilation, often accompanied by an unexpected pause [22].

We also started investigating non-native phoneme productions of French learners of German in comparison to phoneme productions by native German speakers. A set of research questions has been developed for which a customized French/German corpus was designed, and recorded by one reference native speaker of German so far. Based on these initial recordings and according to the targeted research questions, analysis strategies and algorithms have been elaborated and implemented, and are ready to be employed onto a larger data set. By means of these methods we expect to access phonetic and phonological grounds of recurrently occurring mis-pronunciation.

7.2.3.2. Language and reading acquisition by children having some language impairments

We continued examining the schooling experience of 170 children, teenagers and young adults with specific language impairment (dysphasia, dyslexia, dysorthographia) facing severe difficulties in learning to read. The phonemic discrimination, phonological and phonemic analysis difficulties faced in their childhoods had raised reading difficulties, which the pupils did not overcome. With 120 of these young people, we explored the presence of other neuro-developmental disorders. We also studied their reading habits to achieve better understanding of their difficulties.

We continued investigating the acquisition of language by hard-of-hearing children via cued speech (i.e. augmenting the audiovisual speech signal by visualizing the syllables uttered via a code of hand positions). We have used a digital book and a children's picture book with 3 hard-of-hearing children in order to compare scaffolding by the speech therapist or the teacher in these two situations.

We started to examine language difficulties and related problems with children with autism and to work with their parents with a view to creating an environment conducive to their progress [39].

7.2.3.3. Computer assisted language learning

In the METAL project, experiments are planned to investigate the use of speech technologies for foreign language learning and to experiment with middle and high school students learning German. This includes tutoring aspects based on a talking head to show proper articulation of words and sentences; as well as using automatic tools derived from speech recognition technology, for analyzing student pronunciations. The web application is under development, and experiments have continued for analyzing the performance of an automatic detection of mispronunciations made by language learners.

The ALOE project deals with children learning to read. In this project, we are also involved with tutoring aspects based on a talking head, and with grapheme-to-phoneme conversion which is a critical tool for the development of the digitized version of ALOE reading learning tools (tools which were previously developed and offered only in a paper form).

7.2.3.4. Prosody

The keynote [15] summarizes recent research on speech processing and prosody, and presents the extraction of prosodic features, as well as their usage in various tasks. Prosodic correlates of discourse particles have been investigated further. It was found that occurrences of different discourse particles with the same pragmatic value have a great tendency to share the same prosodic pattern; hence, the question of their commutability have been studied [37].

7.3. Speech in its environment

Participants: Denis Jouvet, Antoine Deleforge, Dominique Fohr, Emmanuel Vincent, Md Sahidullah, Irène Illina, Odile Mella, Romain Serizel, Tulika Bose, Guillaume Carbajal, Diego Di Carlo, Sandipana Dowerah, Ashwin Geet Dsa, Adrien Dufraux, Raphaël Duroselle, Mathieu Fontaine, Nicolas Furnon, Mohamed Amine Menacer, Mauricio Michel Olvera Zambrano, Lauréline Perotin, Sunit Sivasankaran, Nicolas Turpault, Nicolas Zampieri, Ismaël Bada, Yassine Boudi, Mathieu Hu, Stephane Level.

7.3.1. Acoustic environment analysis

We are constantly surrounded by ambient sounds and rely heavily on them to obtain important information about our environment. Deep neural networks are useful to learn relevant representations of these sounds. Recent studies have demonstrated the potential of unsupervised representation learning using various flavors of the so-called triplet loss (a triplet is composed of the current sample, a so-called positive sample from the same class, and a negative sample from a different class), and compared it to supervised learning. To address real situations involving both a small labeled dataset and a large unlabeled one, we combined unsupervised and supervised triplet loss based learning into a semi-supervised representation learning approach and compared it with supervised and unsupervised representation learning depending on the ratio between the amount of labeled and unlabeled data [49].

Pursuing our involvement in the community on ambient sound recognition, we co-organized a task on large-scale sound event detection as part of the Detection and Classification of Acoustic Scenes and Events (DCASE) 2019 Challenge [48]. It focused on the problem of learning from audio segments that are either weakly labeled or not labeled, targeting domestic applications. We also published a summary of the outcomes of the DCASE 2017 Challenge, in which we had organized the first version of that task [7] and a detailed analysis of the submissions to that task in 2018 [16] and 2019 [61].

7.3.2. Speech enhancement and noise robustness

7.3.2.1. Sound source localization and counting

In multichannel scenarios, source localization, counting and separation are tightly related tasks. Concerning deep learning based speaker localization, we introduced the real and imaginary parts of the acoustic intensity vector in each time-frequency bin as suitable input features. We analyzed the inner working of the neural network using layerwise relevance propagation [9]. We also defined alternative regression-based approaches for localization and compared them to the usual classification-based approach on a discrete grid [43]. Lauréline Perotin successfully defended her PhD on this topic [2]. In [24], we proposed the first deep-learning based method for blindly estimating early acoustic echoes. We showed how estimates of these echoes enable 2D sound source localization with only two microphones near a reflective surface, a task normally impossible with traditional methods. Finally, we published our former work on motion planning for robot audition [8].

We organized the IEEE Signal Processing Cup 2019, an international competition aimed at teams of undergraduate students [5]. The tasks we proposed were on sound source localization using an array embedded in a flying drone for search and rescue application. Submissions to the first phase of the competition were opened from November 2018 to March 2019, and the final took place on May the 13th at the international conference ICASSP in Brighton. 20 teams of undergraduate students from 18 universities in 11 countries participated, for a total of 132 participants. The drone-embedded sound source localization dataset we recorded for the challenge was made publically available after the competition and has received over 1,000 file downloads as of December 2019.

7.3.2.2. Speech enhancement

We investigated the effect of speaker localization accuracy on deep learning based speech enhancement quality. To do so, we generated a multichannel, multispeaker, reverberated, noisy dataset inspired from the well studied WSJ0-2mix and evaluated enhancement performance in terms of the word error rate. We showed that the signal-to-interference ratio between the speakers has a higher impact on the ASR performance than the angular distance [62]. In addition, we proposed a deflation method which estimates the sources iteratively. At each iteration, we estimate the location of the speaker, derive the corresponding time-frequency mask and remove the estimated source from the mixture before estimating the next one [63].

In parallel, we introduced a method for joint reduction of acoustic echo, reverberation and noise. This method models the target and residual signals after linear echo cancellation and dereverberation using a multichannel Gaussian modeling framework and jointly represents their spectra by means of a neural network. We developed an iterative block-coordinate ascent algorithm to update all the filters. The proposed approach outperforms in terms of overall distortion a cascade of the individual approaches and a joint reduction approach which does not rely on a spectral model of the target and residual signals [53], [57].

In the context of ad-hoc acoustic antennas, we proposed to extend the distributed adaptive node-specific signal estimation approach to a neural networks framework. At each node, a local filtering is performed to send one signal to the other nodes where a mask is estimated by a neural network in order to compute a global multichannel Wiener filter. In an array of two nodes, we showed that this additional signal can be efficiently taken into account to predict the masks and leads to better speech enhancement performances than when the mask estimation relies only on the local signals [58].

We have been pursuing our work on non-Gaussian heavy-tail models for signal processing, and notably investigated whether such models could be of use to devise new cost functions for the training of deep generative models for source separation [34]. In the case of speech enhancement, it turned out that the related log-likelihood functions could advantageously replace the more constraining squared-error and lead to significant performance gains.

We have also been pursuing our theoretical work on multichannel alpha-stable models, devising two new multichannel filtering methods that are adequate for processing multivariate heavy-tailed vectors. The related work is presented in Mathieu Fontaine's PhD manuscript [1].

7.3.2.3. Robust speech recognition

Achieving robust speech recognition in reverberant, noisy, multi-source conditions requires not only speech enhancement and separation but also robust acoustic modeling. In order to motivate further work by the community, we created the series of CHiME Speech Separation and Recognition Challenges in 2011. We are now organizing the 6th edition of the Challenge, and released the French dataset for ambient assisted living applications previously collected as part of the FUI VOICEHOME project [4].

7.3.2.4. Speaker recognition

Automatic speaker recognition systems give reasonably good recognition accuracy when adequate amount of speech data from clean conditions are used for enrollment and test. However, performance degrades substantially in real-world noisy conditions as well as due to the lack of adequate speech data. Apart from these two practical limitations, speaker recognition performance also degrades in presence of spoofing attacks [51] where playback voice or synthetic speech generated with voice conversion or speech synthesis methods are used by attackers to access a system protected with voice biometrics.

We have explored a new speech quality measure for quality-based fusion of speaker recognition systems. The quality metric is formulated with the zero-order statistics estimated during i-vector extraction. The proposed quality metric is shown to capture the speech duration information, and it has outperformed absolute-duration based quality measures when combining multiple speaker recognition systems. Noticeable improvement over existing methods have been observed specifically for the short-duration conditions [10].

We have also participated in speaker recognition evaluation campaigns NIST SREs and VoxSRC. For the NIST SREs [54], the key problem was to recognize speakers from low-quality telephone conversations. In addition, the language mismatch between system development and data under test made the problem more challenging. In VoxSRC, on the other hand, the main problem was to recognize speakers speaking short sentences of about 10 sec where the speech files are extracted from Youtube video clips. We have explored acoustic feature extraction, domain adaptation, parameter optimization and system fusion for these challenges. For VoxSRC, our system has shown substantial improvement over baseline results.

We also introduced a statistical uncertainty-aware method for robust i-vector based speaker verification in noisy conditions, that is the first one to improve over simple chaining of speech enhancement and speaker verification on the challenging NIST-SRE corpus mixed with real domestic noise and reverberation [44].

Robust speaker recognition is an essential component of speaker diarization systems. We have participated in the second DIHARD challenge where the key problem was the diarization of speech signals collected from diverse real-world conditions. We have explored speech activity detection, domain grouping, acoustic features, and speech enhancement for improved speaker recognition. Our proposed system has shown considerable improvement over the Kaldi-based baseline system provided by the challenge organizer [60].

We have co-organized the ASVspoof 2019 challenge, as an effort to develop next-generation countermeasures for automatic detection of spoofed/fake audio [46]. This involved creating the audio dataset, designing experiments, evaluating and analyzing the results. 154 teams or individuals participated in the challenge. The database is available for research and further exploration from Edinburgh DataShare, and has been downloaded/viewed more than a thousand times so far.

We have also analyzed whether target speaker selection can help in attacking speaker recognition systems with voice impersonation [35]. Our study reveals that impersonators were not successful in attacking the systems, however, the speaker similarity scores transfer well from the attacker's system to the attacked system [12]. Though there were modest changes in F0 and formants, we found that the impersonators were able to considerably change their speaking rates when mimicking targets.

7.3.2.5. Language identification

State-of-the-art spoken language identification systems are constituted of three modules: a frame level feature extractor, a segment level embedding extractor and a classifier. The performance of these systems degrades when facing mismatch between training and testing data. Although most domain adaptation methods focus on adaptation of the classifier, we have developed an unsupervised domain adaptation of the embedding extractor.

The proposed approach consists in a modification of the loss of the segment level embedding extractor by adding a regularisation term. Experiments were conducted with respect to transmission channel mismatch between telephone and radio channels using the RATS corpus. The proposed method is superior to adaptation of the classifier and obtain the same performance as published language identification results but without using labelled data from the target domain.

7.3.3. Linguistic and semantic processing

7.3.3.1. Transcription, translation, summarization and comparison of videos

Within the AMIS project, we studied different subjects related to the processing of videos. The first one concerns the machine translation of Arabic-English code-switched documents [41]. Code-switching is defined as the use of more than one language by a speaker within an utterance. The second one deals with the summarization of videos into a target language [11]. This exploits research carried on in several areas including video summarization, speech recognition, machine translation, audio summarization and speech segmentation. One of the big challenges of this work was to conceive a way to evaluate objectively a system composed of several components given that each of them has its limits and that errors propagate through the components. A third aspect was a method for extracting text-based summarization of Arabic videos [40]. The automatic speech recognition system developed to transcribe the videos has been adapted to the Algerian dialect, and additional modules were developed for segmenting the flow of recognized word into sentences, and for summarization. Finally the last aspect concerns the comparison of the opinions of two videos in two different languages [20]. Evaluations have been carried on comparable videos extracted from a corpus of 1503 Arabic and 1874 English videos.

7.3.3.2. Detection of hate speech in social media

The spectacular expansion of the Internet led to the development of a new research problem in natural language processing, the automatic detection of hate speech, since many countries prohibit hate speech in public media. In the context of the M-PHASIS project, we proposed a new approach for the classification of tweets, aiming to predict whether a tweet is abusive, hate or neither. We compare different unsupervised word representations and DNN classifiers, and study the robustness of the proposed approaches to adversarial attacks when adding one (healthy or toxic) word. We are evaluating the proposed methodology on the English Wikipedia Detox corpus and on a Twitter corpus.

7.3.3.3. Introduction of semantic information in an automatic speech recognition system

In current state-of-the-art automatic speech recognition systems, N-gram based models are used to take into account language information. They have a local view and are mainly based on syntax. The introduction of semantic information and longer term information in a recognition system should make it possible to remove some ambiguities and reduce the error rate of the system. Within the MMT project, we are proposing and evaluating methods for integrating semantic information into our speech recognition system through the use of various word embeddings.

7.3.3.4. Music language modeling

Similarly to speech, language models play a key role in music modeling. We represented the hierarchical structure of a temporal scenario (for instance, a chord progression) via a phrase structure grammar and proposed a method to automatically induce this grammar from a corpus and to exploit it in the context of machine improvisation [6].

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

8.1.1. Studio Maia

Company: Studio Maia SARL (France)

Other partners: Imaging Factory

Duration: Jul 2017 – March 2019

Participants: Yassine Boudi, Vincent Colotte, Mathieu Hu, Emmanuel Vincent

Abstract: We developed a software suite for voice processing in the multimedia creation chain. The software was designed for sound engineers, and relied on the team's expertise in speech enhancement, robust speech and speaker recognition, and speech synthesis.

8.1.2. Honda Research Institute Japan

Company: Honda Research Institute Japan (Japan)

Duration: Aug 2018 – Mar 2019

Participants: Nancy Bertin (CNRS - IRISA), Antoine Deleforge, Diego Di Carlo

Abstract: This was a follow-up contract targeting collaborative research on multichannel speech and audio processing and eventual software licensing in order to enable voice-based communication in challenging noisy and reverberant conditions in which current hands-free voice-based interfaces perform poorly.

8.1.3. Dassault and Thalès - Man Machine Teaming Initiative

Company: Dassault and Thalès (France)

Duration: Apr 2019 - Sept 2020

Participants: Irène Illina, Dominique Fohr, Ismael Bada, Stephane Level

Abstract: The primary goal of the project is to develop a new approach that allows coupling speech enhancement with semantic analysis for improving speech recognition robustness.

8.2. Bilateral Grants with Industry

8.2.1. Orange

Company: Orange SA (France)

Duration: Nov 2016 – Oct 2019

Participants: Lauréline Perotin, Romain Serizel, Emmanuel Vincent

Abstract: This CIFRE contract funded the PhD thesis of Lauréline Perotin. Our goal was to develop deep learning based speaker localization and speech enhancement algorithms for robust hands-free voice command. We were especially targeting difficult scenarios involving several simultaneous speakers.

8.2.2. Invoxia

Company: Invoxia SAS (France)

Duration: Mar 2017 – Apr 2020

Participants: Guillaume Carbajal, Romain Serizel, Emmanuel Vincent

Abstract: This CIFRE contract funds the PhD thesis of Guillaume Carbajal. Our goal is to design a unified end-to-end deep learning based speech enhancement system that integrates all steps in the current speech enhancement chain (acoustic echo cancellation and suppression, dereverberation, and denoising) for improved hands-free voice communication.

8.2.3. Ministère des Armées

Company: Ministère des Armées (France)

Duration: Sep 2018 – Aug 2021

Participants: Raphaël Duroselle, Denis Jouvet, Irène Illina

Abstract: This contract corresponds to the PhD thesis of Raphaël Duroselle on the application of deep learning techniques for domain adaptation in speech processing.

8.2.4. Facebook

Company: Facebook AI Research (France)

Duration: Nov 2018 – Nov 2021

Participants: Adrien Dufraux, Emmanuel Vincent

Abstract: This CIFRE contract funds the PhD thesis of Adrien Dufraux. Our goal is to explore cost-effective weakly supervised learning approaches, as an alternative to fully supervised or fully unsupervised learning for automatic speech recognition.

9. Partnerships and Cooperations

9.1. Regional Initiatives

9.1.1. CPER LCHN

Project acronym: CPER LCHN

Project title: CPER “Langues, Connaissances et Humanités Numériques”

Duration: 2015-2020

Coordinator: Bruno Guillaume (LORIA) & Alain Polguère (ATILF)

Participants: Dominique Fohr, Denis Jouvet, Odile Mella, Yves Laprie

Abstract: The main goal is related to experimental platforms for supporting research activities in the domain of languages, knowledge and numeric humanities engineering. MULTISPEECH contributes to automatic speech recognition, speech-text alignment and prosody aspects.

9.1.2. CPER IT2MP

Project acronym: CPER IT2MP

Project title: CPER “Innovation Technologique Modélisation et Médecine Personalisée”

Duration: 2015-2020

Coordinator: Faiez Zannad (Inserm-CHU-UL)

Participants: Romain Serizel, Emmanuel Vincent

Abstract: The goal is to develop innovative technologies for health, and tools and strategies for personalized medicine. MULTISPEECH will collect data for distant-microphone voice commands.

9.1.3. Com-Medic ALOE

Company: Com-Medic (France)

Duration: Mar 2019 – August 2020

Participants: Denis Jouvet, Vincent Colotte, Slim Ouni, Louis Delebecque

Abstract: ALOE is a method of reading relying on a specific representation of sounds. Our involvement in the project is to develop tools to translate automatically and align text sentences into phone sequences as required by the ALOE system, and to provide audio and video tutoring examples.

9.2. National Initiatives

9.2.1. ANR ArtSpeech

Project acronym: ArtSpeech

Project title: Synthèse articulatoire phonétique

Duration: October 2015 - August 2020

Coordinator: Yves Laprie

Other partners: Gipsa-Lab (Grenoble), IADI (Nancy), LPP (Paris)

Participants: Ioannis Douros, Yves Laprie, Anastasiia Tsukanova

Abstract: The objective is to synthesize speech via the numerical simulation of the human speech production processes, i.e. the articulatory, aerodynamic and acoustic aspects. Articulatory data comes from MRI and EPGG acquisitions.

9.2.2. ANR JCJC KAMoulox

Project acronym: KAMoulox

Project title: Kernel additive modelling for the unmixing of large audio archives

Duration: January 2016 - September 2019

Coordinator: Antoine Liutkus (Inria Zenith)

Participants: Mathieu Fontaine

Abstract: The objective is to develop theoretical and applied tools to embed audio denoising and separation tools in web-based audio archives. The applicative scenario is to deal with the notorious audio archive "*Archives du CNRS — Musée de l'Homme*", gathering recordings dating back to the early 1900s.

9.2.3. PIA2 ISITE LUE

Project acronym: ISITE LUE

Project title: Lorraine Université d'Excellence

Duration: 2016 - 2020

Coordinator: Univ. Lorraine

Participants: Ioannis Douros, Yves Laprie

Abstract: LUE (Lorraine Université d'Excellence) was designed as an "engine" for the development of excellence, by stimulating an original dialogue between knowledge fields. Within challenge number 6: "Knowledge engineering" this project funds the PhD thesis of Ioannis Douros on articulatory modeling.

9.2.4. OLKI LUE

Project acronym: OLKI LUE

Project title: Open Language and Knowledge for Citizens, Lorraine Université d'Excellence

Coordinator: Christophe Cerisara (LORIA)

Participants: Tulika Bose, Dominique Fohr, Irène Illina

Abstract: The initiative aims at developing new algorithms that improve the automatic understanding of natural language documents, and a federated language resource distribution platform to enable and facilitate the sharing of open resources. This project funds the PhD thesis of Tulika Bose on the detection and classification of hate speech.

9.2.5. E-FRAN METAL

Project acronym: E-FRAN METAL

Project title: Modèles Et Traces au service de l'Apprentissage des Langues

Duration: October 2016 - September 2020

Coordinator: Anne Boyer (LORIA)

Other partners: Interpsy, LISEC, ESPE de Lorraine, D@NTE (Univ. Versailles Saint Quentin), Sailendra SAS, ITOP Education, Rectorat.

Participants: Theo Biasutto-Lervat, Anne Bonneau, Vincent Colotte, Dominique Fohr, Elodie Gauthier, Thomas Girod, Denis Jouvet, Odile Mella, Slim Ouni, Leon Rohrbacher

Abstract: METAL aims at improving the learning of languages (written and oral) through development of new tools and analysis of numeric traces associated with students' learning. MULTISPEECH is concerned by oral language learning aspects.

9.2.6. ANR VOCADOM

Project acronym: VOCADOM (http://vocadom.imag.fr/)

Project title: Robust voice command adapted to the user and to the context for ambient assisted living

Duration: January 2017 - December 2020

Coordinator: CNRS - LIG (Grenoble)

Other partners: Inria (Nancy), Univ. Lyon 2 - GREPS, THEORIS (Paris)

Participants: Dominique Fohr, Md Sahidullah, Sunit Sivasankaran, Emmanuel Vincent

Abstract: The goal is to design a robust voice control system for smart home applications. MULTISPEECH is responsible for wake-up word detection, overlapping speech separation, and speaker recognition.

9.2.7. ANR JCJC DiSCogs

Project acronym: DiSCogs

Project title: Distant speech communication with heterogeneous unconstrained microphone arrays

Duration: September 2018 – March 2022

Coordinator: Romain Serizel

Participants: Nicolas Furnon, Irène Illina, Romain Serizel, Emmanuel Vincent

Collaborators: Télécom ParisTech, 7sensing

Abstract: The objective is to solve fundamental sound processing issues in order to exploit the many devices equipped with microphones that populate our everyday life. The solution proposed is to apply deep learning approaches to recast the problem of synchronizing devices at the signal level as a multi-view learning problem.

9.2.8. ANR DEEP-PRIVACY

Project acronym: DEEP-PRIVACY

Project title: Distributed, Personalized, Privacy-Preserving Learning for Speech Processing

Duration: January 2019 - December 2022

Coordinator: Denis Jouvet

Other partners: LIUM (Le Mans), MAGNET (Inria Lille), LIA (Avignon)

Participants: Pierre Champion, Denis Jouvet, Emmanuel Vincent

Abstract: The objective is to elaborate a speech transformation that hides the speaker identity for an easier sharing of speech data for training speech recognition models; and to investigate speaker adaptation and distributed training.

9.2.9. ANR ROBOVOX

Project acronym: ROBOVOX

Project title: Robust Vocal Identification for Mobile Security Robots

Duration: Mar 2019 – Mar 2023

Coordinator: Laboratoire d'informatique d'Avignon (LIA)

Other partners: Inria (Nancy), A.I. Mergence

Participants: Antoine Deleforge, Sandipana Dowerah, Denis Jouvet, Romain Serizel

Abstract: The aim is to improve speaker recognition robustness for a security robot in real environment. Several aspects will be particularly considered such as ambiant noise, reverberation and short speech utterances.

9.2.10. ANR LEAUDS

Project acronym: LEAUDS

Project title: Learning to understand audio scenes

Duration: Apr 2019 - Sep 2022

Coordinator: Université de Rouen Normandie

Other partners: Inria (Nancy), Netatmo (Paris)

Participants: Mauricio Michel Olvera Zambrano, Romain Serizel, Emmanuel Vincent, and Christophe Cerisara (CNRS - LORIA)

Abstract: LEAUDS aims to make a leap towards developing machines that understand audio input through breakthroughs in the detection of thousands of audio events from little annotated data, the robustness to "out-of-the lab" conditions, and language-based description of audio scenes. MULTISPEECH is responsible for research on robustness and for bringing expertise on natural language generation.

9.2.11. Inria Project Lab HyAIAI

Project acronym: HyAIAI

Project title: Hybrid Approaches for Interpretable AI

Duration: Sep 2019 - Aug 2023

Coordinator: Inria LACODAM (Rennes)

Other partners: Inria TAU (Saclay), SEQUEL, MAGNET (Lille), MULTISPEECH, ORPAILLEUR (Nancy)

Participants: Irène Illina, Emmanuel Vincent, Georgios Zervakis

Abstract: HyAIAI is about the design of novel, interpretable artificial intelligence methods based on hybrid approaches that combine state of the art numeric models with explainable symbolic models.

9.2.12. ANR BENEPHIDIRE

Project acronym: BENEPHIDIRE

Project title: Stuttering: Neurology, Phonetics, Computer Science for Diagnosis and Rehabilitation

Duration: March 2019 - December 2023

Coordinator: Praxiling (Toulouse)

Other partners: LORIA (Nancy), INM (Toulouse), LiLPa (Strasbourg).

Participants: Yves Laprie, Slim Ouni, Shakeel Ahmad Sheikh

Abstract: This project brings together neurologists, speech-language pathologists, phoneticians, and computer scientists specializing in speech processing to investigate stuttering as a speech impairment and to develop techniques for diagnosis and rehabilitation.

9.2.13. ANR HAIKUS

Project acronym: HAIKUS

Project title: Artificial Intelligence applied to augmented acoustic Scenes

Duration: Dec 2019 - May 2023

Coordinator: Ircam (Paris)

Other partners: Inria (Nancy), IJLRA (Paris)

Participants: Antoine Deleforge, Emmanuel Vincent

Abstract: HAIKUS aims to achieve seamless integration of computer-generated immersive audio content into augmented reality (AR) systems. One of the main challenges is the rendering of virtual auditory objects in the presence of source movements, listener movements and/or changing acoustic conditions.

9.2.14. ANR Flash Open Science HARPOCRATES

Project acronym: HARPOCRATES

Project title: Open data, tools and challenges for speaker anonymization

Duration: Oct 2019 - Mar 2021

Coordinator: Eurecom (Nice)

Other partners: Inria (Nancy), LIA (Avignon)

Participants: Denis Jouvet, Md Sahidullah, Emmanuel Vincent

Abstract: HARPOCRATES will form a working group that will collect and share the first open datasets and tools in the field of speech privacy, and launch the first open challenge on speech privacy, specifically on the topic of voice de-identification.

9.2.15. ATT Dynalips & ATT Dynalips-2

Project acronym: DYNALIPS

Project title: Automatic Lip synchronization with speech

Duration: Jul 2018 - Dec 2019

Coordinator: Slim Ouni

Participants: Valerian Girard, Slim Ouni

Abstract: This is a technology transfer project of our research solution that aims to synchronize precisely and automatically the movement of the mouth of a 3D character with speech. We address 3D animation and video game industries.

9.2.16. InriaHub Carnot Technologies Vocales

Project title: InriaHub Carnot Technologies Vocales

Duration: Jan 2019 - Dec 2020

Coordinator: Denis Jouvet

Participants: Mathieu Hu, Denis Jouvet, Dominique Fohr, Vincent Colotte, Emmanuel Vincent, Romain Serizel

Abstract: This project aims to adjust and finalize the speech synthesis and recognition modules developed for research purposes in the team, so that they can be used in interactive mode.

9.3. European Initiatives

9.3.1. FP7 & H2020 Projects

9.3.1.1. COMPRISE

Program: H2020 ICT-29-2018 (RIA)

Project acronym: COMPRISE

Project title: Cost-effective, Multilingual, Privacy-driven voice-enabled Services

Duration: Dec 2018- Nov 2021

Coordinator: Emmanuel Vincent

Other partners: Inria Magnet, Ascora GmbH, Netfective Technology SA, Rooter Analysis SL, Saarland University, Tilde SIA

Participants: Irène Illina, Denis Jouvet, Imran Sheikh, Brij Mohan Lal Srivastava, Mehmet Ali Tugtekin Turan, Emmanuel Vincent

Abstract: COMPRISE will define a fully private-by-design methodology and tools that will reduce the cost and increase the inclusiveness of voice interaction technologies.

9.3.1.2. AI4EU

Program: ICT-26-2018-2020

Project acronym: AI4EU

Project title: European Artificial Intelligence On-Demand Platform and Ecosystem

Duration: 2019–2021

Coordinator: THALES

Other partners: 80 partners from 22 countries

Participants: Seyed Ahmad Hosseini, Slim Ouni

Abstract: The aim of AI4EU is to develop a European Artificial Intelligence ecosystem, from knowledge and algorithms to tools and resources.

9.3.1.3. CPS4EU

Program: PSPC-ECSEL

Project acronym: CPS4EU

Project title: Cyber-physical systems for Europe

Duration: June 2019 – June 2022

Coordinator: CEA

Other partners: 42 partners from 6 countries

Participants: Antoine Deleforge, Romain Serizel

Abstract: CPS4EU aims to develop key enabling technologies, pre-integration and development expertise to support the industry and research players' interests and needs for emerging interdisciplinary cyber-physical systems (CPS) and securing a supply chain around CPS enabling technologies and products.

9.3.2. Collaborations in European Programs, Except FP7 & H2020

9.3.2.1. AMIS

Program: CHIST-ERA

Project acronym: AMIS

Project title: Access Multilingual Information opinionS

Duration: Dec 2015- Nov 2019

Coordinator: Kamel Smaïli (LORIA)

Other partners: University of Avignon, University of Science and Technology Krakow, University of DEUSTO (Bilbao)

Participants: Dominique Fohr, Denis Jouvet, Odile Mella, Mohamed Amine Menacer

Abstract: The idea is to develop a multilingual system to help people understand broadcast news in a foreign language and compare them to corresponding news available in the user's mother tongue. MULTISPEECH contributions concern mainly the speech recognition in French, English and Arabic videos.

9.3.2.2. M-PHASIS

Program: ANR-DFG

Project acronym: M-PHASIS

Project title: Migration and Patterns of Hate Speech in Social Media - A Cross-cultural Perspective

Duration: March 2019 - Feb 2022

Coordinators: Angeliki Monnier (CREM) and Christian Schemer (Johannes Gutenberg university)

Partners: CREM (UL), LORIA (UL), JGUM (Johannes Gutenberg-Universität), SAAR (Saarland University)

Participants: Irène Illina, Dominique Fohr, Ashwin Geet D'sa

Abstract: Focusing on the social dimension of hate speech, M-PHASIS seeks to study the patterns of hate speech related to migrants, and to provide a better understanding of the prevalence and emergence of hate speech in user-generated content in France and Germany. MULTISPEECH contributions concern mainly the automatic detection of hate speech in social media.

9.4. International Initiatives

9.4.1. Inria International Partners

9.4.1.1. Informal International Partners

- Alessio Brutti & Maurizio Omologo, Fondazione Bruno Kessler (Italy)
  speech enhancement and speaker recognition [60]
- Samuele Cornell & Stefano Squartini, Università Politecnica delle Marche (Italy)
  speech enhancement and speaker recognition [59], [60]
- Tomi Kinnunen, University of Eastern Finland (Finland)
  speaker recognition & spoofing countermeasures [35], [12], [51], [54], [46].
- Justin Salamon, Adobe Research (USA)
  Sound event detection [48], [61]
- Junichi Yamagishi, National Institute of Informatics (Japan)
  speaker recognition & spoofing countermeasures [51], [46].

9.5. International Research Visitors

9.5.1. Visits to International Teams

9.5.1.1. Research Stays Abroad

- 2019 Sixth Frederick Jelinek Memorial Summer Workshop (Jun.–Aug. 2019, M. Pariente, S. Sivasankaran)

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events: Organisation

10.1.1.1. General Chair, Scientific Chair

Elected chair, Steering Committee of the Latent Variable Analysis and Signal Separation (LVA/ICA) conference series (E. Vincent, until Nov. 2019)

General co-chair, 1st Inria-DFKI Workshop on Artificial Intelligence, Nancy, Jan. 2020 (E. Vincent)

General co-chair, 6th CHiME Speech Separation and Recognition Challenge, May 2020 (E. Vincent)

General co-chair, 6th International Workshop on Speech Processing in Everyday Environments, Barcelona, Spain, May 2020 (E. Vincent)

General co-chair, 1st Voice Privacy Challenge, Sept. 2020 (E. Vincent)

General co-chair, Detection and Classification of Acoustic Scenes and Events Challenge (R. Serizel, since Nov. 2018)

Area chair, 2019 IEEE Workshop on Applications of Signal Processing to Audio and Acoustics (WASPAA) (E. Vincent)

Area chair, 2020 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP) (E. Vincent, A. Deleforge)

10.1.1.2. Member of the Organizing Committees

Steering Committee of the Detection and Classification of Acoustic Scenes and Events (DCASE) challenge series (E. Vincent until Nov. 2019, R. Serizel from Nov. 2019)

Organizing Committee of the ASVspoof 2019 Challenge: Automatic Speaker Verification Spoofing And Countermeasures Challenge (M. Sahidullah)

Organizing Committee of Special Sessions on ASVspoof 2019 at INTERSPEECH 2019 and at IEEE ASRU 2019 (M. Sahidullah).

Organizing Committee of AVSP 2019 (S. Ouni)

Main organizer of IEEE Signal Processing Cup 2019 on Search & Rescue with Drone-Embedded Sound Source Localization (A. Deleforge).

10.1.2. Scientific Events Selection

10.1.2.1. Chair of Conference Program Committees

Review chair, IEEE Technical Committee on Audio and Acoustic Signal Processing, responsible for organizing the review of the 443 papers submitted to the 2019 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP) in the general AASP domain (E. Vincent)

10.1.2.2. Member of the Conference Program Committees

ICALP 2019 - International Conference on Arabic Language Processing (D. Jouvet)

SIIE 2019 - Edition of the International Conference on Information Systems and Economic Intelligence (D. Fohr, I. Illina)

SPECOM 2019 - International Conference on Speech and Computer (D. Jouvet)

TSD 2019 - International Conference Text, Speech and Dialogue (D. Jouvet)

10.1.2.3. Reviewer

ASRU 2019 - IEEE Automatic Speech Recognition and Understanding Workshop (D. Jouvet, I. Illina, S. Ouni, M. Sahidullah, E. Vincent)

AVSP 2019 - International Conference on Auditory-Visual Speech Processing (S. Ouni)

DCASE 2019 - Workshop on Detection and Classification of Acoustic Scenes and Events (R. Serizel, E. Vincent)

ECML PKDD Joint International Workshop on Advances in Interpretable Machine Learning and Artificial Intelligence & eXplainable Knowledge Discovery in Data Mining (E. Vincent)

EUSIPCO 2019 - European Signal Processing Conference (M. Sahidullah)

ICALP 2019 - International Conference on Arabic Language Processing (D. Jouvet)

ICASSP 2020 - IEEE International Conference on Acoustics, Speech and Signal Processing (A. Bonneau, A. Deleforge, D. Jouvet, M. Sahidullah, R. Serizel, E. Vincent)

ICPhS 2019 - International Congress of Phonetic Sciences (A. Bonneau, Y. Laprie)

INTERSPEECH 2019 (A. Bonneau, I. Illina, D. Jouvet, S. Ouni, M. Sahidullah, E. Vincent)

IROS 2019 - International Conference on Intelligent Robots and Systems (A. Deleforge)

IVA 2019 - Intelligent Virtual Agents Conference (S. Ouni)

NeurIPS 2019 - Conference on Neural Information Processing Systems (A. Deleforge)

PaPE 2019 - Phonetics and Phonology in Europe conference (A. Bonneau)

SLATE 2019 - Workshop on Speech and Language Technology in Education (A. Bonneau, D. Jouvet)

SPECOM 2019 - International Conference on Speech and Computer (D. Jouvet)

TSD 2019 - International Conference Text, Speech and Dialogue (D. Jouvet)

10.1.3. Journal

10.1.3.1. Member of the Editorial Boards

Speech Communication (D. Jouvet)

Journal on Audio, Speech, and Music Processing (Y. Laprie)

Associate Editor of Circuits, Systems, and Signal Processing (M. Sahidullah)

Associate Editor of IET Signal Processing (M. Sahidullah)

Guest Editor of Computer Speech and Language, Special issue on Advances in Automatic Speaker Verification Anti-spoofing (M. Sahidullah)

Guest Editor of Journal on Audio, Speech and Music Processing, special issue on Advances in Audio Signal Processing for Robots and Drones (A. Deleforge)

10.1.3.2. Reviewer - Reviewing Activities

Computer Speech and Language (A. Deleforge, D. Jouvet, M. Sahidullah)

IEEE Access (A. Deleforge)

IEEE Signal Processing Letters (A. Deleforge, M. Sahidullah)

IEEE Transactions on Audio, Speech and Language Processing (M. Sahidullah, A. Deleforge)

IEEE Transactions on Biometrics, Behavior, and Identity Science (M. Sahidullah)

IEEE Transactions on Cognitive and Developmental Systems (A. Deleforge)

IEEE Transactions on Information Forensics and Security (M. Sahidullah)

IEEE Transactions on Signal Processing (A. Deleforge)

IET Biometrics (M. Sahidullah)

JASA Express Letter (Y. Laprie, S. Ouni)

Journal of the Acoustical Society of America (Y. Laprie)

Journal of Language, Speech and Hearing Research (Y. Laprie)

Journal on Audio, Speech, and Music Processing (A. Deleforge)

Sensors (A. Deleforge)

Speech Communication (D. Jouvet)

10.1.4. Invited Talks

Keynote “Grands défis scientifiques et technologiques en traitement de la parole: quelles initiatives chez Inria et au niveau européen?”, Voice Tech Paris 2019 (E. Vincent) [18]

Keynote “Speech Processing and Prosody”, 22nd International Conference of Text, Speech and Dialogue (TSD 2019) (D. Jouvet) [15]

“COMPRISE”, META-FORUM 2019 (E. Vincent) [17]

Lecture “Taking the Best of Physics and Machine Learning in Robot Audition”, IEEE/EURASIP/ISIF 2019 Summer School of Signal Processing, Arenzano, Italy (A. Deleforge)

Language pathology, Séminaire "Dépistage des troubles des apprentissages" in EHESP, Rennes, Jan. 2019 (A. Piquard-Kipffer)

"Dyslexie, dysorthographie : quels parcours scolaires ? Quelles rémédiations et adapatations ?" in Journée nationale des Dys, Bavilliers, Oct. 2019 (A. Piquard-Kipffer)

10.1.5. Leadership within the Scientific Community

Secretary/Treasurer, executive member of AVISA (Auditory-VIsual Speech Association), an ISCA Special Interest Group (S. Ouni)

Member of the board of AFCP - Association Francophone de la Communication Parlée (S. Ouni)

Elected members of the IEEE Technical committee on Audio and Acoustic Signal Processing (A. Deleforge, R. Serizel).

10.1.6. Scientific Expertise

Member of the Scientific Committee of an Institute for deaf people (INJS-Metz), A. Piquard-Kipffer

Member of an expertise Committee for specific language disabilities (MDPH 54), A. Piquard-Kipffer

10.1.7. Research Administration

Head of the AM2I Scientific Pole of Université de Lorraine (Y. Laprie)

Deputy Head of Science of Inria Nancy - Grand Est (E. Vincent)

Member of Management board of Université de Lorraine (Y. Laprie)

Member of the Comité Espace Transfert of Inria Nancy - Grand Est (E. Vincent)

Member of the national recruitment jury for Inria Junior Research Scientists (E. Vincent)

Member of the recruitment jury for Junior Research Scientists, Inria Paris (E. Vincent)

Member of a recruitment committee for Assistant Professor at Université Paris-Sud, May 2019 (D. Jouvet)

Member of the recruitment jury for an Associate Professor position, University of Lorraine (R. Serizel)

Member of the HCERES committee for Gipsa-Lab (S. Ouni)

Member of the National Council of Universities - CNU 27 (S. Ouni)

Member of “Commission paritaire” of Université de Lorraine (Y. Laprie)

Member of the Commission de développement technologique of Inria Nancy - Grand Est (R. Serizel)

Member of the Commission du personnel scientifique of Inria Nancy - Grand Est (R. Serizel)

Member of the Bureau de la Commission de Mention Informatique (I. Illina, S. Ouni)

Animator of the Commission Locale Développement Durable of Inria Nancy - Grand Est (A. Deleforge)

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

DUT: I. Illina, Java programming (56 hours), Linux programming (58 hours), and Advanced Java programming (40 hours), L1, University of Lorraine, France

DUT: I. Illina, Supervision of student projects and internships (50 hours), L2, University of Lorraine, France

DUT: R. Serizel, Introduction to office tools (108 hours), Multimedia and web (20 hours), Documents and databases (20 hours), L1, University of Lorraine, France

DUT: R. Serizel, Multimedia content and indexing (14 hours), Content indexing and retrieval software (20 hours), L2, University of Lorraine, France

DUT: S. Ouni, Programming in Java (24 hours), Web Programming (24 hours), Graphical User Interface (96 hours), L1, University of Lorraine, France

DUT: S. Ouni, Advanced Algorihms (24 hours), L2, University of Lorraine, France

Licence: A. Bonneau, Speech manipulations (2 hours), L1, Département d'orthophonie, University of Lorraine, France

Licence: A. Bonneau, Phonetics (17 hours), L2, École d'audioprothèse, University of Lorraine, France

Licence: V. Colotte, Digital literacy and tools (hybrid courses, 50 hours), L1, University of Lorraine, France

Licence: V. Colotte, System (45 hours), L3, University of Lorraine, France

Licence: O. Mella, Introduction to Web Programming (22 hours), Digital tools (20 hours), L1, University of Lorraine, France

Licence: O. Mella, Computer Networking (72 hours), L2-L3, University of Lorraine, France

Licence: A. Piquard-Kipffer, Education Science (32 hours), L1, Département d'orthophonie, University of Lorraine, France

Licence: A. Piquard-Kipffer, Learning to Read (34 hours), L2, Département d'orthophonie, University of Lorraine, France

Licence: A. Piquard-Kipffer, Dyslexia, Dysorthographia (12 hours), L3, Département d'orthophonie, University of Lorraine, France

Master: V. Colotte, Introduction to Speech Analysis and Recognition (18 hours), M1, University of Lorraine, France

Master: V. Colotte, Integration project: multimodal interaction with Pepper (10 hours), M2, University of Lorraine, France

Master: D. Jouvet and S. Ouni, Multimodal oral comunication (24 hours), M2, University of Lorraine

Master: Y. Laprie, Speech corpora (30 hours), M1, University of Lorraine, France

Master: O. Mella, Computer Networking (67 hours), Introduction to Speech Analysis and Recognition (12 hours), M1, University of Lorraine, France

Master: S. Ouni, Multimedia in Distributed Information Systems (31 hours), M2, University of Lorraine

Master: A. Piquard-Kipffer, Dyslexia, Dysorthographia diagnosis (9 hours), Deaf people & reading (21 hours), M1, Département d'orthophonie, University of Lorraine, France

Master: A. Piquard-Kipffer , Psycholinguistics (20 hours), Departement Orthophonie, University Pierre et Marie Curie, Paris, France

Master: A. Piquard-Kipffer, French Language Didactics (53 hours), ESPE, INSPE University of Lorraine, France

Master: A. Piquard-Kipffer, Psychology (6 hours), M2, Departement of Psychology, University of Lorraine, France

Master: R. Serizel, Introduction to machine listening (3 hours), M2, University of Lorraine

Master: R. Serizel and S. Ouni, Oral speech processing (24 hours), M2, University of Lorraine

Master: E. Vincent and A. Kulkarni, Neural networks (38 hours), M2, University of Lorraine

Continuous training: O. Mella, DIU "Teaching computer science in high school" (7 hours), Computer science courses for secondary school teachers (ISN courses, 21 hours), ESPE, University of Lorraine, France

Continuous training: A. Piquard-Kipffer, Special Educational Needs (53 hours), ESPE, INSPE, University of Lorraine, France

Other: V. Colotte, Co-Responsible for NUMOC (Digital literacy by hybrid courses) for the University of Lorraine, France (for 7000 students)

Doctorat: A. Piquard-Kipffer , Language Pathology (20 hours), EHESP, University of Sorbonne, Paris, France

10.2.2. Supervision

PhD: Mathieu Fontaine, “Processus alpha-stable pour le traitement du signal”, University of Lorraine, Jun. 12, 2019, A. Liutkus and R. Badeau (Télécom ParisTech) [1].

PhD: Lauréline Perotin, “Localisation et rehaussement de sources de parole au format Ambisonique”, University of Lorraine, Oct. 31, 2019, R. Serizel, E. Vincent, and A. Guérin (Orange) [2].

PhD: Anastasiia Tsukanova, “Coarticulation modeling in articulatory synthesis”, University of Lorraine, Dec. 13, 2019, Y. Laprie .

PhD in progress: Amal Houidhek, "Synthèse paramétrique de parole arabe", Dec. 2015, cotutelle, V. Colotte, D. Jouvet and Z. Mnasri (ENIT, Tunisia).

PhD in progress: Amine Menacer, “Traduction automatique de vidéos”, May 2016, K. Smaïli (LORIA) and D. Jouvet.

PhD in progress: Nathan Libermann, “Deep learning for musical structure analysis and generation”, Oct. 2016, F. Bimbot (IRISA) and E. Vincent.

PhD in progress: Théo Biasutto, "Multimodal coarticulation modeling: Towards the animation of an intelligible speaking head", Dec. 2016, S. Ouni.

PhD in progress: Sara Dahmani, "Modeling facial expressions to animate a realistic 3D virtual talking head", Jan. 2017, S. Ouni and V. Colotte.

PhD in progress: Guillaume Carbajal, “Apprentissage profond bout-en-bout pour le rehaussement de la parole”, Mar. 2017, R. Serizel, E. Vincent and É. Humbert (Invoxia).

PhD in progress: Sunit Sivasankaran, “Exploiting contextual information in the speech processing chain”, Jul. 2017, D. Fohr and E. Vincent.

PhD in progress: Ioannis Douros, “Combining cineMRI and static MRI to analyze speech production”, Jul. 2017, P.-A. Vuissoz (IADI) and Y. Laprie.

PhD in progress: Diego Di Carlo, “Estimating the Geometry of Audio Scenes Using Virtually-Supervised Learning”, Oct. 2017, A. Deleforge and N. Bertin (Inria Rennes).

PhD in progress: Lou Lee, “Du lexique au discours: les particules discursives en français”, Oct. 2017, Y. Keromnes (ATILF) and D. Jouvet.

PhD in progress: Nicolas Turpault, “Deep learning for sound scene analysis in real environments”, Jan. 2018, R. Serizel and E. Vincent.

PhD in progress: Raphaël Duroselle, “Adaptation de domaine par réseaux de neurones appliquée au traitement de la parole”, Sept. 2018, D. Jouvet and I. Illina.

PhD in progress: Nicolas Furnon, “Deep-learning based speech enhancement with ad-hoc microphone arrays”, Oct. 2018, R. Serizel, I. Illina and S. Essid (Télécom ParisTech).

PhD in progress: Ajinkya Kulkarni, "Synthèse de parole expressive par apprentissage profond", Oct. 2018, V. Colotte and D. Jouvet.

PhD in progress: Manuel Pariente, “Deep learning-based phase-aware audio signal modeling and estimation”, Oct. 2018, A. Deleforge and E. Vincent.

PhD in progress: Adrien Dufraux, “Leveraging noisy, incomplete, or implicit labels for automatic speech recognition”, Nov. 2018, E. Vincent, A. Brun (LORIA) and M. Douze (Facebook AI Research).

PhD in progress: Ashwin Geet D’Sa, "Natural Language Processing: Online hate speech against migrants", Apr. 2019, I. Illina and D. Fohr.

PhD in progress: Tulika Bose, "Online hate speech and topic classification", Sep. 2019, I. Illina, D. Fohr and A. Monnier (CREM).

PhD in progress: Mauricio Michel Olvera Zambrano, “Robust audio event detection”, Oct. 2019, E. Vincent and G. Gasso (LITIS).

PhD in progress: Shakeel Ahmad Sheikh, "Identifying disfluency in speakers with stuttering, and its rehabilitation, using DNN", Oct. 2019, S. Ouni.

PhD in progress: Sandipana Dowerah, “Robust speaker verification from far-field speech”, Oct. 2019, D. Jouvet and R. Serizel.

PhD in progress: Georgios Zervakis, “Integration of symbolic knowledge into deep learning”, Nov. 2019, M. Couceiro (LORIA) and E. Vincent.

PhD in progress: Nicolas Zampieri, "Automatic classification using deep learning of hate speech posted on the Internet", Nov. 2019, I. Illina and D. Fohr.

10.2.3. Juries

10.2.3.1. Participation in HDR and PhD juries

Participation in the HDR jury of Fabrice Hirsch (Sorbonne nouvelle University, Nov. 2019), Y. Laprie.

Participation in the HDR jury of Éric Bavu (CNAM, Dec. 2019), E. Vincent, president.

Participation in the PhD jury of Corentin Louboutin (Bretagne Loire University, Mar. 2019), E. Vincent, president.

Participation in the PhD jury of Neil Zeghidour (PSL Research University, Mar. 2019), E. Vincent, reviewer and president.

Participation in the PhD jury of Zied Elloumi (Communauté Université Grenoble Alpes, Mar. 2019), D. Jouvet, reviewer.

Participation in the PhD jury of Céline Jacques (Sorbonne University, Apr. 2019), E. Vincent.

Participation in the PhD jury of João Felipe Santos (University of Québec, Jul. 2019), E. Vincent, reviewer.

Participation in the PhD jury of Alice Cohen-Hadria (Sorbonne University, Oct. 2019), E. Vincent, reviewer.

Participation in the PhD jury of Lode Vuegen (KU Leuven, Oct. 2019), R. Serizel.

Participation in the PhD jury of Anne Bouvet (Grenoble Alpes University, Nov. 2019), Y. Laprie.

Participation in the Phd jury of Kevin Vythelingum (Le Mans Université, Dec. 2019), D. Jouvet, reviewer.

Participation in the PhD jury of Karima Abidi (Univertsité de Lorraine, Dec. 2019), D. Jouvet, president.

10.2.3.2. Participation in other juries

Participation in CAFIPEMPF Jury - Master Learning Facilitator, Académie de Nancy-Metz & Université de Lorraine, Apr. & May 2019, A. Piquard-Kipffer

Participation in the Competitive Entrance Examination into Speech-Language Pathology Department, University of Lorraine, Jun. 2019, A. Piquard-Kipffer.

10.3. Popularization

10.3.1. Internal or external Inria responsibilities

Member of the Commission Information et Edition Scientifique of Inria Nancy (A. Deleforge).

10.3.2. Articles and contents

Interview for “Un assistant vocal qui protège les données”, *France 3 Grand Est*, Jun. 7, 2019 (E. Vincent)

Interview for “La voix crescendo”, *L’Usine Nouvelle*, Jun. 27, 2019 (E. Vincent)

Interview for “On transmet beaucoup plus d’informations par la voix qu’un message”, *Rue89 Strasbourg*, Nov. 20, 2019 (E. Vincent)

Participation to the white paper “AI in the media and creative industries”, New European Media (NEM) consortium (E. Vincent) [52]

10.3.3. Education

5 interventions (3 hours) : "Dyslexic pupils in mainstream and special education". Training of trainers. ESPE de l’Académie de Nancy-Metz. Feb., Mar. & May 2019 (A. Piquard-Kipffer)

10.3.4. Interventions

6 interventions (1 hour) on robot audition and artificial intelligence research in classes from 5th (*CM2*) to 12th (*terminale*) grade around Nancy, Jan. 2019 (A. Deleforge)

Talk “Parole & deep learning: succès et grands défis”, Journée IA, Langage et Citoyens, LORIA, Mar. 2019; and also at Meetup IA Nancy, Jun. 2019 (E. Vincent)

Panel discussion on “Se positionner à l’Europe, une opportunité à saisir”, General assembly of Pôle Materalia, Nancy, Apr. 2019 (E. Vincent)

Demos and talk "Aider des enfants ayant des troubles du langage, quels métiers ? Quels outils ?" Forum des métiers, Collège Péguy, Le Chesnay, Apr. 2019 (A. Piquard-Kipffer)

4 interventions (1 hour) on robot audition and artificial intelligence research in high-school classes in Serbia, Sep. 2019 (A. Deleforge)

Demo “Apprendre aux robots à nous entendre” at the “Nuit des Chercheurs” of Belgrade, Serbia in Sept. 2019 and of Nancy for the 80th anniversary of CNRS in Oct. 2019 (A. Deleforge)

Demos “Apprendre aux robots à nous entendre” and “Assistants vocaux et vie privée”, Fête de la Science, Université de Lorraine, Oct. 2019 (A. Deleforge, I. Illina, M. Sahidullah, B. M. L. Srivastava, E. Vincent)

Panel discussion “Tous connectés et après : les enjeux des applications d’interactions vocales”, Shadok, Strasbourg, Nov. 2019 (E. Vincent)

10.3.5. Internal action

“H2020 COMPRISE”, Internal “Café’In” event, Inria Nancy, Jun. 2019 (E. Vincent & Z. Chelly-Dagdia)

10.3.6. Creation of media or tools for science outreach

Video “Exposed by your own voice”, https://www.youtube.com/watch?v=gm2cC8za8Us.

Video ‘When voice assistants don’t understand”, https://www.youtube.com/watch?v=-HvADcfEOuE.

Video "Why is voice assistant integration so expensive", https://www.youtube.com/watch?v=5LQb9X3RtUs

11. Bibliography

Publications of the year

Doctoral Dissertations and Habilitation Theses

[1] M. FONTAINE.*Alpha-stable processes for signal processing*, Université de Lorraine, June 2019, https://tel.archives-ouvertes.fr/tel-02188304

[2] L. PEROTIN.*Localization and enhancement of speech from the Ambisonics format : analyse de scènes sonores pour faciliter la commande vocale*, Université de Lorraine, October 2019, https://hal.univ-lorraine.fr/tel-02393258

[3] A. TSUKANOVA.*Articulatory speech synthesis*, Univeristé de lorraine, December 2019, https://hal.archives-ouvertes.fr/tel-02433528

Articles in International Peer-Reviewed Journal

[4] N. BERTIN, E. CAMBERLEIN, R. LEBARBENCHON, E. VINCENT, S. SIVASANKARAN, I. ILLINA, F. BIMBOT.*VoiceHome-2, an extended corpus for multichannel speech processing in real homes*, in "Speech Communication", January 2019, vol. 106, p. 68-78 [*DOI :* 10.1016/J.SPECOM.2018.11.002], https://hal.inria.fr/hal-01923108

[5] A. DELEFORGE, D. DI CARLO, M. STRAUSS, R. SERIZEL, L. MARCENARO.*Audio-Based Search and Rescue with a Drone: Highlights from the IEEE Signal Processing Cup 2019 Student Competition*, in "IEEE Signal Processing Magazine", September 2019, vol. 36, n^{o} 5, p. 138-144, https://arxiv.org/abs/1907.04655 [*DOI :* 10.1109/MSP.2019.2924687], https://hal.archives-ouvertes.fr/hal-02161897

[6] K. DÉGUERNEL, E. VINCENT, J. NIKA, G. ASSAYAG, K. SMAÏLI.*Learning of Hierarchical Temporal Structures for Guided Improvisation*, in "Computer Music Journal", 2019, vol. 43, n^{o} 2, https://hal.inria.fr/hal-02378273

[7] A. MESAROS, A. DIMENT, B. ELIZALDE, T. HEITTOLA, E. VINCENT, B. RAJ, T. VIRTANEN.*Sound event detection in the DCASE 2017 Challenge*, in "IEEE/ACM Transactions on Audio, Speech and Language Processing", June 2019, vol. 27, n^{o} 6, p. 992-1006 [*DOI :* 10.1109/TASLP.2019.2907016], https://hal.inria.fr/hal-02067935

[8] Q. V. NGUYEN, F. COLAS, E. VINCENT, F. CHARPILLET.*Motion planning for robot audition*, in "Autonomous Robots", December 2019, vol. 43, n^{o} 8, p. 2293-2317 [*DOI :* 10.1007/S10514-019-09880-1], https://hal.inria.fr/hal-02188342

[9] L. PEROTIN, R. SERIZEL, E. VINCENT, A. GUÉRIN.*CRNN-based multiple DoA estimation using acoustic intensity features for Ambisonics recordings*, in "IEEE Journal of Selected Topics in Signal Processing", February 2019, vol. 13, n^{o} 1, p. 22-33 [*DOI :* 10.1109/JSTSP.2019.2900164], https://hal.inria.fr/hal-01839883

[10] A. PODDAR, M. SAHIDULLAH, G. SAHA.*Quality Measures for Speaker Verification with Short Utterances*, in "Digital Signal Processing", January 2019, vol. 88, p. 66-79 [*DOI :* 10.1016/J.DSP.2019.01.023], https://hal.inria.fr/hal-01998376

[11] K. SMAÏLI, D. FOHR, C.-E. GONZÁLEZ-GALLARDO, M. L. GREGA, L. JANOWSKI, D. JOUVET, A. KOŹBIAŁ, D. LANGLOIS, M. LESZCZUK, O. MELLA, M.-A. MENACER, A. MENDEZ, E. L. L. PONTES, E. SANJUAN, J.-M. TORRES-MORENO, B. GARCIA-ZAPIRAIN.*Summarizing videos into a target language: Methodology, architectures and evaluation*, in "Journal of Intelligent and Fuzzy Systems", July 2019, vol. 1, p. 1-12 [*DOI :* 10.3233/JIFS-179350], https://hal.archives-ouvertes.fr/hal-02271287

[12] V. VESTMAN, T. KINNUNEN, R. G. HAUTAMÄKI, M. SAHIDULLAH.*Voice Mimicry Attacks Assisted by Automatic Speaker Verification*, in "Computer Speech and Language", June 2019, vol. 59, p. 36-54 [*DOI :* 10.1016/J.CSL.2019.05.005], https://hal.archives-ouvertes.fr/hal-02161773

Invited Conferences

[13] C. DODANE, D. BOUTET, F. HIRSCH, S. OUNI, A. MORGENSTERN.*MODALISA une plateforme intégrative pour capturer l'orchestration des gestes et de la parole*, in "Défi Instrumentation aux Limites, Colloque de restitution", Paris, France, CNRS, September 2019, https://hal.archives-ouvertes.fr/hal-02375011

[14] F. FORBES, A. DELEFORGE, R. HORAUD, E. PERTHAME.*Robust non-linear regression approach for generalized inverse problems in a high dimensional setting*, in "AIP 2019 - Applied Inverse Problem conference", Grenoble, France, July 2019, https://hal.archives-ouvertes.fr/hal-02415115

[15] D. JOUVET.*Speech Processing and Prosody*, in "TSD 2019 - 22nd International Conference of Text, Speech and Dialogue", Ljubljana, Slovenia, September 2019, https://hal.inria.fr/hal-02177210

[16] R. SERIZEL, N. TURPAULT.*Sound Event Detection from Partially Annotated Data: Trends and Challenges*, in "IcETRAN conference", Srebrno Jezero, Serbia, June 2019, https://hal.inria.fr/hal-02114652

[17] E. VINCENT.*COMPRISE*, in "META-FORUM", Bruxelles, Belgium, October 2019, https://hal.inria.fr/hal-02377051

[18] E. VINCENT.*Grands défis scientifiques et technologiques en traitement de la parole: quelles initiatives chez Inria et au niveau européen?*, in "Voice Tech Paris 2019", Paris, France, November 2019, https://hal.inria.fr/hal-02377036

[19] E. VINCENT.*Parole & deep learning : succès et grands défis*, in "Journée IA, Langage et Citoyens", Nancy, France, March 2019, https://hal.inria.fr/hal-02090623

International Conferences with Proceedings

[20] K. ABIDI, D. FOHR, D. JOUVET, D. LANGLOIS, O. MELLA, K. SMAÏLI.*A Fine-grained Multilingual Analysis Based on the Appraisal Theory: Application to Arabic and English Videos*, in "ICALP: International Conference on Arabic Language Processing", Nancy, France, Springer, August 2019, vol. Communications in Computer and Information Science book series (CCIS, volume 1108), p. 49-61 [*DOI :* 10.1007/978-3-030-32959-4_4], https://hal.archives-ouvertes.fr/hal-02314244

[21] T. BIASUTTO–LERVAT, S. DAHMANI, S. OUNI.*Modeling Labial Coarticulation with Bidirectional Gated Recurrent Networks and Transfer Learning*, in "INTERSPEECH 2019 - 20th Annual Conference of the

International Speech Communication Association", Graz, Austria, September 2019, https://hal.inria.fr/hal-02175780

[22] A. BONNEAU.*German obstruent sequences by French L2 learners*, in "ICPhS 2019 - International Congress of Phonetic Sciences", Melbourne, Australia, August 2019, https://hal.inria.fr/hal-02143360

[23] S. DAHMANI, V. COLOTTE, V. GIRARD, S. OUNI.*Conditional Variational Auto-Encoder for Text-Driven Expressive AudioVisual Speech Synthesis*, in "INTERSPEECH 2019 - 20th Annual Conference of the International Speech Communication Association", Graz, Austria, September 2019, https://hal.inria.fr/hal-02175776

[24] D. DI CARLO, A. DELEFORGE, N. BERTIN.*Mirage: 2D Source Localization Using Microphone Pair Augmentation with Echoes*, in "ICASSP 2019 - IEEE International Conference on Acoustic, Speech Signal Processing", Brighton, United Kingdom, IEEE, May 2019, p. 775-779, https://arxiv.org/abs/1906.08968 [*DOI :* 10.1109/ICASSP.2019.8683534], https://hal.archives-ouvertes.fr/hal-02160940

[25] C. DODANE, D. BOUTET, I. DIDIRKOVA, F. HIRSCH, S. OUNI, A. MORGENSTERN.*An integrative platform to capture the orchestration of gesture and speech*, in "GeSpIn 2019 - Gesture and Speech in Interaction", Paderborn, Germany, September 2019, https://hal.inria.fr/hal-02278345

[26] I. K. DOUROS, J. FELBLINGER, J. FRAHM, K. ISAIEVA, A. JOSEPH, Y. LAPRIE, F. ODILLE, A. TSUKANOVA, D. VOIT, P.-A. VUISSOZ.*A Multimodal Real-Time MRI Articulatory Corpus of French for Speech Research*, in "INTERSPEECH 2019 - 20th Annual Conference of the International Speech Communication Association", Graz, Austria, September 2019, https://hal.inria.fr/hal-02167756

[27] I. K. DOUROS, Y. LAPRIE, P.-A. VUISSOZ, B. ELIE.*Acoustic Evaluation of Simplifying Hypotheses Used in Articulatory Synthesis*, in "ICA 2019 - 23rd International Congress on Acoustics", Aachen, Germany, September 2019, https://hal.inria.fr/hal-02180617

[28] I. K. DOUROS, A. TSUKANOVA, K. ISAIEVA, P.-A. VUISSOZ, Y. LAPRIE.*Towards a method of dynamic vocal tract shapes generation by combining static 3D and dynamic 2D MRI speech data*, in "INTERSPEECH 2019 - 20th Annual Conference of the International Speech Communication Association", Graz, Austria, September 2019, https://hal.inria.fr/hal-02181333

[29] I. K. DOUROS, P.-A. VUISSOZ, Y. LAPRIE.*Acoustic impacts of geometric approximation at the level of velum and epiglottis on French vowels*, in "ICPhS 2019 - International Congress of Phonetic Sciences", Melbourne, Australia, August 2019, https://hal.inria.fr/hal-02180566

[30] I. K. DOUROS, P.-A. VUISSOZ, Y. LAPRIE.*Comparison between 2D and 3D models for speech production: a study of French vowels*, in "ICPhS 2019 - International Congress of Phonetic Sciences", Melbourne, Australia, August 2019, https://hal.inria.fr/hal-02180606

[31] I. K. DOUROS, P.-A. VUISSOZ, Y. LAPRIE.*Effect of head posture on phonation of French vowels*, in "ICPhS 2019 - Proceedings of International Congress of Phonetic Sciences", Melbourne, Australia, August 2019, https://hal.inria.fr/hal-02180486

[32] A. DUFRAUX, E. VINCENT, A. HANNUN, A. BRUN, M. DOUZE.*Lead2Gold: Towards exploiting the full potential of noisy transcriptions for speech recognition*, in "ASRU 2019 - IEEE Automatic Speech Recognition and Understanding Workshop", Singapour, Singapore, December 2019, https://hal.inria.fr/hal-02316572

[33] B. ELIE, A. AMELOT, Y. LAPRIE, S. MAEDA.*Glottal Opening Measurements in VCV and VCCV Sequences*, in "ICA 2019 - 23rd International Congress on Acoustics", Aachen, Germany, September 2019, https://hal.inria.fr/hal-02180626

[34] M. FONTAINE, A. A. NUGRAHA, R. BADEAU, K. YOSHII, A. LIUTKUS.*Cauchy Multichannel Speech Enhancement with a Deep Speech Prior*, in "EUSIPCO 2019 - 27th European Signal Processing Conference", Coruña, Spain, September 2019, https://hal.telecom-paristech.fr/hal-02288063

[35] T. KINNUNEN, R. G. HAUTAMÄKI, V. VESTMAN, M. SAHIDULLAH.*Can We Use Speaker Recognition Technology to Attack Itself? Enhancing Mimicry Attacks Using Automatic Target Speaker Selection*, in "ICASSP 2019 – 44th International Conference on Acoustics, Speech, and Signal Processing", Brighton, United Kingdom, May 2019, https://hal.inria.fr/hal-02051701

[36] A. KULKARNI, V. COLOTTE, D. JOUVET.*Layer adaptation for transfer of expressivity in speech synthesis*, in "LTC'19 - 9th Language & Technology Conference", Poznan, Poland, May 2019, https://hal.inria.fr/hal-02177945

[37] L. LEE, K. BARTKOVA, D. JOUVET, M. DARGNAT, Y. KEROMNES.*Can prosody meet pragmatics? Case of discourse particles in French*, in "ICPhS 2019 - International Congress of Phonetic Sciences", Melbourne, Australia, August 2019, https://hal.inria.fr/hal-02177202

[38] K. A. LEE, V. HAUTAMÄKI, T. KINNUNEN, H. YAMAMOTO, K. OKABE, V. VESTMAN, J. HUANG, G. DING, H. SUN, A. LARCHER, R. K. DAS, H. LI, M. ROUVIER, P.-M. B. BOUSQUET, W. RAO, Q. WANG, C. ZHANG, F. BAHMANINEZHAD, H. DELGADO, J. PATINO, Q. WANG, L. GUO, T. KOSHINAKA, J. ZHANG, K. SHINODA, T. NGO TRONG, M. SAHIDULLAH, F. LU, Y. TANG, M. TU, K. KUAN TEH, H. DAT TRAN, K. K. GEORGE, I. KUKANOV, F. DESNOUS, J. YANG, E. YILMAZ, L. XU, J.-F. BONASTRE, C. XU, Z. H. LIM, S. CHNG, S. RANJAN, J. H. L. HANSEN, M. TODISCO, N. EVANS.*I4U Submission to NIST SRE 2018: Leveraging from a Decade of Shared Experiences*, in "INTERSPEECH 2019 - 20th Annual Conference of the International Speech Communication Association", Graz, Austria, September 2019, https://hal.archives-ouvertes.fr/hal-02280151

[39] T. LÉONOVA, G. COFFE, A. TARASCONI, A. PIQUARD-KIPFFER, D. SARDIN, A. GOSSE, J. BORÉ.*L'impact du trouble du spectre de l'autisme sur le bien-être psychologique des parents*, in "XVIIIème Congrès de l'Association Internationale de Formation et de Recherche en Éducation Familiale", Schoelcher, Martinique, France, May 2019, https://hal.inria.fr/hal-02179616

[40] M. A. MENACER, C. E. GONZÁLEZ-GALLARDO, K. ABIDI, D. FOHR, D. JOUVET, D. LANGLOIS, O. MELLA, F. SADAT, J. M. TORRES-MORENO, K. SMAÏLI.*Extractive Text-Based Summarization of Arabic videos: Issues, Approaches and Evaluations*, in "ICALP: International Conference on Arabic Language Processing", Nancy, France, Springer, August 2019, vol. Communications in Computer and Information Science book series (CCIS, volume 1108), p. 65-78 [*DOI :* 10.1007/978-3-030-32959-4_5], https://hal.archives-ouvertes.fr/hal-02314238

[41] M. MENACER, D. LANGLOIS, D. JOUVET, D. FOHR, O. MELLA, K. SMAÏLI.*Machine Translation on a parallel Code-Switched Corpus*, in "Canadian AI 2019 - 32nd Conference on Canadian Artificial Intelligence", Ontario, Canada, Lecture Notes in Artificial Intelligence, May 2019, https://hal.archives-ouvertes.fr/hal-02106010

[42] M. PARIENTE, A. DELEFORGE, E. VINCENT.*A Statistically Principled and Computationally Efficient Approach to Speech Enhancement using Variational Autoencoders*, in "INTERSPEECH", Graz, Austria, September 2019, https://arxiv.org/abs/1905.01209 , https://hal.inria.fr/hal-02116165

[43] *Best Paper*
L. PEROTIN, A. DÉFOSSEZ, E. VINCENT, R. SERIZEL, A. GUÉRIN.*Regression versus classification for neural network based audio source localization*, in "WASPAA 2019 - IEEE Workshop on Applications of Signal Processing to Audio and Acoustics", New Paltz, United States, IEEE, October 2019, https://hal.inria.fr/hal-02125985.

[44] D. RIBAS, E. VINCENT.*An improved uncertainty propagation method for robust i-vector based speaker recognition*, in "ICASSP 2019 - 44th International Conference on Acoustics, Speech, and Signal Processing", Brighton, United Kingdom, May 2019, https://arxiv.org/abs/1902.05761 , https://hal.inria.fr/hal-02010199

[45] B. M. L. SRIVASTAVA, A. BELLET, M. TOMMASI, E. VINCENT.*Privacy-Preserving Adversarial Representation Learning in ASR: Reality or Illusion?*, in "INTERSPEECH 2019 - 20th Annual Conference of the International Speech Communication Association", Graz, Austria, September 2019, https://hal.inria.fr/hal-02166434

[46] M. TODISCO, X. WANG, V. VESTMAN, M. SAHIDULLAH, H. DELGADO, A. NAUTSCH, J. YAMAGISHI, N. EVANS, T. KINNUNEN, K. A. LEE.*ASVspoof 2019: Future Horizons in Spoofed and Fake Audio Detection*, in "INTERSPEECH 2019 - 20th Annual Conference of the International Speech Communication Association", Graz, Austria, September 2019, https://hal.archives-ouvertes.fr/hal-02172099

[47] A. TSUKANOVA, I. K. DOUROS, A. SHIMORINA, Y. LAPRIE.*Can static vocal tract positions represent articulatory targets in continuous speech? Matching static MRI captures against real-time MRI for the French language*, in "ICPhS 2019 - International Congress of Phonetic Sciences", Melbourne, Australia, August 2019, https://hal.inria.fr/hal-02181314

[48] N. TURPAULT, R. SERIZEL, A. PARAG SHAH, J. SALAMON.*Sound event detection in domestic environments with weakly labeled data and soundscape synthesis*, in "Workshop on Detection and Classification of Acoustic Scenes and Events", New York City, United States, October 2019, https://hal.inria.fr/hal-02160855

[49] N. TURPAULT, R. SERIZEL, E. VINCENT.*Semi-supervised triplet loss based learning of ambient audio embeddings*, in "ICASSP", Brighton, United Kingdom, 2019, https://hal.archives-ouvertes.fr/hal-02025824

[50] I. ZANGAR, Z. MNASRI, V. COLOTTE, D. JOUVET.*F0 modeling using DNN for Arabic parametric speech synthesis*, in "INNSBDDL 2019 - INNS Big Data and Deep Learning", Sestri Levante, Italy, April 2019, https://hal.inria.fr/hal-02177496

Scientific Books (or Scientific Book chapters)

[51] M. SAHIDULLAH, H. DELGADO, M. TODISCO, T. KINNUNEN, N. EVANS, J. YAMAGISHI, K. A. LEE.*Introduction to Voice Presentation Attack Detection and Recent Advances*, in "Handbook of Biometric Anti-Spoofing: Presentation Attack Detection", S. MARCEL, M. S. NIXON, J. FIERREZ, N. EVANS (editors), Advances in Computer Vision and Pattern Recognition, Springer, 2019, p. 321-361 [*DOI :* 10.1007/978-3-319-92627-8_15], https://hal.inria.fr/hal-01974528

Research Reports

[52] B. Caramiaux, F. Lotte, J. Geurts, G. Amato, M. Behrmann, F. Bimbot, F. Falchi, A. Garcia, J. Gibert, G. Gravier, H. Holken, H. Koenitz, S. Lefebvre, A. Liutkus, A. Perkis, R. Redondo, E. Turrin, T. Viéville, E. Vincent.*AI in the media and creative industries*, New European Media (NEM), April 2019, p. 1-35, https://arxiv.org/abs/1905.04175 , https://hal.inria.fr/hal-02125504

[53] G. Carbajal, R. Serizel, E. Vincent, E. Humbert.*Joint DNN-Based Multichannel Reduction of Acoustic Echo, Reverberation and Noise: Supporting Document*, Inria Nancy, équipe Multispeech ; Invoxia SAS, November 2019, n^{o} RR-9303, https://hal.inria.fr/hal-02372431

[54] K. A. Lee, V. Hautamäki, T. Kinnunen, H. Yamamoto, K. Okabe, V. Vestman, J. Huang, G. Ding, H. Sun, A. Larcher, R. K. Das, H. Li, M. Rouvier, P.-M. B. Bousquet, W. Rao, Q. Wang, C. Zhang, F. Bahmaninezhad, H. Delgado, J. Patino, Q. Wang, L. Guo, T. Koshinaka, J. Zhang, K. Shinoda, T. Ngo Trong, M. Sahidullah, F. Lu, Y. Tang, M. Tu, K. Kuan Teh, H. Dat Tran, K. K. George, I. Kukanov, F. Desnous, J. Yang, E. Yilmaz, L. Xu, J.-F. Bonastre, C. Xu, Z. H. Lim, S. Chng, S. Ranjan, J. H. L. Hansen, M. Todisco, N. Evans.*I4U Submission to NIST SRE 2018: Leveraging from a Decade of Shared Experiences*, I4U Consortium, April 2019, https://hal.archives-ouvertes.fr/hal-02174317

[55] M. Pariente, A. Deleforge, E. Vincent.*A Statistically Principled and Computationally Efficient Approach to Speech Enhancement using Variational Autoencoders : Supporting Document*, Inria, April 2019, n^{o} RR-9268, p. 1-8, https://hal.inria.fr/hal-02089062

Software

[56] M. Kowalski, E. Vincent, R. Gribonval.*Underdetermined Reverberant Source Separation*, October 2019
[SWH-ID : swh:1:dir:ec4ae097465d9ea51589537ea94b2ea50e8d134d], Software, https://hal.archives-ouvertes.fr/hal-02309043

Other Publications

[57] G. Carbajal, R. Serizel, E. Vincent, E. Humbert.*Joint DNN-Based Multichannel Reduction of Acoustic Echo, Reverberation and Noise*, December 2019, working paper or preprint, https://hal.inria.fr/hal-02372579

[58] N. Furnon, R. Serizel, I. Illina, S. Essid.*DNN-Based Distributed Multichannel Mask Estimation for Speech Enhancement in Microphone Arrays*, October 2019, Submitted to ICASSP2020, https://hal.archives-ouvertes.fr/hal-02389159

[59] M. Pariente, S. Cornell, A. Deleforge, E. Vincent.*Filterbank design for end-to-end speech separation*, October 2019, Submitted to ICASSP2020, https://hal.archives-ouvertes.fr/hal-02355623

[60] M. Sahidullah, J. Patino, S. Cornell, R. Yin, S. Sivasankaran, H. Bredin, P. Korshunov, A. Brutti, R. Serizel, E. Vincent, N. Evans, S. Marcel, S. Squartini, C. Barras.*The Speed Submission to DIHARD II: Contributions & Lessons Learned*, November 2019, working paper or preprint, https://hal.inria.fr/hal-02352840

[61] R. SERIZEL, N. TURPAULT, A. SHAH, J. SALAMON.*Sound event detection in synthetic domestic environments*, November 2019, working paper or preprint, https://hal.inria.fr/hal-02355573

[62] S. SIVASANKARAN, E. VINCENT, D. FOHR.*Analyzing the impact of speaker localization errors on speech separation for automatic speech recognition*, November 2019, Submitted to ICASSP 2020, https://hal.inria.fr/hal-02355669

[63] S. SIVASANKARAN, E. VINCENT, D. FOHR.*SLOGD: Speaker Location Guided Deflation Approach to Speech Separation*, November 2019, Submitted to ICASSP 2020, https://hal.inria.fr/hal-02355613

[64] B. M. L. SRIVASTAVA, N. VAUQUIER, M. SAHIDULLAH, A. BELLET, M. TOMMASI, E. VINCENT.*Evaluating Voice Conversion-based Privacy Protection against Informed Attackers*, November 2019, working paper or preprint, https://hal.inria.fr/hal-02355115

Project-Team NEUROSYS

Analysis and modeling of neural systems by a system neuroscience approach

IN COLLABORATION WITH: Laboratoire lorrain de recherche en informatique et ses applications (LORIA)

IN PARTNERSHIP WITH:
CNRS

Université de Lorraine

RESEARCH CENTER
Nancy - Grand Est

THEME
Computational Neuroscience and Medicine

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Project-Team NEUROSYS

Creation of the Team: 2013 January 01, updated into Project-Team: 2015 July 01

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A3.4.4. - Optimization and learning
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1. Team, Visitors, External Collaborators

Research Scientist

Axel Hutt [Inria, Senior Researcher, secondment at Deutscher Wetterdienst, until Oct 2019, HDR]

Faculty Members

Laurent Bougrain [Team leader, Univ de Lorraine, Associate Professor]
Laure Buhry [Univ de Lorraine, Associate Professor]

External Collaborators

Radu Ranta [Univ Lorraine, HDR]
Patrick Hénaff [Univ Lorraine, Professor, HDR]
Dominique Martinez [CNRS, Senior Researcher, HDR]
Abderrahman Iggidr [Inria, Researcher, HDR]

PhD Students

Amélie Aussel [Univ de Lorraine, PhD Student, until Sep 2019]
Oleksii Avilov [Univ de Lorraine, PhD Student]
Nathalie Azevedo Carvalho [Inria, PhD Student]
Sébastien Rimbert [Inria, PhD Student]

Visiting Scientists

Hiroaki Wagatsuma [Univ de Lorraine, from Jun 2019 until Jul 2019]
Asako Watanabe [Univ de Lorraine, until Jun 2019]

Administrative Assistants

Hélène Cavallini [Inria, Administrative Assistant]
Antoinette Courrier [CNRS, Administrative Assistant]

2. Overall Objectives

2.1. General Objectives

The team aims at understanding the dynamics of neural systems on multiple scales and develops methods to invent monitoring devices. The approach is inspired by systems neuroscience, which relates microscopic modifications in neural systems to macroscopic changes in behavior. The team employs this systems neuroscience approach and develops models and data analysis tools in order to bridge the gap between microscopic and mesoscopic, and mesoscopic and macroscopic/behavior activity. These bridges are necessary to better understand neural systems and, in turn, control the neural systems. They also may allow to develop data monitors utilizing the derived principles. As a long-term goal, the team shall develop such devices in medicine with application in general anesthesia.

3. Research Program

3.1. Main Objectives

The main challenge in computational neuroscience is the high complexity of neural systems. The brain is a complex system and exhibits a hierarchy of interacting subunits. On a specific hierarchical level, such subunits evolve on a certain temporal and spatial scale. The interactions of small units on a low hierarchical level build up larger units on a higher hierarchical level evolving on a slower time scale and larger spatial scale. By virtue of the different dynamics on each hierarchical level, until today the corresponding mathematical models and data analysis techniques on each level are still distinct. Only few analysis and modeling frameworks are known which link successfully at least two hierarchical levels.

After extracting models for different description levels, they are typically applied to obtain simulated activity which is supposed to reconstruct features in experimental data. Although this approach appears straightforward, it presents various difficulties. Usually the models involve a large set of unknown parameters which determine the dynamical properties of the models. To optimally reconstruct experimental features, it is necessary to formulate an inverse problem to extract optimally such model parameters from the experimental data. Typically this is a rather difficult problem due to the low signal-to-noise ratio in experimental brain signals. Moreover, the identification of signal features to be reconstructed by the model is not obvious in most applications. Consequently an extended analysis of the experimental data is necessary to identify the interesting data features. It is important to combine such a data analysis step with the parameter extraction procedure to achieve optimal results. Such a procedure depends on the properties of the experimental data and hence has to be developed for each application separately. Machine learning approaches that attempt to mimic the brain and its cognitive processes have had a lot of success in classification problems during the last decade. These hierarchical and iterative approaches use non-linear functions, which imitate neural cell responses, to communicate messages between neighboring layers. In our team, we work towards developing polysomnography-specific classifiers that might help in linking the features of particular interest for building systems for sleep signal classification with sleep mechanisms, with the accent on memory consolidation during the Rapid Eye Movement (REM) sleep phase.

3.2. Challenges

Techniques for the implementation and analysis of models achieved promises to be able to construct novel data monitors. This construction involves additional challenges and requires contact with realistic environments. By virtue of the specific applications of the research, close contact to hospitals and medical companies shall be established over a longer term in order to (i) gain deeper insight into the specific application of the devices and (ii) build specific devices in accordance with the actual need. Collaborations with local and national hospitals and the pharmaceutical industry already exist.

3.3. Research Directions

- From the microscopic to the mesoscopic scale:
  One research direction focuses on the *relation of single-neuron activity* on the microscopic scale *to the activity of neuronal populations*. To this end, the team investigates the stochastic dynamics of single neurons subject to external random inputs and involving random microscopic properties, such as random synaptic strengths and probability distributions of spatial locations of membrane ion channels. Such an approach yields a stochastic model of single neurons and allows the derivation of a stochastic neural population model.

  This bridge between the microscopic and mesoscopic scale may be performed via two pathways. The analytical and numerical treatment of the microscopic model may be called a *bottom-up approach*, since it leads to a population activity model based on microscopic activity. This approach allows theoretical neural population activity to be compared to experimentally obtained population activity. The *top-down approach* aims at extracting signal features from experimental data gained from neural populations which give insight into the dynamics of neural populations and the underlying microscopic activity. The work on both approaches represents a well-balanced investigation of the neural system based on the systems properties.
- From the mesoscopic to the macroscopic scale:
  The other research direction aims to link neural population dynamics to macroscopic activity and behavior or, more generally, to phenomenological features. This link is more indirect but a very powerful approach to understand the brain, e.g., in the context of medical applications. Since real neural systems, such as in mammals, exhibit an interconnected network of neural populations, the team studies analytically and numerically the network dynamics of neural populations to gain deeper insight into possible phenomena, such as traveling waves or enhancement and diminution of certain neural rhythms. Electroencephalography (EEG) is a powerful brain imaging technique

to study the overall brain activity in real time non-invasively. However it is necessary to develop robust techniques based on stable features by investigating the time and frequency domains of brain signals. Two types of information are typically used in EEG signals: (i) transient events such as evoked potentials, spindles and K-complexes and (ii) the power in specific frequency bands.

4. Application Domains

4.1. Medical applications

Our research directions are motivated by applications with a high healthcare or social impact. They are developed in collaboration with medical partners, neuroscientists and psychologists. Almost all of our applications can be seen as neural interfaces which require the analysis and modeling of sensorimotor rhythms.

4.1.1. Per-operative awareness during general anesthesia

Collaborators: Univ. Hospital of Nancy-Brabois/dept. Anesthesia & Resuscitation
During general anesthesia, brain oscillations change according to the anesthetic drug concentration. Nowadays, 0.2 to 1.3% of patients regain consciousness during surgery and suffer from post-traumatic disorders. Despite the absence of subject movements due to curare, an electroencephalographic analysis of sensorimotor rhythms can help to detect an intention of movement. Within a clinical protocol, we are working on a brain-computer interface adapted to the detection of intraoperative awareness.

4.1.2. Recovery after stroke

Collaborators: Regional Institute of Physical Medicine and Rehabilitation/Center for Physical Medicine and Rehabilitation (Lay St Christophe), Univ. of Lorraine/PErSEUs.
Stroke is the main cause of acquired disability in adults. Neurosys aims at recovering limb control by improving the kinesthetic motor imagery (KMI) generation of post-stroke patients. We propose to design a KMI-based EEG neural interface which integrates complementary modalities of interactions such as tangible and haptic ones to stimulate the sensorimotor loop. This solution would provide a more engaging and compelling stroke rehabilitation training program based on KMI production.

4.1.3. Modeling Parkinson's disease

Collaborators: Center for Systems Biomedicine (Luxembourg), Institute of Neurodegenerative Diseases (Bordeaux), Human Performance & Robotics laboratory (California State Univ., Long Beach).
Effective treatment of Parkinson's disease should be based on a realistic model of the disease. We are currently developing a neuronal model based on Hodgkin-Huxley neurons reproducing to a certain extent the pathological synchronization observed in basal ganglia in Parkinsonian rats. Moreover, our mesoscopic models of plastic Central Pattern Generator neural circuitries involved in rhythmic movements will allow us to reproduce incoherent coordination of limbs observed on humans affected by Parkinson's diseases like frozen gait, crouch gait. Our long-term objective is to understand how oscillatory activity in the basal ganglia affects motor control in spinal structures.

4.1.4. Modeling propagation of epileptic spikes

Collaborators: Epileptology Unit of the CHRU Nancy (University hospital), CRAN (Research Center in Automation and Signal Processing of Nancy). Effective treatment of patients with refractory epilepsy requires a better understanding of the underlying neuronal mechanisms. In particular, it has been observed that epileptic spikes propagate more easily during stage III sleep (slow wave sleep) than during wakefulness, but the origin of these behaviours still remains misunderstood. At least both, a combination of anatomical structure/connectivity changes and changes in level of neurotransmitters, namely functional connectivity, can cause the propagation. A better knowledge of the functional and structural circuitry could allow a better targetting of structures to be treated, either surgically or pharmacologically, and to better individually adapt the pharmacology to each patient according to their symptomatology.

5. Highlights of the Year

5.1. Highlights of the Year

Laurent Bougrain is the coordinator of the 4-years ANR project Grasp-IT on the design and the evaluation of a tangible and haptic brain-computer interface for upper limb rehabilitation after stroke including 4 research teams, 3 centers or hospital departments for physical medicine and rehabilitation and one manifacturer of 3D printers (see Sec. 8.2.1).

6. New Software and Platforms

6.1. OpenVIBE

KEYWORDS: Neurosciences - Interaction - Virtual reality - Health - Real time - Neurofeedback - Brain-Computer Interface - EEG - 3D interaction

FUNCTIONAL DESCRIPTION: OpenViBE is a free and open-source software platform devoted to the design, test and use of Brain-Computer Interfaces (BCI). The platform consists of a set of software modules that can be integrated easily and efficiently to design BCI applications. The key features of OpenViBE software are its modularity, its high-performance, its portability, its multiple-users facilities and its connection with high-end/VR displays. The designer of the platform enables to build complete scenarios based on existing software modules using a dedicated graphical language and a simple Graphical User Interface (GUI). This software is available on the Inria Forge under the terms of the AGPL licence, and it was officially released in June 2009. Since then, the OpenViBE software has already been downloaded more than 60000 times, and it is used by numerous laboratories, projects, or individuals worldwide. More information, downloads, tutorials, videos, documentations are available on the OpenViBE website.

- Participants: Cedric Riou, Thierry Gaugry, Anatole Lécuyer, Fabien Lotte, Jussi Tapio Lindgren, Laurent Bougrain, Maureen Clerc and Théodore Papadopoulo
- Partners: INSERM - GIPSA-Lab
- Contact: Anatole Lécuyer
- URL: http://openvibe.inria.fr

7. New Results

7.1. From the microscopic to the mesoscopic scale

Participants: Laure Buhry, Amélie Aussel, Nathalie Azevedo Carvalho, Dominique Martinez (CNRS), Radu Ranta (Univ. Lorraine, CRAN).
In collaboration with Harry Tran (Univ. Lorraine, CRAN), Louise Tyvaert (Univ. Lorraine, CRAN, CHRU Nancy), Olivier Aron (Univ. Lorraine, CRAN, CHRU Nancy), Sylvain Contassot-Vivier (Univ. Lorraine),

7.1.1. Hippocampal oscillatory activity

7.1.1.1. Healthy hippocampus

We proposed a detailed anatomical and mathematical model of the hippocampal formation for the generation of healthy hippocampal activity, especially sharp-wave ripples and theta-nested gamma oscillations [24], [25]. Indeed, the mechanisms underlying the broad variety of oscillatory rhythms measured in the hippocampus during the sleep-wake cycle are not yet fully understood. We proposed a computational model of the hippocampal formation based on a realistic topology and synaptic connectivity, and we analyzed the effect of different changes on the network, namely the variation of synaptic conductances, the variations of the CAN channel conductance and the variation of inputs. By using a detailed simulation of intracerebral recordings, we showed that this model is able to reproduce both the theta-nested gamma oscillations that are seen in awake brains and the sharp-wave ripple complexes measured during slow-wave sleep. The results of our simulations support the idea that the functional connectivity of the hippocampus, modulated by the sleep-wake variations in Acetylcholine concentration, is a key factor in controlling its rhythms [24].

We further extended this work with an extensive study of the parameter range of the healthy hippocampus activity and showed that the "healthy model" was unable to reproduce pathological hippocampal oscillations observed in temporal lobe epilepsy.

7.1.1.2. Modeling LFP measures

The development of this model was also the opportunity to extend our model of the measure of the local field potential (LFP) and to study the contribution of spikes (not only synaptic currents) to the generation of the LFP. Indeed, simulating extracellular recordings of neuronal populations is a challenging task for understanding the nature of extracellular field potentials (LFPs), investigating specific brain structures and mapping cognitive functions. In general, it is assumed that extracellular recording devices (micro and/or macro-electrodes) record a mixture of low frequency patterns, mainly attributed to the synaptic currents and high-frequency components reflecting action potential (APs) activity. Simulating such signals often requires a high computational burden due to the multicompartmental neuron models used. Therefore, different LFP proxies coexist in the literature, most of them only reproducing some of the features of experimental signals. This may be an issue in producing and validating computational models of phenomena where the fast and slow components of neural activity are equally important, such as hippocampal oscillations. In this part of the work, we proposed an original approach for simulating large-scale neural networks efficiently while computing a realistic approximation of the LFP signal including extracellular signatures of both synaptic and action potentials [26]. We applied this method on the hippocampal network we developed earlier and compared the simulated signal with intracranial measurements from human patients.

7.1.1.3. Epilepsy of the mesial temporal lobe

The model described above has then been extended to include pathological changes observed in temporal lobe epilepsy, the future goal being to better understand the generation and propagation of epileptic activity throughout the brain, and therefore to investigate new potential therapeutic targets.

The mechanisms underlying the generation of hippocampal epileptic seizures and interictal events during the sleep-wake cycle are not yet fully understood. In this article, based on our previous computational modeling work of the hippocampal formation based on realistic topology and synaptic connectivity, we study the role of network specificity and channel pathological conditions of the epileptic hippocampus in the generation and maintenance of seizures and interictal oscillations. Indeed, the epilepsies of the mesial temporal lobe are associated with hippocampal neuronal and axonal loss, mossy fiber sprouting and channelopathies, namely impaired potassium and chlore dynamics. We show, through the simulations of hippocampal activity during slow-wave sleep and wakefulness that: (i) both mossy fiber sprouting and sclerosis account for epileptic seizures, (ii) high hippocampal sclerosis with low sprouting suppresses seizures, (iii) impaired potassium and chloride dynamics have little influence on the generation of seizures, (iv) but do have an influence on interictal spikes that decreases with high mossy fiber sprouting. A manuscript is in preparation for the Journal of Neuroscience.

7.1.2. Synchronization phenomena in neuronal network models

From a more computational point of view, we got interested in interneuronal gamma oscillations and synchronization in hippocampus-like networks via different models, especially in adaptive exponential integrate-and-fire neurons. Fast neuronal oscillations in gamma frequencies are observed in neocortex and hippocampus during essential arousal behaviors. Through a four-variable Hodgkin–Huxley type model, Wang and Buzsáki have numerically demonstrated that such rhythmic activity can emerge from a random network of GABAergic interneurons via minimum synaptic inputs. In this case, the intrinsic neuronal characteristics and network structure act as the main drive of the rhythm. We investigate inhibitory network synchrony with a low complexity, two-variable adaptive exponential integrate-and-fire (AdEx) model, whose parameters possess strong physiological relevances, and provide a comparison with the two-variable Izhikevich model and Morris–Lecar model. Despite the simplicity of these three models, the AdEx model shares two important results with the previous biophysically detailed Hodgkin–Huxley type model: the minimum number of synaptic inputs necessary to initiate network gamma-band rhythms remains the same, and this number is weakly dependent on the network size. Meanwhile, Izhikevich and Morris–Lecar neurons demonstrate different results in this study. We further investigated the necessary neuronal, synaptic and connectivity properties, including gap junctions and shunting inhibitions, for AdEx model leading to sparse and random network synchrony in gamma rhythms and nested theta gamma rhythms. These findings suggest a computationally more tractable framework for studying synchronized networks in inducing cerebral gamma band activities.

7.1.3. *Event-driven simulation of large scale neural models with on-demand connectivity generation*

Accurate simulations of brain structures is a major problem in neuroscience. Many works are dedicated to design better models or to develop more efficient simulation schemes. In this work, we propose to combine time-stepping numerical integration of Hodgkin-Huxley type neurons with event-driven updating of the synaptic currents. A spike detection method was also developed to determine the spike time more precisely in order to preserve the second-order Runge-Kutta methods. This hybrid approach allows us to regenerate the outgoing connections at each event, thereby avoiding the storage of the connectivity. Consequently, memory consumption and execution time are significantly reduced while preserving accurate simulations, especially spike times of detailed point neuron models. The efficiency of the method has been demonstrated on the simulation of 10^6 interconnected MSN neurons with Parkinson disease (an article has been submitted to Frontiers in Neuroinformatics) [23].

7.2. From the Mesoscopic to the Macroscopic Scale

Participants: Laurent Bougrain, Sébastien Rimbert, Oleksii Avilov, Rahaf Al-Chwa, Anais Coster, Elina Ortega Herrera, Nicolas Rault, Radu Ranta (univ. Lorraine).
In collaboration with Stéphanie Fleck (Univ. Lorraine)

7.2.1. *On source space resolution in EEG brain imaging for motor imagery*

Brain source localization accuracy is known to be dependent on the EEG sensor placement over the head surface. In Brain-Computer Interfaces (BCI), according to the paradigm used, Motor Imagery (MI) and Steady-State Visual Evoked Potential (SSVEP) in particular, electrodes are not well distributed over the head, and their number is not standardized as in classical clinical applications. We proposed a method for quantifying the expected quality of source localization with respect of the sensor placement, known as EEG montage. Our method, based on a subspace correlation metric, can be used to assess which brain sources can be distinguished (as they generate sufficiently different potentials on the electrodes), and also to identify regions/volumes in which precise source localization is impossible (i.e. all sources inside those regions could generate similar electrode potentials). In particular, for a MI dedicated montage, we show that source localization is less precise than for standard montages, although the local density of electrodes over the areas of interest is higher [13].

7.2.2. *Median nerve stimulation based BCI: a new approach to detect intraoperative awareness during general anesthesia*

Hundreds of millions of general anesthesia are performed each year on patients all over the world. Among these patients, 0.2 to 1.3% are victims of Accidental Awareness during General Anesthesia (AAGA), i.e. an unexpected awakening of the patient during a surgical procedure under general anesthesia. This terrifying experience may be very traumatic for the patient and should be avoided by the anesthesiologists. Out of all the techniques used to reduce these awakenings, there is currently no solution based on the EEG signal to detect this phenomenon efficiently. Since the first reflex for a patient during an AAGA is to move, a passive BCI based on the intention of movement is conceivable. However, the challenge of using such BCI is that the intention to move from the waking patient is not initiated by a trigger that could be used to guide a classifier. We proposed a solution based on Median Nerve Stimulation (MNS), which causes specific modulations in the motor cortex and can be altered by an intention of movement. We showed that MNS may provide a foundation for an innovative BCI that would allow the detection of an AAGA [15], [7].

Moreover the way in which propofol (i.e., an anesthetic commonly used for the general anesthesia induction) affects motor brain activity within the electroencephalographic (EEG) signal has been poorly investigated and is not clearly understood. For this reason, a detailed study of the motor activity behavior with a step-wise increasing dose of propofol is required and would provide a proof of concept for such an innovative BCI. We started a study to highlight the occurrence of movement attempt patterns, mainly changes in oscillations called event-related desynchronization (ERD) and event-related synchronization (ERS), in the EEG signal over the motor cortex, in healthy subjects, without and under propofol sedation, during four different motor tasks [8], [12].

7.2.3. *Can a subjective questionnaire be used as a brain-computer interface performance predictor?*

Predicting a subject's ability to use a Brain Computer Interface (BCI) is one of the major issues in the BCI domain. Relevant applications of forecasting BCI performance include: the ability to adapt the BCI to the needs and expectations of the user; assessing the efficiency of BCI use in stroke rehabilitation; and finally, homogenizing a research population. A limited number of recent studies have proposed the use of subjective questionnaires, such as, the Motor Imagery Questionnaire Revised-Second Edition (MIQ-RS). However, further research is necessary to confirm the effectiveness of this type of subjective questionnaire as a BCI performance estimation tool. We aimed to answer the following questions: can the MIQ-RS be used to estimate the performance of an MI-based BCI? If not, can we identify different markers that could be used as performance estimators? To answer these questions, we recorded EEG signals from 35 voluntary healthy subjects during BCI use. The subjects previously had completed the MIQ-RS questionnaire. We conducted an offline analysis to assess the correlation between the questionnaire scores related to Kinesthetic and Motor imagery tasks and the performances of four classification methods. Our results show no significant correlation between BCI performance and the MIQ-RS scores. However, we revealed that BCI performance is correlated to habits and frequency of practicing manual activities [6].

7.2.3.1. *Hypnotic State Modulates Sensorimotor Beta Rhythms During Real Movement and Motor Imagery*

Hypnosis techniques are currently used in the medical field and directly influence the patient's state of relaxation, perception of the body, and its visual imagination. There is evidence to suggest that a hypnotic state may help patients to better achieve tasks of motor imagination, which is central in the rehabilitation protocols after a stroke. However, the hypnosis techniques could also alter activity in the motor cortex. To the best of our knowledge, the impact of hypnosis on the EEG signal during a movement or an imagined movement is poorly investigated. In particular, how event-related desynchronization (ERD) and event-related synchronization (ERS) patterns would be modulated for different motor tasks may provide a better understanding of the potential benefits of hypnosis for stroke rehabilitation. To investigate this purpose, we recorded EEG signals from 23 healthy volunteers who performed real movements and motor imageries in a closed eye condition. Our results suggest that the state of hypnosis changes the sensorimotor beta rhythm during the ERD phase but maintains the ERS phase in the mu and beta frequency band, suggesting a different activation of the motor cortex in a hypnotized state [14], [9].

8. Partnerships and Cooperations

8.1. Regional Initiatives

Within the *Contrat de Projet État Région (CPER) IT2MP* 2015-2020 on *Technological innovations, modeling and Personalized Medicine*, we are contributing on platform SCIARAT (*cognitive stimulation, Ambient Intelligence, Robotic assistance and Telemedicine*) observing electroencephalographic activity of humans during motor tasks. The acquisition of a new 64-channel EEG system has been approuved.

8.2. National Initiatives

8.2.1. ANR

Program: PRCE CES 33 (interaction, robotics)

Project acronym: Grasp-IT

Project title: Design and evaluation of a tangible and haptic brain-computer interface for upper limb rehabilitation after stroke

Duration: Jan 2020 - Jan 2024

Coordinator: Laurent Bougrain (Neurosys)

Other partners: 4 research teams (UL/Perseus, Inria/Camin, Inria/Hybrid) and 3 centers or hospital departments for physical medicine and rehabilitation (IRR/CMPR Lay St Christophe, CHU Rennes, CHU Toulouse) and 1 manufacturer of 3D printers (Alchimies/OpenEdge)

Abstract: This project aims to recover upper limb control improving the kinesthetic motor imagery (KMI) generation of post-stroke patients using a tangible and haptic interface within a gamified Brain-Computer Interface (BCI) training environment. (i) This innovative KMI-based BCI will integrate complementary modalities of interactions such as tangible and haptic interactions in a 3D printable flexible orthosis. We propose to design and test usability (including efficacy towards the stimulation of the motor cortex) and acceptability of this multimodal BCI. (ii) The GRASP-IT project proposes to design and integrate a gamified non-immersive virtual environment to interact with. This multimodal solution should provide a more meaningful, engaging and compelling stroke rehabilitation training program based on KMI production. (iii) In the end, the project will integrate and evaluate neurofeedbacks, within the gamified multimodal BCI in an ambitious clinical evaluation with 75 hemiplegic patients in 3 different rehabilitation centers in France.
The GRASP-IT project represents a challenge for the industrial 3D printing field. The materials of the 3D printable orthosis, allowing the integration of haptic-tangible interfaces, will come from a joint R & D work performed by the companies Alchimies and Open Edge.

8.3. International Research Visitors

8.3.1. Visits of International Scientists

- Hiroaki Wagatsuma, Ass. Prof, 11-28 Jun. 2019, Kyutech (Japan). Methodological design for integration of human EEG data with behavioral analyses into human-human/robot interactions in a real-world context.

8.3.1.1. Internships

- Asako Watanabe, Master Student, Jan-Mar 2019, Kyutech (Japan). Feature Extraction of EEG Signals Using Power Spectral Entropy.

8.3.2. Visits to International Teams

L. Bougrain, A. Aussel and S. Rimbert participated in the Kyutech-LORIA workshop organized jointly by University of Lorraine and Kyutech (4-8 March 2019).

9. Dissemination

9.1. Promoting Scientific Activities

Laurent Bougrain is a member of the steering committee of the research network in neuroscience of the university of Lorraine.

Laure Buhry is an elected member of the "Pôle Scientifique AM2I" council of university of Lorraine.

9.1.1. Scientific Events: Organisation

Laurent Bougrain is a member of the organization committee of the scientific days of the research network in neuroscience of the university of Lorraine, April 25th 2019 (topic: emotions, motivation and addictions) & December 5th 2019.

9.1.2. Leadership within the Scientific Community

Laurent Bougrain is a member of the Board of Directors of the scientific society CORTICO for the promotion of Brain-Computer Interfaces in France.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Engineering school: L. Bougrain, Brain-Computer Interfaces, 4.5h, 3rd year, Supelec, France

Engineering school: L. Bougrain, Artificial Intelligence, 61h, 3rd year, Telecom Nancy, France

Engineering school: A. Aussel, Python, Ecole des Mines, Nancy, France

Master: L. Buhry, Algorithms for Articifial Inteligence, 31h, Master of cognitive science, M1, University of Lorraine, France

Master: L. Buhry, Fondamental Artificial Intelligence and data mining, 18h, Master of cognitive science, M1, University of Lorraine, France

Master: L. Buhry, Formalisms for representation and reasoning, 25h, Master of cognitive science, M1, University of Lorraine, France

Master: L. Buhry, Memory and Machine Learning, 38h, Master of cognitive science, M1, University of Lorraine, France

Master: L. Buhry, Computationnal Neurosciences, 25h, Master of cognitive science/SCMN, M2, University of Lorraine, France

Master: L. Bougrain, Learning and reasoning in the uncertain, 32h, Master of computer science, M2, University of Lorraine, France

Master: S. Rimbert, Brain-Computer Interface, 17h, Master of cognitive sciences, M2, University of Lorraine, France

Master: A. Aussel, Computational Neuroscience, Master of cognitive sciences, M2, University of Lorraine, France

Licence: S. Rimbert, Introduction to Neurosciences, 15h, Licence of cognitive sciences, L1 University of Lorraine, France

Licence: L. Buhry, Programmation Python, 37h, level L1 MIASHS, University of Lorraine, France

Licence: L. Buhry, Probability and statistics, 30h, L1 MIASHS, University of Lorraine, France

Licence: L. Buhry, Artificial Intelligence and problem solvinges, 25h, L3 MIASHS, University of Lorraine, France

Licence: L. Bougrain, programming on mobile devices, 17h, Licence of computer science, L3, University of Lorraine, France

Licence: N. Azevedo Carvalho, Mathematics, 64h, L1 SPI, University of Lorraine, France

9.2.2. Supervision

PhD: Amélie Aussel, Extraction of electrophysiological markers and mathematical modelling of the epileptic hippocampus, October 14 2019, Laure Buhry and Radu Ranta (CRAN).

PhD in progress: Sébastien Rimbert, Study of the dynamic of cerebral motor patterns during general anesthesia, January 1st 2016, Axel Hutt and Laurent Bougrain.

PhD in progress: Oleksii Avilov, methods for on-line detection of neural rythm changes in the motor system: application to brain-computer interfaces, June 1st 2018, Patrick Hénaff, Laurent Bougrain and Anton Popov (Kiev Polytechnic institute).

PhD in progress: Nathalie Azevedo Carvalho, a biologically plausible computer model of pathological neuronal oscillations observed in Parkinson's disease, November 1st 2018, Dominique Martinez and Laure Buhry.

9.2.3. Juries

Amélie Aussel, Extraction of electrophysiological markers and mathematical modelling of the epileptic hippocampus, October 14 2016, Univ Lorraine, (Laure Buhry and Radu Ranta, supervisors)

Committee of selection for an assistant professor position MCF69/19 University of Toulouse (2019), Laurent Bougrain

10. Bibliography

Publications of the year

Doctoral Dissertations and Habilitation Theses

[1] A. AUSSEL.*Computational modeling of healthy and epileptic hippocampal oscillations*, Université de Lorraine, November 2019, https://hal.archives-ouvertes.fr/tel-02437326

Articles in International Peer-Reviewed Journal

[2] M. JOUAITI, P. HENAFF.*Comparative Study of Forced Oscillators for the Adaptive Generation of Rhythmic Movements in Robot Controllers*, in "Biological Cybernetics (Modeling)", October 2019, vol. 113, n^{o} 5-6, p. 547-560 [*DOI :* 10.1007/S00422-019-00807-8], https://hal.archives-ouvertes.fr/hal-02291575

[3] M. JOUAITI, P. HENAFF.*Robot-Based Motor Rehabilitation in Autism: A Systematic Review*, in "International Journal of Social Robotics", 2019, vol. 11, n^{o} 5, p. 753–764 [*DOI :* 10.1007/S12369-019-00598-9], https://hal.archives-ouvertes.fr/hal-02295952

[4] F. LOTTE, C. JEUNET, R. CHAVARRIAGA, L. BOUGRAIN, D. THOMPSON, R. SCHERER, M. R. MOWLA, A. KÜBLER, M. GROSSE-WENTRUP, K. DIJKSTRA, N. DAYAN.*Turning negative into positives! Exploiting "negative" results in Brain-Machine Interface (BMI) research*, in "Brain-Computer Interfaces", 2019, forthcoming, https://hal.inria.fr/hal-02375400

[5] V. OSAULENKO, B. GIRAU, O. MAKARENKO, P. HENAFF.*Increasing Capacity of Association Memory by Means of Synaptic Clustering*, in "Neural Processing Letters", May 2019, vol. 50, n^{o} 3, p. 2717-2730 [*DOI :* 10.1007/S11063-019-10051-7], https://hal.archives-ouvertes.fr/hal-02143550

[6] S. RIMBERT, N. GAYRAUD, L. BOUGRAIN, M. CLERC, S. FLECK.*Can a Subjective Questionnaire Be Used as Brain-Computer Interface Performance Predictor?*, in "Frontiers in Human Neuroscience", January 2019, vol. 12, 11 [*DOI :* 10.3389/FNHUM.2018.00529], https://hal.inria.fr/hal-01990935

[7] S. RIMBERT, P. RIFF, N. GAYRAUD, D. SCHMARTZ, L. BOUGRAIN.*Median Nerve Stimulation Based BCI: A New Approach to Detect Intraoperative Awareness During General Anesthesia*, in "Frontiers in Neuroscience", June 2019, vol. 13, 13 [*DOI :* 10.3389/FNINS.2019.00622], https://hal.inria.fr/hal-02159777

[8] S. RIMBERT, D. SCHMARTZ, L. BOUGRAIN, C. MEISTELMAN, C. BAUMANN, P. GUERCI.*MOTANA: study protocol to investigate motor cerebral activity during a propofol sedation*, in "Trial", September 2019, vol. 20, n^o 534, 9 [*DOI :* 10.1186/S13063-019-3596-9], https://hal.inria.fr/hal-02270649

[9] S. RIMBERT, M. ZAEPFFEL, P. RIFF, P. ADAM, L. BOUGRAIN.*Hypnotic State Modulates Sensorimotor Beta Rhythms During Real Movement and Motor Imagery*, in "Frontiers in Psychology", October 2019, vol. 10 [*DOI :* 10.3389/FPSYG.2019.02341], https://hal.archives-ouvertes.fr/hal-02325588

[10] C. SAAVEDRA, R. SALAS, L. BOUGRAIN.*Wavelet-Based Semblance Methods to Enhance the Single-Trial Detection of Event-Related Potentials for a BCI Spelling System*, in "Computational Intelligence and Neuroscience", August 2019, vol. 2019, n^o Article ID 8432953, 10 [*DOI :* 10.1155/2019/8432953], https://hal.inria.fr/hal-02313981

[11] L. SHIAU, L. BUHRY.*Interneuronal gamma oscillations in hippocampus via adaptive exponential integrate-and-fire neurons*, in "Neurocomputing", February 2019, vol. 331, p. 220-234 [*DOI :* 10.1016/J.NEUCOM.2018.11.017], https://hal.archives-ouvertes.fr/hal-02431627

International Conferences with Proceedings

[12] P. GUERCI, S. RIMBERT, D. SCHMARTZ, M.-R. LOSSER, L. BOUGRAIN, C. MEISTELMAN.*Effet du propofol sur les synchronisations/désynchronisations neuronales corticales motrices analysées par une interface cerveau-machine: rapport préliminaire d'une étude prospective chez le volontaire sain*, in "Congrès SFAR 2019", Paris, France, September 2019, https://hal.inria.fr/hal-02144809

[13] R. RANTA, S. LE CAM, G. BERGMANIS-KORATS, S. RIMBERT, L. BOUGRAIN.*On source space resolution in EEG brain imaging for motor imagery*, in "9th International IEEE/EMBS Conference on Neural Engineering, NER 2019", San Francisco, United States, March 2019, https://hal.inria.fr/hal-01985178

[14] S. RIMBERT, O. AVILOV, P. ADAM, L. BOUGRAIN.*Can suggestive hypnosis be used to improve Brain-Computer Interface performance?*, in "8th Graz Brain-Computer Interface Conference 2019", Graz, Austria, September 2019, https://hal.inria.fr/hal-02098864

[15] S. RIMBERT, P. GUERCI, N. GAYRAUD, C. MEISTELMAN, L. BOUGRAIN.*Innovative Brain-Computer Interface based on motor cortex activity to detect accidental awareness during general anesthesia*, in "IEEE SMC 2019 - IEEE International Conference on Systems, Man, and Cybernetics", Bari, Italy, October 2019, https://hal.inria.fr/hal-02166934

[16] M. R. V. SANCHEZ, S. MISHIMA, M. FUJIWARA, G. AI, M. JOUAITI, Y. KOBRYN, S. RIMBERT, L. BOUGRAIN, P. HENAFF, H. WAGATSUMA.*Methodological Design for Integration of Human EEG Data with Behavioral Analyses into Human-Human/Robot Interactions in a Real-World Context*, in "International Conference on Innovative Computing, Information and Control", Seoul, South Korea, August 2019, vol. 7, 8, https://hal.inria.fr/hal-02437374

Conferences without Proceedings

[17] A. AUSSEL, H. TRAN, L. BUHRY, S. LE CAM, L. MAILLARD, S. COLNAT-COULBOIS, V. LOUIS-DORR, R. RANTA.*Extracellular synaptic and action potential signatures in the hippocampal formation: a modelling study*, in "28th Annual Computational Neuroscience Meeting, CNS*2019", Barcelone, Spain, July 2019, https://hal.archives-ouvertes.fr/hal-02284821

[18] M. JOUAITI, P. HENAFF.*Motor Coordination Learning for Rhythmic Movements*, in "Development and Learning and Epigenetic Robotics (ICDL-Epirob), 2019 Joint IEEE International Conferences on", Oslo, Norway, August 2019, https://hal.archives-ouvertes.fr/hal-02144957

[19] M. JOUAITI, P. HENAFF.*Real Time Movement Classification in Versatile CPG Control*, in "Workshop on Robust Artificial Intelligence for Neurorobotics", Edinburgh, United Kingdom, August 2019, https://hal.archives-ouvertes.fr/hal-02291647

[20] M. JOUAITI, P. HENAFF.*The Sound of Actuators: Disturbance in Human -Robot Interactions?*, in "Development and Learning and Epigenetic Robotics (ICDL-Epirob), 2019 Joint IEEE International Conferences on", Oslo, Norway, August 2019, Accepted to the Development and Learning and Epigenetic Robotics (ICDL-Epirob), Aug 2019, Oslo, Norway conference, https://hal.archives-ouvertes.fr/hal-02144955

[21] M. JOUAITI.*Improving Motor Coordination in HRI with Bio-Inspired Controllers*, in "HRI Pioneers Workshop", Cambridge, United Kingdom, March 2020 [*DOI :* 10.1145/3371382.3377439], https://hal.archives-ouvertes.fr/hal-02435758

[22] A. D. SHACHYKOV, O. SHULIAK, P. HENAFF.*Closed-loop Central Pattern Generator Control of Human Gaits in OpenSim Simulator*, in "IJCNN 2019 - International Joint Conference on Neural Networks", Budapest, Hungary, July 2019, https://hal.archives-ouvertes.fr/hal-02309658

Other Publications

[23] N. AZEVEDO CARVALHO, S. CONTASSOT-VIVIER, L. BUHRY, D. MARTINEZ.*Event-driven simulation of large scale neural models with on-demand connectivity generation*, January 2020, working paper or preprint, https://hal.inria.fr/hal-02433782

References in notes

[24] A. AUSSEL, L. BUHRY, L. TYVAERT, R. RANTA.*A detailed anatomical and mathematical model of the hippocampal formation for the generation of sharp-wave ripples and theta-nested gamma oscillations*, in "Journal of Computational Neuroscience", December 2018, vol. 45, n^{o} 3, 207 [*DOI :* 10.1007/s10827-018-0704-x], https://hal.archives-ouvertes.fr/hal-01917285

[25] A. AUSSEL, R. RANTA, L. BUHRY, L. TYVAERT, P. HENAFF.*A detailed model of the hippocampal formation for the generation of sharp-wave ripples and theta-nested gamma oscillations*, in "27th Annual Computational Neuroscience Meeting, CNS*2018", Seatle, WA, United States, July 2018, https://hal.archives-ouvertes.fr/hal-01843023

[26] A. AUSSEL, H. TRAN, L. BUHRY, S. LE CAM, L. MAILLARD, S. COLNAT-COULBOIS, V. LOUIS-DORR, R. RANTA.*Extracellular synaptic and action potential signatures in the hippocampal formation: a modelling study*, in "28th Annual Computational Neuroscience Meeting, CNS*2019", Barcelone, Spain, July 2019, https://hal.archives-ouvertes.fr/hal-02284821

Project-Team ORPAILLEUR

Knowledge discovery, knowledge engineering

IN COLLABORATION WITH: Laboratoire lorrain de recherche en informatique et ses applications (LORIA)

IN PARTNERSHIP WITH:
CNRS

Université de Lorraine

RESEARCH CENTER
Nancy - Grand Est

THEME
Data and Knowledge Representation and Processing

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Project-Team ORPAILLEUR

Creation of the Project-Team: 2008 January 01

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B9.5.6. - Data science

1. Team, Visitors, External Collaborators

Research Scientists

Amedeo Napoli [Team leader (until Oct 1st), CNRS, Senior Researcher, HDR]
Esther Catherine Galbrun [Inria, Researcher, on sabbatical leave since 2018]
Chedy Raïssi [Inria, Researcher, on sabbatical leave since 2019]

Faculty Members

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Adrien Coulet [Univ. de Lorraine, Associate Professor, sabbatical leave at University of Stanford, USA, until September 1st, HDR]
Sébastien Da Silva [Univ. de Lorraine, Associate Professor]
Jean-François Mari [Univ. de Lorraine, Professor, HDR]
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Abdelkader Ouali [Inria (until August 31)]

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Delphine Hubert [Univ. de Lorraine, Administrative Assistant]
Annick Jacquot [CNRS, Administrative Assistant]
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Messaoudi Anne-Marie [Univ de Lorraine, Administrative Assistant (since Apr 2019)]

2. Overall Objectives

2.1. Introduction

Knowledge discovery in databases (KDD) consists in processing large volumes of data in order to discover knowledge units that are significant and reusable. Assimilating knowledge units to gold nuggets, and databases to lands or rivers to be explored, the KDD process can be likened to the process of searching for gold. This explains the name of the research team: in French "orpailleur" denotes a person who is searching for gold in rivers or mountains. The KDD process is based on three main operations: data preparation, data mining and interpretation of the extracted units as knowledge units. Moreover, the KDD process is iterative, interactive, and generally controlled by an expert of the data domain, called the analyst. The analyst selects and interprets a subset of the extracted units for obtaining knowledge units having a certain plausibility. In this view, KDD is an exploratory process similar to "exploratory data analysis".

As a person searching for gold may have a certain experience about the task and the location, the analyst may use general and domain knowledge for improving the whole KDD process. Accordingly, the KDD process may be associated with knowledge bases –or domain ontologies– related to the domain of data for implementing *knowledge discovery guided by domain knowledge* (KDDK). In KDDK, extracted units may have "a life" after the interpretation step for becoming "actionable": they are represented as knowledge units using a knowledge representation formalism and integrated within an ontology to be reused for problem-solving needs. In this way, knowledge discovery extends and updates existing knowledge bases, materializing a complementarity between knowledge discovery and knowledge engineering.

3. Research Program

3.1. Hybrid and Exploratory Knowledge Discovery

Keywords: knowledge discovery in databases, knowledge discovery in databases guided by domain knowledge, data mining, data exploration, formal concept analysis, classification, pattern mining, numerical methods in data mining.

Knowledge discovery in databases (KDD) aims at discovering intelligible and reusable patterns in possibly large databases. These patterns can then be interpreted as knowledge units to be reused in knowledge-based systems. From an operational point of view, the KDD process is based on three main steps: (i) selection and preparation of the data, (ii) data mining, (iii) interpretation of the discovered patterns. Moreover, the KDD process is iterative, interactive, and generally controlled by an expert of the data domain, called the analyst. The analyst selects and interprets a subset of the extracted units for obtaining knowledge units having a certain plausibility. In this view, KDD is an exploratory process similar to "exploratory data analysis".

The KDD process –as implemented in the Orpailleur team– is based on data mining methods which are either symbolic or numerical. Symbolic methods are based on pattern mining (e.g. mining frequent itemsets, association rules, sequences...), Formal Concept Analysis (FCA) and extensions such as Pattern Structures and Relational Concept Analysis (RCA), and redescription mining. Numerical methods are based on Random Forests, Support Vector Machines (SVM), Neural Networks, and probabilistic approaches such as second-order Hidden Markov Models (HMM). Moreover, for being able to deal with complex data, numerical data mining methods can be associated with symbolic methods, for improving applicability and efficiency of knowledge discovery. This is particularly true in classification, where supervised and unsupervised approaches may be combined with benefits.

A main operation in the research work of Orpailleur is "classification", which is a polymorphic process involved in modeling, mining, representing, and reasoning tasks. In this way, domain knowledge, when available, can improve and guide the KDD process, materializing the idea of *Knowledge Discovery guided by Domain Knowledge* or KDDK. In KDDK, domain knowledge plays a role at each step of KDD: the discovered patterns can be interpreted as knowledge units and reused for problem-solving activities in knowledge systems, implementing the exploratory process "mining, interpreting, modeling, representing, and reasoning". Then knowledge discovery can be considered as a key task in knowledge engineering (KE), having an impact in various semantic activities, e.g. information retrieval, recommendation, and ontology engineering. In addition, if knowledge discovery can feed knowledge-based systems, in turn, domain knowledge can be used to support the knowledge discovery process.

Finally, life sciences, i.e. agronomy, biology, chemistry, and medicine, are application domains where the Orpailleur team has a very rich experience. The team intends to keep and to extend this experience, paying also more attention to the impact of knowledge discovery in the real world. This should lead to the design of green (sustainable), explainable, and fair data mining systems.

3.2. Text Mining

Keywords: text mining, knowledge discovery from texts, text classification, annotation, ontology engineering from texts.

The objective of a text mining process is to extract useful knowledge units from large collections of texts [71]. The text mining process shows specific characteristics due to the fact that texts are complex objects written in natural language. The information in a text is expressed in an informal way, following linguistic rules, making text mining a difficult task. A text mining process has to take into account –as much as possible– paraphrases, ambiguities, specialized vocabulary and terminology. This is why the preparation of texts for text mining is usually dependent on linguistic resources and methods.

From a knowledge discovery perspective, text mining aims at extracting "interesting units" (nouns and relations) from texts with the help of domain knowledge encoded within a knowledge base. The process is roughly similar for text annotation. Text mining is especially useful in the context of semantic web for ontology engineering. In the Orpailleur team, we work on the mining of real-world texts in application domains such as biology and medicine, using numerical and symbolic data mining methods. Accordingly, the text mining process may be involved in a loop used to enrich and to extend linguistic resources. In turn, linguistic and ontological resources can be exploited to guide a "knowledge-based text mining process".

3.3. Knowledge Systems and Web of Data

Keywords: knowledge engineering, web of data, semantic web, ontology, description logics, classification-based reasoning, case-based reasoning, information retrieval, recommendation.

The web of data constitutes a good platform for experimenting ideas on knowledge engineering (KE) and knowledge discovery. A software agent may be able to read, understand, and manipulate information on the web, if and only if the knowledge necessary for achieving those tasks is available. This is why domain knowledge and ontologies are of main importance. OWL ("Web Ontology Language" https://www.w3.org/OWL/) is based on description logics (DLs [72]) and is the representation language commonly used for designing ontologies. In OWL, knowledge units are represented by classes having properties and instances. Concepts are organized within a partially ordered set based on a subsumption relation, and the inference services are based on subsumption and classification.

Actually, there are many interconnections between concept lattices in FCA and ontologies, e.g. the partial order underlying an ontology can be supported by a concept lattice. Moreover, a pair of implications within a concept lattice can provide a possible materialization of a concept definition in an ontology. In this way, we study how the web of data, considered as a set of knowledge sources, e.g. DBpedia, Wikipedia, Yago, Freebase, can be mined for guiding the design of a knowledge base, and further, how knowledge discovery techniques can be applied for allowing a better usage of the web of data, e.g. Linked Open Data (LOD) classification and completion.

Then, a part of the research work in Knowledge Engineering is oriented towards knowledge discovery in the web of data, as, with the increased interest in machine processable data, more and more data is now published in RDF (Resource Description Framework) format. Particularly, we are interested in the completeness of the data and their potential to provide concept definitions in terms of necessary and sufficient conditions. We have proposed algorithms based on FCA and Redescription Mining which allow data exploration as well as the discovery of definition (bidirectional implication rules).

4. Application Domains

4.1. Life Sciences: Agronomy, Biology, Chemistry, and Medicine

Keywords: knowledge discovery in life sciences, biology, chemistry, medicine, pharmacogenomics and precision medicine.

One major application domain which is currently investigated by the Orpailleur team is related to life sciences, with particular emphasis on biology, medicine, and chemistry. The understanding of biological systems provides complex problems for computer scientists, and the developed solutions bring new research ideas or possibilities for biologists and for computer scientists as well. Indeed, the interactions between researchers in biology and researchers in computer science improve not only knowledge about systems in biology, chemistry, and medicine, but knowledge about computer science as well.

Knowledge discovery is gaining more and more interest and importance in life sciences for mining either homogeneous databases such as protein sequences and structures, or heterogeneous databases for discovering interactions between genes and the environment, or between genetic and phenotypic data, especially for public health and precision medicine (pharmacogenomics). Pharmacogenomics is one main challenge for the Orpailleur team as it considers a large panel of complex data ranging from biological to medical data, and various kinds of encoded domain knowledge ranging from texts to formal ontologies.

On the same line as biological data, chemical data are presenting important challenges w.r.t. knowledge discovery, for example for mining collections of molecular structures and collections of chemical reactions in organic chemistry. The mining of such collections is an important task for various reasons including the challenge of graph mining and the industrial needs (especially in drug design, pharmacology and toxicology). Molecules and chemical reactions are complex data that can be modeled as labeled graphs. Graph mining and Formal Concept Analysis methods play an important role in this application domain and can be used in an efficient and well-founded way [87].

Finally, research in agronomy is mainly based on cooperation between Inria and INRA. One research dimension is related to the characterization and the simulation of hedgerow structures in agricultural landscapes, based on Hilbert-Peano curves and Markov models [79]. Another research dimension is based on the mining of survey data for evaluating groundwater quality risks [86].

5. Highlights of the Year

5.1. Highlights of the Year

This year we would like to mention two publications as highlights of the year.

- The conference paper [10] got the best paper award at the International Conference on Formal Concept Analysis 2019 in Frankfurt, June 2019 (https://icfca2019.frankfurt-university.de/).
- Classical properties of functions such as associativity, although algebraically easy to read, are hard to meaningfully interpret. In [18], Miguel Couceiro and colleagues showed that associative and quasi-trivial operations that are non-decreasing are characterized in terms of total and weak orderings through the so-called single-peakedness property introduced in social choice theory by Duncan Black. This enabled visual interpretations of the above mentioned algebraic properties, and the enumeration of such operations led to several, previously unknown, integer sequences in Sloane's On-Line Encyclopedia of Integer Sequences (http://www.oeis.org), e.g., `A292932`, `A292933`, and `A292934`.

BEST PAPERS AWARDS :
[42]
J. REYNAUD, Y. TOUSSAINT, A. NAPOLI.*Using Redescriptions and Formal Concept Analysis for Mining Definitions Linked Data*, in "ICFCA 2019 - 15th International Conference on Formal Concept Analysis", Francfort, Germany, June 2019, https://hal.inria.fr/hal-02170760

6. New Software and Platforms

6.1. ARPEnTAge

Analyse de Régularités dans les Paysages : Environnement, Territoires, Agronomie

KEYWORDS: Stochastic process - Hidden Markov Models

FUNCTIONAL DESCRIPTION: ARPEnTAge is a software based on stochastic models (HMM2 and Markov Field) for analyzing spatio-temporal data-bases. ARPEnTAge is built on top of the CarottAge system to fully take into account the spatial dimension of input sequences. It takes as input an array of discrete data in which the columns contain the annual land-uses and the rows are regularly spaced locations of the studied landscape. It performs a Time-Space clustering of a landscape based on its time dynamic Land Uses (LUS). Displaying tools and the generation of Time-dominant shape files have also been defined.

- Partner: INRA
- Contact: Jean-François Mari
- URL: http://carottage.loria.fr/index_in_english.html

6.2. CarottAge

KEYWORDS: Stochastic process - Hidden Markov Models

FUNCTIONAL DESCRIPTION: The system CarottAge is based on Hidden Markov Models of second order and provides a non supervised temporal clustering algorithm for data mining and a synthetic representation of temporal and spatial data. CarottAge is currently used by INRA researchers interested in mining the changes in territories related to the loss of biodiversity (projects ANR BiodivAgrim and ACI Ecoger) and/or water contamination. CarottAge is also used for mining hydromorphological data. Actually a comparison was performed with three other algorithms classically used for the delineation of river continuum and CarottAge proved to give very interesting results for that purpose.

- Participants: Florence Le Ber and Jean-François Mari
- Partner: INRA
- Contact: Jean-François Mari
- URL: http://carottage.loria.fr/index_in_english.html

6.3. CORON

KEYWORDS: Data mining - Closed itemset - Frequent itemset - Generator - Association rule - Rare itemset

FUNCTIONAL DESCRIPTION: The Coron platform is a KDD toolkit organized around three main components: (1) Coron-base, (2) AssRuleX, and (3) pre- and post-processing modules.

The Coron-base component includes a complete collection of data mining algorithms for extracting itemsets such as frequent itemsets, closed itemsets, generators and rare itemsets. In this collection we can find APriori, Close, Pascal, Eclat, Charm, and, as well, original algorithms such as ZART, Snow, Touch, and Talky-G. AssRuleX generates different sets of association rules (from itemsets), such as minimal non-redundant association rules, generic basis, and informative basis. In addition, the Coron system supports the whole life-cycle of a data mining task and proposes modules for cleaning the input dataset, and for reducing its size if necessary.

- Participants: Adrien Coulet, Aleksey Buzmakov, Amedeo Napoli, Florent Marcuola, Jérémie Bourseau, Laszlo Szathmary, Mehdi Kaytoue, Victor Codocedo and Yannick Toussaint
- Contact: Amedeo Napoli
- URL: http://coron.loria.fr/site/index.php

6.4. LatViz: Visualization of Concept Lattices

- Contact: Amedeo Napoli
- URL: http://latviz.loria.fr/
- KEYWORDS: Formal Concept Analysis, Pattern Structures, Concept Lattice, Implications, Visualization

FUNCTIONAL DESCRIPTION.

LatViz is a tool allowing the construction, the display and the exploration of concept lattices. LatViz proposes some noticeable improvements over existing tools and introduces various functionalities focusing on interaction with experts, such as visualization of pattern structures for dealing with complex non-binary data, AOC-poset which is composed of the core elements of the lattice, concept annotations, filtering based on various criteria and a visualization of implications [75]. This way the user can effectively perform interactive exploratory knowledge discovery as often needed in knowledge engineering.

The LatViz platform can be associated with the Coron platform and extends its visualization capabilities (see http://coron.loria.fr). Recall that the Coron platform includes a complete collection of data mining algorithms for extracting itemsets and association rules.

6.5. OrphaMine: Data Mining Platform for Orphan Diseases

- Contact: Laureline Nevin
- URL: http://orphamine.inria.fr/
- KEYWORDS: Bioinformatics, data mining, biology, health, data visualization, drug development.

FUNCTIONAL DESCRIPTION.

The OrphaMine platform enables visualization, data integration and in-depth analytics in the domain of “orphan diseases”, where data is extracted from the OrphaData ontology (http://www.orpha.net/consor/cgi-bin/index.php). At present, we aim at building a true collaborative portal that will serve different actors: (i) a general visualization of OrphaData data for physicians working, maintaining and developing this knowledge database about orphan diseases, (ii) the integration of analytics (data mining) algorithms developed by the different academic actors, (iii) the use of these algorithms to improve our general knowledge of rare diseases.

6.6. Siren: Interactive and Visual Redescription Mining

- Contact: Esther Catherine Galbrun
- URL: http://siren.gforge.inria.fr/main/
- KEYWORDS: Redescription mining, Interactivity, Visualization.

FUNCTIONAL DESCRIPTION.

Siren is a tool for interactive mining and visualization of redescriptions. Redescription mining aims to find distinct common characterizations of the same objects and, vice versa, to identify sets of objects that admit multiple shared descriptions. The goal is to provide domain experts with a tool allowing them to tackle their research questions using redescription mining. Merely being able to find redescriptions is not enough. The expert must also be able to understand the redescriptions found, adjust them to better match his domain knowledge and test alternative hypotheses with them, for instance. Thus, Siren allows mining redescriptions in an anytime fashion through efficient, distributed mining, to examine the results in various linked visualizations, to interact with the results either directly or via the visualizations, and to guide the mining algorithm toward specific redescriptions.

New features, such as a visualization of the contribution of individual literals in the queries and the simplification of queries as a post-processing, have been added to the tool.

7. New Results

7.1. Mining of Complex Data

Participants: Nacira Abbas, Guilherme Alves Da Silva, Alexandre Bazin, Alexandre Blansché, Lydia Boudjeloud-Assala, Quentin Brabant, Brieuc Conan-Guez, Miguel Couceiro, Adrien Coulet, Sébastien Da Silva, Alain Gély, Laurine Huber, Nyoman Juniarta, Florence Le Ber, Tatiana Makhalova, Jean-François Mari, Pierre Monnin, Amedeo Napoli, Laureline Nevin, Abdelkader Ouali, François Pirot, Frédéric Pennerath, Justine Reynaud, Claire Theobald, Yannick Toussaint, Laura Alejandra Zanella Calzada, Georgios Zervakis.

7.1.1. FCA and Variations: RCA, Pattern Structures, and Biclustering

Advances in data and knowledge engineering have emphasized the needs for pattern mining tools working on complex and possibly large data. FCA, which usually applies to binary data-tables, can be adapted to work on more complex data. In this way, we have contributed to some main extensions of FCA, namely Pattern Structures, Relational Concept Analysis and application of the "Minimum Description Length" (MDL) within FCA. Pattern Structures (PS [80], [85]) allow building a concept lattice from complex data, e.g. numbers, sequences, trees and graphs. Relational Concept Analysis (RCA [90]) is able to analyze objects described both by binary and relational attributes and can play an important role in text classification and text mining. Many developments were carried out in pattern mining and FCA for improving data mining algorithms and their applicability, and for solving some specific problems such as information retrieval, discovery of functional dependencies and biclustering.

We got several results in the discovery of approximate functional dependencies [29], the mining of RDF data, the visualization of the discovered patterns, and redescription mining. Moreover, based on Relational Concept Analysis, we worked also on the discovery and representation of n-ary relations in the framework of FCA [3]. In the same way, reusing ideas form subgroup discovery, we have initiated a whole line of research on the covering of the pattern spaces based on the "Minimum Description Length" (MDL) principle and we are working on the adaptation of MDL within the FCA framework [36] [7].

We are also working on designing hybrid mining methods, based on mining methods able to deal with symbolic and numerical data in parallel. In the context of the GEENAGE project, we are interested in the identification, in biomedical data, of biomarkers that are predictive of the development of diseases in the elderly population. Actually, the data are issued from a preceding study on metabolomic data for the detection of diabetes of type 2 [23]. The problem can be viewed as a classification problem where features which are predictive of a class should be identified. This leads us to study the notions of prediction and discrimination in classification problems. Combining numerical machine learning methods such as random forests, neural networks, and SVM, then multicriteria decision making methods (Pareto fronts), and pattern mining methods (including FCA), we developed a hybrid mining approach for selecting the features which are the most predictive and/or discriminant. Then the selected features are organized within a concept lattice to be presented to the analyst together with the reasons for their selection. The concept lattice makes more easy and natural the understanding of the feature selection. As such, this approach can also be seen as an explicable mining method, where the output includes the reasons for which features are selected in terms of prediction and discrimination.

In the framework of the CrossCult European Project about cultural heritage, we worked on the mining of visitor trajectories in a museum or a touristic site. We presented a theoretical and practical research work about the characterization of visitor trajectories and the mining of these trajectories as sequences [83], [84]. The mining process is based on two approaches in the framework of FCA. We focused on different types of sequences and more precisely on subsequences without any constraint and frequent contiguous subsequences. We also introduced a similarity measure allowing us to build a hierarchical classification which is used for interpretation and characterization of the trajectories. A natural extension of this research work on the characterization of trajectories is related to recommendation, i.e. based on an actual trajectory, how to recommend next items to be visited? Biclustering is a good candidate for designing recommendation methods and we especially worked on this topic this current year. In particular, we worked on several aspects of biclustering in the framework of FCA and we also tried to build a generic and unified framework from which several biclustering methods can be derived [34], [52].

7.1.2. Redescription Mining

Redescription mining is one of the pattern mining methods developed in the team. This method aims at finding distinct common characterizations of the same objects and, reciprocally, at identifying sets of objects having multiple shared descriptions [89]. This is motivated by the idea that in scientific investigations data oftentimes have different nature. For example, they might originate from distinct sources or be cast over separate terminologies.

In order to gain insight into the phenomenon of interest, a natural task is to identify the correspondences existing between these different aspects. A practical example in biology consists in finding geographical areas having two characterizations, one in terms of their climatic profile and one in terms of the occupying species. Discovering such redescriptions can contribute to better understand the influence of climate over species distribution. Besides biology, redescription mining can be applied in many concrete domains.

Following this way, we applied redescription mining for analyzing and mining RDF data in the web of data with the objective of discovering definitions of concepts and as well disjunctions (incompatibilities) of concepts, for completing knowledge bases in a semi-automated way [41] [10]. Redescription mining is well adapted to the task as a definition is naturally based on two sides of an equation, a left-hand side and a right-hand side.

7.1.3. Text Mining

The research work in text mining is mainly based on two ongoing PhD theses. The first research subject is related to the study of discourse and argumentation structures in a text based on tree mining and redescription mining [33], while the second research work is related to the mining of Pubmed abstracts about rare diseases. In the first research line, we investigate the similarities existing between discourse and argumentation structures by aligning subtrees in a corpus where texts are annotated. Contrasting related work, here we focus on the comparison of substructures within the text and not only the matching of relations. Based on data mining techniques such as tree mining and redescription mining, we are able to show that the structures underlying discourse and argumentation can be (partially) aligned. There the annotations related to discourse and argumentation allow us to derive a mapping between the structures. In addition, the approach enables the study of similarities between diverse discourse structures, and as well the differences in terms of expressive power.

In the second research line, the objective is to discover features related to rare diseases, e.g. symptoms, related diseases, treatments, and possible disease evolution or variations. The texts to be analyzed are from Pubmed, i.e. a platform collecting millions of publications in the medical domain. This research project aims at developing new methods and tools for supporting knowledge discovery in textual data by combining methods from Natural Language Processing (NLP) and Knowledge Discovery in Databases (KDD). Here a key idea is to design an interacting and convergent process where NLP methods are used for guiding text mining and KDD methods are used for analyzing textual documents. In this way, NLP is based on extraction of general and temporal information, while KDD methods are especially based on pattern mining, FCA, and graph mining.

7.1.4. Consensus, Aggregation Functions and Multicriteria Decision Aiding Functions

Aggregation and consensus theory study processes dealing with the problem of merging or fusing several objects, e.g., numerical or qualitative data, preferences or other relational structures, into a single or several objects of similar type and that best represents them in some way. Such processes are modeled by so-called aggregation or consensus functions [81], [82]. The need to aggregate objects in a meaningful way appeared naturally in classical topics such as mathematics, statistics, physics and computer science, but it became increasingly emergent in applied areas such as social and decision sciences, artificial intelligence and machine learning, biology and medicine.

We are working on a theoretical basis of a unified theory of consensus and to set up a general machinery for the choice and use of aggregation functions. This choice depends on properties specified by users or decision makers, the nature of the objects to aggregate as well as computational limitations due to prohibitive algorithmic complexity. This problem demands an exhaustive study of aggregation functions that requires an axiomatic treatment and classification of aggregation procedures as well as a deep understanding of their structural behavior. It also requires a representation formalism for knowledge, in our case decision rules and methods for discovering them. Typical approaches include rough-set and FCA approaches, that we aim to extend in order to increase expressivity, applicability and readability of results. Applications of these efforts already appeared and further are expected in the context of three multidisciplinary projects, namely the "Fight Heart Failure" (research project with the Faculty of Medicine in Nancy), the European H2020 "CrossCult" project, and the "ISIPA" (Interpolation, Sugeno Integral, Proportional Analogy) project.

In the context of the project RHU "Fighting Heart Failure" (that aims to identify and describe relevant bio-profiles of patients suffering from heart failure) we are dealing with biomedical data, highly complex and heterogeneous, that include, among other, sociodemographical aspects, biological and clinical features, drugs taken by the patients, etc. One of our main challenges is to define relevant aggregation operators on this heterogeneous patient data that lead to a clustering of the patients. Each cluster should correspond to a bio-profile, i.e. a subgroup of patients sharing the same form of the disease and thus the same diagnosis and medical care strategy. We are working on ways for comparing and clustering patients, namely, by defining multidimensional similarity measures on this complex and heterogeneous biomedical data. To this end, we recently proposed a novel approach, that we named "unsupervised extremely randomized trees" (UET), that is inspired by the frameworks of unsupervised random forests (URF) and of extremely randomized trees (ET). The empirical study of UET showed that it outperforms existing methods (such as URF) in running time, while giving better clustering. However, UET was implemented for numerical data only, and this is a drawback when dealing with biomedical data.

To overcome this limitation we have recently proposed an adaptation of UET [63] that is agnostic to variable types –numerical, symbolic or both–, that is robust to noise, to correlated variables, and to monotone transformations, thus drastically limiting the need for preprocessing. In addition, this provides similarity measures for clustering purposes that show outperforming results compared to state-of-the-art clustering methodologies.

Also, motivated by current trends in graph clustering for applications in the semantic web, and community identification in computer and social networks, we recently proposed a novel graph clustering method, i.e. GraphTrees [61], that is based on random decision trees to compute pairwise dissimilarities between vertices in vertex-attributed graphs. Unlike existing methodologies, it applies directly to graphs whose vertex-attributes are heterogeneous without preprocessing, and with promising results in benchmark datasets that are competitive with best known methods.

In the context of the project ISIPA, we mainly focused on the utility-based preference model in which preferences are represented as an aggregation of preferences over different attributes, structured or not, both in the numerical and qualitative settings. In the latter case, the Sugeno integral is widely used in multiple criteria decision making and decision under uncertainty, for computing global evaluations of items based on local evaluations (utilities). The combination of a Sugeno integral with local utilities is called a Sugeno utility functional (SUF). A noteworthy property of SUFs is that they represent multi-threshold decision rules.

However, not all sets of multi-threshold rules can be represented by a single SUF. We showed how to represent any set of multi-threshold rules as a combination of SUFs. Moreover, we studied their potential advantages as a compact representation of large sets of rules, as well as an intermediary step for extracting rules from empirical datasets [51]. We also proposed a novel method [58] for learning sets of decision rules that optimally fit the training data and that favors short rules over long ones. This is a competitive alternative to other methods for monotonic classification as in [78].

7.2. Knowledge Discovery in Healthcare and Life Sciences

Participants: Alexandre Bazin, Miguel Couceiro, Adrien Coulet, Sébastien Da Silva, Florence Le Ber, Jean-François Mari, Pierre Monnin, Amedeo Napoli, Abdelkader Ouali, Yannick Toussaint.

7.2.1. Ontology-based Clustering of Biological Data

Biomedical objects can be characterized by ontology annotations. For example, Gene Ontology annotations provide information on the functions of genes, while Human Phenotype Ontology (HPO) annotations provide information about phenotypes associated with diseases. It is usual to consider such annotations in the analysis of biomedical data, most of the time annotations from only one single ontology. However, complex objects such as diseases can be annotated at the same time w.r.t. different ontologies, making clear distinct dimensions. We are investigating how annotations from several ontologies may be cooperating in disease classification. In particular, we classified Genetic Intellectual Disabilities, on the basis of their HPO annotations and of Gene Ontology annotations of genes known for being responsible for these diseases [88]. We used clustering algorithms based on semantic similarities that enable us to compare sets of annotations. In particular, this experiment illustrates the fact that considering several ontologies provides better results in clustering, while selecting the best set of ontologies to combine is depending on the dataset and on the classification task. This study is still going on.

7.2.2. Validation of Pharmacogenomic Knowledge

State of the art knowledge in pharmacogenomics is heterogeneous w.r.t. validation. Some units of knowledge are well validated, observed on a large population and already used in clinical practice, while a large majority of this knowledge is lacking validation and reproducibility, mainly because of scarce observation. Accordingly, validating state of the art knowledge in pharmacogenomics by mining Electronic Health Records (EHRs) is one objective of the ANR project "PractiKPharma" initiated in 2016 (http://practikpharma.loria.fr/).

To carry out this validation, we define a minimal data schema for pharmacogenomic knowledge units (PGxO ontology), which is instantiated with data of different provenance (e.g. biomedical databases, literature and EHRs). The output of this instantiation is a (unique) knowledge graph called PGxLOD (https://pgxlod.loria.fr/). We defined and applied a set of so-called "reconciliation rules" that compare and align whenever possible knowledge units of different provenance [9]. The results of these rule applications are of particular interest since they highlight knowledge units defined in various data and knowledge sources. We are continuing this effort by studying how graph convolutional networks enable us to learn and then to compare the representation of n-ary relationships in the form of graph embeddings [39].

In addition, following our participation in the Biohackathon 2018 in Paris (https://2018.biohackathon-europe.org/), we firstly updated PGxLOD and improved its quality, completeness, and interconnection with other resources. Secondly we mined PGxLOD and searched for explanations about molecular mechanisms of adverse drug responses. Preliminary results where presented at the MedInfo Conference [59].

7.2.3. Mining Electronic Health Records

In the context of the Snowball Inria Associate Team, we studied the use of Electronic Health Records (EHRs) to predict at first prescription the need for a patient to be prescribed with a reduced drug dose [6]. We particularly focused on drugs whose dosage is known to be sensitive and variable. We used data from the Stanford Hospital to construct cohorts of patients that either did or did not need a dose change for each considered drug. After feature selection, we trained Random Forest models which successfully predict whether a new patient will or not require a dose change after being prescribed one of 23 drugs among 22 drug classes. Several of these drugs are related to clinical guidelines that recommend dose reduction exclusively in the case of adverse reaction. For these cases, a reduction in dosage may be considered as a surrogate for an adverse reaction, which our system could help to predict and to prevent.

In collaboration with Stanford University, we continued studying the development of predictive models from EHR data, in particular to evaluate the risk of atherosclerotic cardiovascular diseases (ASCVD). The evaluation of ASCVD risk is crucial for deciding upon the prescription of preventive therapies such as statins and others lipid lowering therapies. The prevalence of these diseases is depending on subgroups in a population, such as African-American and Asian people, which are indeed under-represented in cohorts that were used to fit the model currently used in clinics to evaluate the risk of ASCVD [25]. Due to such under-representation, biases are appearing in the evaluation of the risk when considering these different subgroups in the population. Then we proposed a method and a predictive model that controls, to some extent, the variability in the prediction of ASCVD when considering such "foreign" subgroups [40].

7.3. Knowledge Engineering and Web of Data

Participants: Nacira Abbas, Alexandre Bazin, Miguel Couceiro, Adrien Coulet, Florence Le Ber, Pierre Monnin, Amedeo Napoli, Justine Reynaud, Yannick Toussaint.

A first research topic in this axis relies on knowledge discovery in the web of data. This follows the increase of data published in RDF (Resource Description Framework) format and the interest in machine processable data. The quick growth of Linked Open Data (LOD) has led to challenging aspects regarding quality assessment and data exploration of the RDF triples that shape the LOD cloud. In the team, we are particularly interested in the completeness and the quality of data and their potential to provide concept definitions in terms of necessary and sufficient conditions [73], [74]. We have proposed a novel technique based on Formal Concept Analysis which classifies subsets of RDF data into a concept lattice. This allows data exploration as well as the discovery of implication rules which are used to automatically detect possible completions of RDF data and to provide definitions. Experiments on the DBpedia knowledge base show that this kind of approach is well-founded and effective [41] [10]. In addition, it should be noticed that this research work also involves redescription mining, showing the potential complementarity between definition mining and redescription mining.

The second topic in this axis is related to dependencies [77]. In the relational database model, functional dependencies (FDs) indicate a functional relation between sets of attributes: the values of a set of attributes are determined by the values of another set of attributes. FDs can be generalized into relational dependencies, also known as "link keys" in the web of data [76]. For example, link keys may identify the same book or article in different bibliographical data sources, where a link key is a statement of the form: $\{\langle \texttt{auteur}, \texttt{creator}\rangle, \langle \texttt{titre}, \texttt{title}\rangle\}\ linkkey\ \langle \texttt{Livre}, \texttt{Book}\rangle$ stating that whenever an instance of the class `Livre` has the same values for properties `auteur` and `titre` as an instance of class `Book` has for properties `creator` and `title`, then they denote the same entity. Such link keys are more complex than FDs in databases in several respects and they raise new problems to solve [2].

One main objective of this research work is to follow the lines initiated in recent papers [29], and to extend to link keys the characterization of FDs and of Similarity Dependencies within FCA and pattern structures. Indeed, this is one of the objective of the ANR ELKER project. Accordingly, one purpose is to extend the initial proposals based on FCA and to provide adapted implementations. This is part of the thesis work of Nacira Abbas initiated at the end of 2018 [26]. Moreover, we are currently investigating possible connections with Relational Concept Analysis and redescription mining. We would like to study the formulation of the discovery of link keys in reusing and extending some construction heuristics that were developed in redescription mining. Actually, redescription mining is a data mining technique which aims at constructing pairs of descriptions, i.e., pairs of logical statements, one for each of two datasets, such that their support sets, i.e., the sets of objects that satisfy each statements of a pair, respectively, are most similar, as measured for example by their Jaccard index.

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

8.1.1. AGREV-3

Participant: Jean-François Mari.

The AGREV 3 project (for "Agriculture Environment Vittel") is part of "Agrivair" –a subsidiary of Nestlé Waters– in actions to protect the natural resources of natural mineral water. We used ARPEnTAge to mine survey data about the Vittel-Contrexéville territory, which is suspected of groundwater quality risks [8]. This allowed us to locate regions having the same behavior. In addition, this provided a more contrasted simulation by eliminating the influence of stable zones (forests, permanent grasslands) and a more precise definition of a "neutral" model.

8.1.2. Hydreos

Participants: Nicolas Dante, Jean-François Mari, Amedeo Napoli.

Hydreos is a state organization, so-called "Pôle de compétitivité", aimed at monitoring and evaluating the quality of water and its delivery (http://www.hydreos.fr/fr). Actually, data about water resources rely on many agronomic variables, including land use successions. The data to be analyzed are obtained by surveys or by satellite images and describe the land use at the level of the agricultural parcel. Then there is a search for detecting changes in land use and for correlating these changes to groundwater quality. Accordingly, one main challenge in our participation in Hydreos is to process and analyze space-time data for reaching a better understanding of the changes in the organization of a territory. The systems ARPEnTAge and CarottAge are used in this context, especially by agronomists of INRA (ASTER Mirecourt http://www6.nancy.inra.fr/sad-aster).

On other aspects, we tested new deep graph convolutional learning over data provided by the SEDIF "Syndicat des eaux d'Île-de-France" to predict the likelihood of water leaks in a network of pipes and compared it with a master thesis where spatial point process techniques were used (master thesis of Nicolas Dante, M2 IMSD Nancy).

8.1.3. The Smart Knowledge Discovery Project

Participants: Laureline Nevin, Amedeo Napoli.

The SKD project for "Smart Knowledge Discovery" aims at analyzing complex industrial data for troubleshooting and decision making, and is funded by "Grand Est Region". We are working on exploratory knowledge discovery with the Vize company, which is based in Nancy and specialized in visualization-based data mining. The data which are under study are provided by the Arcelor-Mittal Steel Company and are related to the monitoring of rolling mills. Data are complex time series and the problem is related to a so-called "predictive maintenance", or how to anticipate problems in the furnaces and avoid their stop. In this way, one main objective of SKD is to combine sequence mining and visualization tools for recognizing temperature problems in the furnaces, and thus preventing the occurrences of defects in the outputs of the rolling mills.

9. Partnerships and Cooperations

9.1. National Initiatives

9.1.1. ANR

9.1.1.1. ANR ELKER (2017–2020)

Participants: Nacira Abbas, Miguel Couceiro, Amedeo Napoli.

The objectives of the ELKER ANR Research Project (https://project.inria.fr/elker/) are to study, formalize, and implement the search for link keys in RDF data [2]. Link keys generalize database keys in two independent directions, as firstly they deal with RDF data and secondly they apply across two relation datasets. In this project, we study the discovery of link keys and reasoning with link keys, being based on the FCA formalism. The ELKER project relies on the competencies of the Orpailleur Team in FCA and pattern structure algorithms, and also in partition pattern structures which are related to the discovery of functional dependencies. This project involves the EPI Orpailleur at Inria Nancy Grand Est, the EPI MOEX at Inria Grenoble Rhône Alpes, and LIASD at Université Paris 8.

9.1.1.2. ANR PractiKPharma (2016–2020)

Participants: Miguel Couceiro, Adrien Coulet, Pierre Monnin, Amedeo Napoli, Yannick Toussaint.

PractiKPharma for "Practice-based evidences for actioning Knowledge in Pharmacogenomics" is an ANR research project (http://practikpharma.loria.fr/) about the validation of domain knowledge in pharmacogenomics. Pharmacogenomics is interested in understanding how genomic variations related to patients have an impact on drug responses. While most of the available knowledge in pharmacogenomics –state of the art knowledge– lies in the biomedical literature, with various levels of validation, an originality of PractiKPharma is to use Electronic Health Records (EHRs) to constitute cohorts of patients where to discover knowledge units. Indeed, these cohorts are mined for discovering potential pharmacogenomics patterns to be then validated w.r.t. literature knowledge for becoming actionable knowledge units. More precisely, firstly we have to discover pharmacogenomic patterns from the literature, and secondly we should confirm or moderate the interpretation and validation of these units by mining EHRs. Comparing knowledge patterns extracted from the literature with facts extracted from EHRs is a complex task depending on the EHR language –the literature is in English whereas EHRs are in French– and on knowledge level, as EHRs represent observations at the patient level whereas the literature is related to sets of patients. The PractiKPharma involves three other laboratories, namely LIRMM in Montpellier, SSPIM in St-Etienne, and CRC in Paris.

9.1.1.3. ANR AstroDeep (2019–2022)

Participants: Miguel Couceiro, Amedeo Napoli, Claire Theobald.

Astronomical surveys planned for the coming years will produce data that present analysis challenges not only because of their scale (hundreds of petabytes), but also by the complexity of the measurement challenges on very deep images (for instance subpercent-level measurement of colors or shapes on blended objects). New machine learning techniques appear very promising: once trained, they are very efficient and excel at extracting features from complex images. In the AstroDeep project, we aim at developing such machine learning techniques that can be applied directly on complex images without going through the traditional steps of astronomical image processing, that lose information at each stage. The developed techniques will help to leverage the observation capabilities of future surveys (LSST, Euclid, and WFIRST), and will allow a joint analysis of data.

The AstroDeep ANR Project involves three labs, namely APC Paris ("Astroparticules et Cosmologie Paris"), the Orpailleur Team at Inria Nancy Grand Est/LORIA, and "Département d'Astrophysique CEA Saclay".

9.1.2. Inria Project Labs, Exploratory Research Actions, and Technological Development Actions

Participants: Guilherme Alves Da Silva, Alexandre Bazin, Miguel Couceiro, Nyoman Juniarta, Tatiana Makhalova, Amedeo Napoli, Laureline Nevin, Abdelkader Ouali, Claire Theobald, Georgios Zervakis.

HyAiAI (IPL 2019-2022) Recent progress in Machine Learning (ML) and especially in Deep Learning has made ML present and prominent in a wide range of applications. However, current and efficient ML approaches rely on complex numerical models. Then, the decisions which are proposed may be accurate but cannot be easily explained to the layman, especially in some cases where complex and human-oriented decisions should be made, e.g. to get a loan or not, to obtain a chosen enrollment at university. The objectives of the HyAIAI IPL are to study the problem of making ML methods interpretable. For that, we will design hybrid ML approaches that combine state of the art numerical models (e.g. neural networks) with explainable symbolic models (e.g. pattern mining). More precisely, one goal is to integrate high level domain constraints into ML models, to provide model designers information on ill-performing parts of the model, and to give the layman/practitioner understandable explanations on the results of the ML model.

The HyAIAI IPL project involves seven Inria Teams, namely Lacodam in Rennes (project leader), Magnet and SequeL in Lille, Multispeech and Orpailleur in Nancy, and TAU in Saclay.

Ordem (ADT 2019-2020) One of the outputs of the former Hybride ANR project was the Orphamine system which aims at information retrieval and diagnosis aid in the domain of "rare diseases". The Orphamine system is based on domain knowledge, and in particular on medical ontologies such as ORDO ("Orphanet Rare Diseases Ontology") and HPO ("Human Phenotype Ontology"). In this way, the objective of the "Ordem" ADT is to update Orphamine, in making the system more accessible and more open. This requires many developments for developing the connections with domain knowledge, graph mining methods for retrieving relevant units in knowledge graphs, actual visualization tools, pattern mining, statistical decision tools for decision making (in particular log-linear models), and as well text mining tools for analyzing expert queries and medical literature about rare diseases. Such developments are and will be carried out until the end of next year, for making the system robust and publicly accessible through a web interface.

HyGraMi (PRE Inria 2018-2020) Finally, the so called "projet de recherche exploratoire" (PRE) HyGraMi for "Hybrid Graph Mining for the Design of New Antibacterials" is about the fight against resistance of bacteria to antibiotics. The objective of HyGraMi is to design a hybrid data mining system for discovering new antibacterial agents. This system should rely on a combination of numeric and symbolic classifiers, that will be guided by expert domain knowledge. The analysis and classification of the chemical structures is based on an interaction between symbolic methods e.g. graph mining techniques, and numerical supervised classifiers based on exact and approximate matching. This year we work on a method based on tree decomposition for performing feature selection and improving data lining of such complex molecular structures [49].

9.2. European Initiatives

9.2.1. The H2020 CrossCult Project (2016-2019)

Participants: Miguel Couceiro, Nyoman Juniarta, Amedeo Napoli.

The H2020 CrossCult [0] project aims at making "reflective history" a reality in the European cultural context, by enabling the re-interpretation of European (hi)stories through cross-border interconnections among cultural digital resources, citizen viewpoints and physical venues. The project has two main goals, (i) to lower cultural EU barriers and create unique cross-border perspectives, by connecting existing digital historical resources and by creating new ones through public participation, (ii) to create long-lasting experiences of social learning and entertainment that will provide a better understanding and re-interpretation of European history. To achieve this, CrossCult aims at connecting and combining existing digital cultural assets, at increasing integration, interaction, and reflection about European past and present history. CrossCult was implemented w.r.t. four real-world pilots including cities, museums, and cultural sites. The role of the Orpailleur Team, in conjunction with the LORIA Kiwi Team, was to work on data mining –actually sequence mining– and recommendation, with a focus on the mining visitor trajectories in a museum or a touristic site, and on the definition of a visitor profile in connection with domain knowledge.

The CrossCult project involved many teams, namely Luxembourg Institute for Science and Technology and Centre Virtuel de la Connaissance sur l'Europe (Luxembourg, leaders of the project), University College London (England), University of Malta (Malta), University of Peloponnese and Technological Educational Institute of Athens (Greece), Università degli Studi di Padova (Italy), University of Vigo (Spain), National Gallery (London, England), and GVAM Guìas Interactivas (Spain), and the Kiwi Team from LORIA together with the Orpailleur team.

[0] http://www.crosscult.eu/

9.3. International Initiatives

9.3.1. Inria International Labs

Inria@SiliconValley
Associate Team involved in the International Lab:

9.3.1.1. Snowball

Title: Discovering knowledge on drug response variability by mining electronic health records

International Partner (Institution - Laboratory - Researcher):

University of Stanford (United States) - Department of Medicine, Stanford Center for Biomedical Informatics Research (BMIR) - Nigam Shah

Start year: 2017

See also: http://snowball.loria.fr/

Snowball (2017-2019) is an Inria Associate Team and the continuation of the preceding Associate Team called Snowflake (2014-2016). The objective of Snowball is to study drug response variability through the lens of Electronic Health Records (EHRs). This is motivated by the fact that many factors, genetic as well as environmental, contribute to different responses from people to the same drug. The mining of EHRs can bring substantial elements for understanding and explaining drug response variability.

Accordingly the objectives of Snowball are to identify in EHR repositories groups of patients which are responding differently to similar treatments, and then to characterize these groups and predict patient drug sensitivity. These objectives are complementary to those of the PractiKPharma ANR project. Moreover, Adrien Coulet finished in September 2019 a two-years sabbatical stay in the lab of Nigam Shah at Stanford University initiated in September 2017 (and partly granted by an “Inria délégation”).

9.3.2. Informal International Partners: Research Collaboration with HSE Moscow

Participants: Alexandre Bazin, Nacira Abbas, Guilherme Alves Da Silva, Miguel Couceiro, Nyoman Juniarta, Tatiana Makhalova, Amedeo Napoli, Justine Reynaud.

An ongoing collaboration involves the Orpailleur team and Sergei O. Kuznetsov at Higher School of Economics in Moscow (HSE). Amedeo Napoli visited HSE laboratory several times while Sergei O. Kuznetsov visits Inria Nancy Grand Est every year. The collaboration is materialized by the joint supervision of students (such as the thesis of Aleksey Buzmakov defended in 2015 and the ongoing thesis of Tatiana Makhalova), and the the organization of scientific events, as the workshop FCA4AI with seven editions between 2012 and 2019 (see http://www.fca4ai.hse.ru).

This year, we participated in the writing of common publications around the thesis work of Tatiana Makhalova and the organization of one main event, namely the seventh edition of the FCA4AI workshop in August 2019 at the IJCAI Conference which was held in Macao China.

10. Dissemination

10.1. Scientific Events Organization, General Chairs, Scientific Chairs

- Amedeo Napoli was the scientific co-chair with Sergei Kuznetsov of the track “General Topics of Data Analysis” at the AIST Conference held in Kazan Russia on July 17-19 2019 (8th International Conference on Analysis of Images, Social Networks, and Texts http://aistconf.org/ and http://aistconf.org/board/).

- Amedeo Napoli was the scientific co-chair with Sergei O. Kuznetsov (HSE Moscow) and Sebastian Rudolph (TU Dresden) of the seventh workshop FCA4AI “What can do FCA for Artificial Intelligence”, which was co-located with the IJCAI Conference in Macao China, August 10 2019 (see http://www.fca4ai.hse.ru/).
- Miguel Couceiro and Amedeo Napoli were the general and scientific chairs of the 26ièmes Rencontres de la Société Francophone de Classification (SFC 2019) that were held on September 3-5 at Inria NGE/LORIA Nancy (see https://project.inria.fr/sfc2019/).

10.2. Scientific Animation

- The scientific animation in the Orpailleur team is based on the Team Seminar which is called the “Malotec” seminar (http://malotec.loria.fr/). The Malotec seminar is held in general twice a month and is used either for general presentations of members of the team or for invited presentations of external researchers.
- Members of the Orpailleur team are all involved, as members or as head persons, in various national research groups.
- The members of the Orpailleur team are involved in the organization of conferences and workshops, as members of conference program committees (AAAI, ECAI, ECML-PKDD, ESWC, ICCBR, ICDM, ICFCA, IJCAI, ISWC, KDD, SDM...), as members of editorial boards, and finally in the organization of journal special issues.

10.3. Teaching - Supervision - Juries

10.3.1. Teaching

- All the permanent members of the Orpailleur team are involved in teaching at all levels and mainly at Université de Lorraine. Actually, most of the members of the Orpailleur team are employed on “Université de Lorraine” positions.
- Responsability of the 2nd year of the NLP Master’s program in the IDMC, Université de Lorraine.
- Local coordination of the European Erasmus Mundus Master’s program LCT (Language and Communication Technologies).

  The LCT Master’s program “Language and communication Technologies” (LCT) is designed to provide students with practice–oriented knowledge in computational and theoretical linguistics, natural language processing, and computer science, to meet the demands of industry and research in these rapidly growing areas. The LCT consortium includes 7 European Universities, i.e. Saarland, Lorraine, Trento, Malta, Groningen, Charles in Prague, Basque Country, and includes several partners, e.g., DFKI, IBM (Czech Rep.), VICOMTECH, Sony (Europe), IBM (Ireland), and Inria (France).
- Responsability in teaching courses about Artificial Intelligence and Knowledge-Based Systems at TELECOM Nancy, a engineer school for graduation in computer science at Université de Lorraine.

10.3.2. Supervision – Juries

- The members of the Orpailleur team are also involved in student supervision, at all university levels, from under-graduate until post-graduate students, engineers, PhD, postdoc students.
- Finally, the permanent members of the Orpailleur team are involved in HDR and thesis defenses, being thesis referees or thesis committee members.

11. Bibliography

Major publications by the team in recent years

[1] M. ANSDELL, Y. IOANNOU, H. OSBORN, M. SASDELLI, J. SMITH, D. CALDWELL, J. JENKINS, C. RAÏSSI, D. ANGERHAUSEN.*Scientific Domain Knowledge Improves Exoplanet Transit Classification with Deep Learning*, in "The Astrophysical Journal Letters", December 2018, vol. 869, n^{o} 1, L7 [*DOI :* 10.3847/2041-8213/AAF23B], https://hal.inria.fr/hal-01957950

[2] M. ATENCIA, J. DAVID, J. EUZENAT, A. NAPOLI, J. VIZZINI.*Link key candidate extraction with relational concept analysis*, in "Discrete Applied Mathematics", 2019, p. 1-19 [*DOI :* 10.1016/J.DAM.2019.02.012], https://hal.archives-ouvertes.fr/hal-02196757

[3] A. BAZIN, J. CARBONNEL, M. HUCHARD, G. KAHN, P. KEIP, A. OUZERDINE.*On-demand Relational Concept Analysis*, in "ICFCA: 15th International Conference on Formal Concept Analysis", Frankfurt, Germany, D. CRISTEA, F. L. BER, B. SERTKAYA (editors), Formal Concept Analysis, Springer International Publishing, 2019, vol. 11511, p. 155-172 [*DOI :* 10.1007/978-3-030-21462-3_11], https://hal-lirmm.ccsd.cnrs.fr/lirmm-02092140

[4] M. COUCEIRO, N. HUG, H. PRADE, G. RICHARD.*Behavior of Analogical Inference w.r.t. Boolean Functions*, in "IJCAI 2018 - 27th International Joint Conference on Artificial Intelligence", Stockholm, Sweden, July 2018, p. 2057–2063, https://hal.inria.fr/hal-02139765

[5] M. COUCEIRO, E. LEHTONEN, P. MERCURIALI, R. PÉCHOUX.*On the efficiency of normal form systems for representing Boolean functions*, in "Theoretical Computer Science", 2019, forthcoming, https://hal.inria.fr/hal-02153506

[6] A. COULET, N. H. SHAH, M. WACK, M. CHAWKI, N. JAY, M. DUMONTIER.*Predicting the need for a reduced drug dose, at first prescription*, in "Scientific Reports", October 2018, vol. 8, n^{o} 1 [*DOI :* 10.1038/S41598-018-33980-0], https://hal.inria.fr/hal-01901566

[7] T. MAKHALOVA, S. O. KUZNETSOV, A. NAPOLI.*Numerical Pattern Mining Through Compression*, in "DCC 2019 - 2019 Data Compression Conference", Snowbird, United States, IEEE, March 2019, p. 112-121, https://hal.archives-ouvertes.fr/hal-02162927

[8] J.-F. MARI, A. GOBILLOT, M. BENOÎT.*Time Space Simulation of Land Use changes by stochastic modeling*, in "Revue Internationale de Géomatique", August 2018, vol. 28, n^{o} 2, p. 219–242, https://hal.inria.fr/hal-01662140

[9] P. MONNIN, J. LEGRAND, G. HUSSON, P. RINGOT, A. TCHECHMEDJIEV, C. JONQUET, A. NAPOLI, A. COULET.*PGxO and PGxLOD: a reconciliation of pharmacogenomic knowledge of various provenances, enabling further comparison*, in "BMC Bioinformatics", April 2019, vol. 20, n^{o} S4 [*DOI :* 10.1186/S12859-019-2693-9], https://hal.inria.fr/hal-02103899

[10] J. REYNAUD, Y. TOUSSAINT, A. NAPOLI.*Using Redescriptions and Formal Concept Analysis for Mining Definitions Linked Data*, in "ICFCA 2019 - 15th International Conference on Formal Concept Analysis", Francfort, Germany, June 2019, https://hal.inria.fr/hal-02170760

Publications of the year

Doctoral Dissertations and Habilitation Theses

[11] Q. BRABANT.*Lattice polynomial functions for interpolation and monotonic classification*, Université de Lorraine, January 2019, https://hal.univ-lorraine.fr/tel-02096400

[12] A. COULET.*Mappings between data, texts and knowledge for biomedical knowledge discovery*, Université de Lorraine, December 2019, Habilitation à diriger des recherches, https://hal.inria.fr/tel-02429926

[13] N. JUNIARTA.*Mining complex data and biclustering using formal concept analysis*, Université de Lorraine, December 2019, https://hal.inria.fr/tel-02426034

[14] J. REYNAUD.*Mining definitions in the web of data*, Université de Lorraine (Nancy), December 2019, https://hal.inria.fr/tel-02426421

Articles in International Peer-Reviewed Journal

[15] M. ATENCIA, J. DAVID, J. EUZENAT, A. NAPOLI, J. VIZZINI.*Link key candidate extraction with relational concept analysis*, in "Discrete Applied Mathematics", 2019, p. 1-19 [*DOI :* 10.1016/J.DAM.2019.02.012], https://hal.archives-ouvertes.fr/hal-02196757

[16] Q. BRABANT, M. COUCEIRO, J. R. FIGUEIRA.*Interpolation by lattice polynomial functions: a polynomial time algorithm*, in "Fuzzy Sets and Systems", August 2019, vol. 368, p. 101-118 [*DOI :* 10.1016/J.FSS.2018.12.009], https://hal.archives-ouvertes.fr/hal-01958903

[17] M. COUCEIRO, J. DEVILLET.*Every quasitrivial n-ary semigroup is reducible to a semigroup*, in "Algebra Universalis", 2019, forthcoming [*DOI :* 10.1007/S00012-019-0626-0], https://hal.inria.fr/hal-02099236

[18] M. COUCEIRO, J. DEVILLET, J.-L. MARICHAL.*Quasitrivial semigroups: Characterizations and enumerations*, in "Semigroup Forum", June 2019, vol. 98, n^o 3, p. 472-498 [*DOI :* 10.1007/S00233-018-9928-3], https://hal.inria.fr/hal-01826868

[19] M. COUCEIRO, E. LEHTONEN, P. MERCURIALI, R. PÉCHOUX.*On the efficiency of normal form systems for representing Boolean functions*, in "Theoretical Computer Science", 2019, forthcoming, https://hal.inria.fr/hal-02153506

[20] M. COUCEIRO, M. MARÓTI, T. WALDHAUSER, L. ZADORI.*Computing version spaces in the qualitative approach to multicriteria decision aid*, in "International Journal of Foundations of Computer Science", February 2019, vol. 30, n° 2, p. 333-353 [*DOI :* 10.1142/S0129054119500084], https://hal.inria.fr/hal-01404590

[21] M. COUCEIRO, P. MERCURIALI, R. PÉCHOUX, A. SAFFIDINE.*On the complexity of minimizing median normal forms of monotone Boolean functions and lattice polynomials*, in "Journal of Multiple-Valued Logic and Soft Computing", 2019, vol. 33, n° 3, p. 197-218, forthcoming, https://hal.inria.fr/hal-01905491

[22] E. FIMMEL, C. C. MICHEL, F. PIROT, J.-S. SERENI, L. STRÜNGMANN.*Mixed circular codes*, in "Mathematical Biosciences", July 2019, vol. 317, 108231 [*DOI :* 10.1016/J.MBS.2019.108231], https://hal.archives-ouvertes.fr/hal-02188407

[23] D. GRISSA, B. COMTE, M. PETERA, E. PUJOS-GUILLOT, A. NAPOLI.*A hybrid and exploratory approach to knowledge discovery in metabolomic data*, in "Discrete Applied Mathematics", January 2019, forthcoming [*DOI :* 10.1016/J.DAM.2018.11.025], https://hal.inria.fr/hal-02195463

[24] P. MONNIN, J. LEGRAND, G. HUSSON, P. RINGOT, A. TCHECHMEDJIEV, C. JONQUET, A. NAPOLI, A. COULET.*PGxO and PGxLOD: a reconciliation of pharmacogenomic knowledge of various provenances, enabling further comparison*, in "BMC Bioinformatics", April 2019, vol. 20, n° S4 [*DOI :* 10.1186/S12859-019-2693-9], https://hal.inria.fr/hal-02103899

[25] F. RODRIGUEZ, S. CHUNG, M. BLUM, A. COULET, S. BASU, L. PALANIAPPAN.*Atherosclerotic Cardiovascular Disease Risk Prediction in Disaggregated Asian and Hispanic Subgroups Using Electronic Health Records*, in "Journal of the American Heart Association", July 2019, vol. 8, n^{o} 14 [*DOI :* 10.1161/JAHA.118.011874], https://hal.inria.fr/hal-02196129

International Conferences with Proceedings

[26] N. ABBAS, J. DAVID, A. NAPOLI.*Linkex: A Tool for Link Key Discovery Based on Pattern Structures*, in "ICFCA 2019 - workshop on Applications and tools of formal concept analysis", Frankfurt, Germany, Proc. ICFCA workshop on Applications and tools of formal concept analysis, 2019, p. 33-38, abbas2019a, https://hal.archives-ouvertes.fr/hal-02168775

[27] G. ALVES, M. COUCEIRO, A. NAPOLI.*Sélection de mesures de similarité pour les données catégorielles*, in "20ème édition de la conférence Extraction et Gestion des Connaissances (EGC)", Bruxelles, Belgium, January 2020, https://hal.archives-ouvertes.fr/hal-02410221

[28] A. BAZIN, J. CARBONNEL, M. HUCHARD, G. KAHN, P. KEIP, A. OUZERDINE.*On-demand Relational Concept Analysis*, in "ICFCA: 15th International Conference on Formal Concept Analysis", Frankfurt, Germany, D. CRISTEA, F. LE BER, B. SERTKAYA (editors), Formal Concept Analysis, Springer International Publishing, 2019, vol. 11511, p. 155-172 [*DOI :* 10.1007/978-3-030-21462-3_11], https://hal-lirmm.ccsd.cnrs.fr/lirmm-02092140

[29] V. CODOCEDO, J. BAIXERIES, M. KAYTOUE, A. NAPOLI.*Sampling Representation Contexts with Attribute Exploration*, in "15th International Conference on Formal Concept Analysis", Frankfurt, Germany, D. CRISTEA, F. LE BER, B. SERTKAYA (editors), Proceedings of the 15th International Conference on Formal Concept Analysis (ICFCA 2019), Springer, May 2019, vol. Lecture Notes in Artificial Intelligence, n^{o} 11511, p. 307-314 [*DOI :* 10.1007/978-3-030-21462-3_20], https://hal.inria.fr/hal-02195498

[30] M. COUCEIRO, L. HADDAD, V. LAGERKVIST.*Fine-Grained Complexity of Constraint Satisfaction Problems through Partial Polymorphisms: A Survey (Dedicated to the memory of Professor Ivo Rosenberg)*, in "ISMVL2019 - IEEE 49th International Symposium on Multiple-Valued Logic", Fredericton, NB, Canada, May 2019, https://hal.inria.fr/hal-02190089

[31] M. COUCEIRO, L. HADDAD, M. POUZET.*The mathematics of Ivo Rosenberg (Dedicated to the memory of Professor Ivo Rosenberg)*, in "ISMVL2019 - IEEE 49th International Symposium on Multiple-Valued Logic", Fredericton, NB, Canada, May 2019, p. 43-48, https://hal.inria.fr/hal-02190088

[32] M. COUCEIRO, A. NAPOLI.*Elements About Exploratory, Knowledge-Based, Hybrid, and Explainable Knowledge Discovery*, in "ICFCA 2019 - 15th International Conference on Formal Concept Analysis", Frankfurt, Germany, D. CRISTEA, F. LE BER, B. SERTKAYA (editors), Proceedings of the 15th International Conference on Formal Concept Analysis, Springer, 2019, vol. Lecture Notes in Artificial Intelligence, n^{o} 11511, p. 3-16 [*DOI :* 10.1007/978-3-030-21462-3_1], https://hal.inria.fr/hal-02195480

[33] L. HUBER, Y. TOUSSAINT, C. ROZE, M. DARGNAT, C. BRAUD.*Aligning Discourse and Argumentation Structures using Subtrees and Redescription Mining*, in "6th International Workshop on Argument Mining", Florence, Italy, Proceedings of the 6th Workshop on Argument Mining, August 2019, https://hal.archives-ouvertes.fr/hal-02165048

[34] N. JUNIARTA, M. COUCEIRO, A. NAPOLI.*A Unified Approach to Biclustering Based on Formal Concept Analysis and Interval Pattern Structures*, in "DS 2019 - 22nd International Conference on Discovery Science",

Split, Croatia, Discovery Science - 22nd International Conference, October 2019, https://hal.inria.fr/hal-02266200

[35] T. Makhalova, S. O. Kuznetsov, A. Napoli.*Numerical Pattern Mining Through Compression*, in "DCC 2019 - 2019 Data Compression Conference", Snowbird, United States, IEEE, March 2019, p. 112-121, https://hal.archives-ouvertes.fr/hal-02162927

[36] T. Makhalova, S. O. Kuznetsov, A. Napoli.*On Coupling FCA and MDL in Pattern Mining*, in "The 15th International Conference on Formal Concept Analysis", Frankfurt, Germany, D. Cristea, F. Le Ber, B. Sertkaya (editors), Springer, May 2019, vol. 11511, p. 332-340, https://hal.archives-ouvertes.fr/hal-02162928

[37] T. Makhalova, S. O. Kuznetsov, A. Napoli.*Pattern Mining through compression: towards to probabilistic models*, in "Proceedings of the 17th Russian Conference on Artificial Intelligence", Ulyanovsk, Russia, O. P. Kuznetsov, I. A. Sokolov, S. N. Vasiliev, G. S. Osipov (editors), Proceedings of the 17th Russian Conference on Artificial Intelligence, Yarushkina, Nadezhda G., October 2019, vol. 2, p. 164-172, https://hal.archives-ouvertes.fr/hal-02192794

[38] T. Makhalova, M. Trnecka.*A Study of Boolean Matrix Factorization Under Supervised Settings*, in "ICFCA 2019 - The 15th International Conference on Formal Concept Analysis", Frankfurt, Germany, Springer, May 2019, p. 341-348 [*DOI :* 10.1007/978-3-030-21462-3_24], https://hal.archives-ouvertes.fr/hal-02162929

[39] P. Monnin, C. Raïssi, A. Napoli, A. Coulet.*Knowledge Reconciliation with Graph Convolutional Networks: Preliminary Results*, in "DL4KG2019 - Workshop on Deep Learning for Knowledge Graphs", Portoroz, Slovenia, M. Alam, D. Buscaldi, M. Cochez, F. Osborne, D. R. Recupero, H. Sack (editors), June 2019, vol. CEUR Workshop Proceedings, n^{o} 2377, https://hal.inria.fr/hal-02155546

[40] S. Pfohl, B. Marafino, A. Coulet, F. Rodriguez, L. Palaniappan, N. Shah.*Creating Fair Models of Atherosclerotic Cardiovascular Disease Risk*, in "AIES '19 - Proceedings of the 2019 AAAI/ACM Conference on AI, Ethics, and Society", Honolulu, United States, ACM Press, January 2019, p. 271-278 [*DOI :* 10.1145/3306618.3314278], https://hal.inria.fr/hal-02388730

[41] J. Reynaud, Y. Toussaint, A. Napoli.*Redescription mining for learning definitions and disjointness axioms in Linked Open Data*, in "ICCS 2019 - 24th International Conference on Conceptual Structures", Marburg, Germany, July 2019, https://hal.inria.fr/hal-02170763

[42] *Best Paper*
J. Reynaud, Y. Toussaint, A. Napoli.*Using Redescriptions and Formal Concept Analysis for Mining Definitions Linked Data*, in "ICFCA 2019 - 15th International Conference on Formal Concept Analysis", Francfort, Germany, June 2019, https://hal.inria.fr/hal-02170760.

National Conferences with Proceeding

[43] K. Dalleau, M. Couceiro, M. Smaïl-Tabbone.*Les forêts d'arbres extrêmement aléatoires : utilisation dans un cadre non supervisé*, in "EGC 2019 - 19ème Conférence Francophone sur l'Extraction et Gestion des connaissances", Metz, France, Hermann-Éditions, January 2019, vol. RNTI E-35, p. 395-400, https://hal.inria.fr/hal-02099532

[44] L. HUBER, Y. TOUSSAINT, C. ROZE, M. DARGNAT, C. BRAUD.*Aligning Discourse and Argumentation Structures using Subtrees and Redescription Mining*, in "26èmes Rencontres de la Société Francophone de Classification (SFC)", Nancy, France, Actes des 26èmes Rencontres de la Société Francophone de Classification (SFC), September 2019, https://hal.archives-ouvertes.fr/hal-02266623

[45] N. JUNIARTA, M. COUCEIRO, A. NAPOLI.*Application des Pattern Structures à la découverte de biclusters à changements de signes cohérents*, in "EGC 2019 - 19ème Conférence francophone sur Extraction et Gestion des connaissances", Metz, France, Hermann-Éditions, January 2019, vol. RNTI E-35, p. 285-290, https://hal.inria.fr/hal-02099607

[46] T. MAKHALOVA, S. O. KUZNETSOV, A. NAPOLI.*On Entropy in Pattern Mining*, in "SFC 2019 - XXVIe Rencontres de la Société Francophone de Classification", Nancy, France, September 2019, https://hal.archives-ouvertes.fr/hal-02193296

Conferences without Proceedings

[47] G. ALVES, M. COUCEIRO, A. NAPOLI.*Towards a Constrained Clustering Algorithm Selection*, in "26èmes Rencontres de la Société Francophone de Classification", Nancy, France, M. COUCEIRO, A. NAPOLI (editors), September 2019, vol. Actes des 26èmes Rencontres de la Société Francophone de Classification, https://hal.archives-ouvertes.fr/hal-02397436

[48] T. MAKHALOVA, S. O. KUZNETSOV, A. NAPOLI.*On compression, learning & searching regularity in big data*, in "13es journées scientifiques", Toulon, France, March 2019, https://hal.archives-ouvertes.fr/hal-02162931

[49] A. OUALI, N. JUNIARTA, B. MAIGRET, A. NAPOLI.*A Feature Selection Method based on Tree Decomposition of Correlation Graph*, in "LEG@ECML-PKDD 2019 - The third International Workshop on Advances in Managing and Mining Large Evolving Graphs", Würzburg, Germany, September 2019, https://hal.archives-ouvertes.fr/hal-02194229

Scientific Books (or Scientific Book chapters)

[50] D. ALLOUCHE, S. BARBE, S. DE GIVRY, G. KATSIRELOS, Y. LEBBAH, S. LOUDNI, A. OUALI, T. SCHIEX, D. SIMONCINI, M. ZYTNICKI.*Cost Function Networks to Solve Large Computational Protein Design Problems*, in "Operations Research and Simulation in healthcare", M. MASMOUDI, B. JARBOUI, P. SIARRY (editors), Springer, 2019, forthcoming, https://hal.archives-ouvertes.fr/hal-02177634

[51] M. COUCEIRO, D. DUBOIS, H. FARGIER, M. GRABISCH, H. PRADE, A. RICO.*New directions in ordinal evaluation: Sugeno integrals and beyond*, in "New Perspectives in Multiple Criteria Decision Making", M. DOUMPOS, J. FIGUEIRA, S. GRECO, C. ZOPOUNIDIS (editors), Springer, Cham, April 2019, https://hal.inria.fr/hal-01941776

[52] N. JUNIARTA, M. COUCEIRO, A. NAPOLI.*Order-preserving Biclustering Based on FCA and Pattern Structures*, in "Complex Pattern Mining: New Challenges, Methods and Applications", A. APPICE, M. CECI, C. LOGLISCI, G. MANCO, E. MASCIARI, Z. W. RAS (editors), Springer Series on Studies in Computational Intelligence, 2019, forthcoming, https://hal.inria.fr/hal-02181585

Books or Proceedings Editing

[53] M. Couceiro, A. Napoli (editors). *Société Francophone de Classification (SFC) Actes des 26èmes Rencontres*, Actes des 26èmes Rencontres de la Société Francophone de Classification (SFC), 2019, 147, https://hal.inria.fr/hal-02432406

[54] S. O. Kuznetsov, A. Napoli, S. Rudolph (editors). *Workshop Notes of the Seventh International Workshop "What can FCA do for Artificial Intelligence?"*, CEUR-WS.org, 2019, vol. CEUR Workshop Proceedings 2529, 87, https://hal.inria.fr/hal-02431335

[55] W. M. van der Aalst, V. Batagelj, D. I. Ignatov, M. Khachay, V. Kuskova, A. Kutuzov, S. O. Kuznetsov, I. A. Lomazova, N. Loukachevitch, A. Napoli, P. M. Pardalos, M. Pelillo, A. V. Savchenko, E. Tutubalina. , W. M. van der Aalst, V. Batagelj, I. A. Lomazova, N. Loukachevitch, A. Napoli, P. M. Pardalos, M. Pelillo, A. V. Savchenko, E. Tutubalina, D. I. Ignatov, M. Khachay, M. Khachay, V. Kuskova, A. Kutuzov, S. O. Kuznetsov (editors)*Analysis of Images, Social Networks and Texts*, Lecture Notes in Computer Science, Springer, 2019, vol. 11832, 426 [*DOI :* 10.1007/978-3-030-37334-4], https://hal.inria.fr/hal-02432920

Other Publications

[56] M. Alam, T. A. Ghorfi, E. Agrawal, O. Alqawasmeh, A. Annane, C. d'Amato, A. Azzam, A. Berezovskyi, R. Biswas, M. Bonduel, Q. Brabant, C.-i. Bucur, E. Camossi, V. A. Carriero, S. Chari, D. C. Fraga, F. Ciroku, M. Cochez, V. Cutrona, R. Dandan, P. D. P. Jimnez, D. Dess, V. Di Carlo, A. E. A. Djebri, M. Van Erp, F. M. Falakh, A. F. Izquierdo, G. Futia, A. Gangemi, S. Gasperoni, A. Grall, L. Heling, P.-H. Paris, N. Herradi, S. Issa, S. Jozashoori, N. Juniarta, L.-a. Kaffee, I. Keles, P. Khare, V. Kovtun, V. Leone, S. Li, S. Lieber, P. Lisena, T. Makhalova, L. Marinucci, T. Minier, B. Moreau, A. M. Loustaunau, D. Nandini, S. Ozdowska, A. P. De Moura, S. Padhee, G. Palma, V. Presutti, R. Reda, E. Rizza, H. Rosales-mndez, S. Rudolph, H. Sack, L. Sciullo, H. Simanjuntak, C. Stomeo, T. Thanapalasingam, T. Tietz, D. Varanka, M.-E. Vidal, M. Wolowyk, M. Zocholl.*Linked Open Data Validity – A Technical Report from ISWS 2018*, April 2019, https://arxiv.org/abs/1903.12554 - working paper or preprint, https://hal.inria.fr/hal-02087112

[57] G. Alves, M. Couceiro, A. Napoli.*Similarity Measure Selection for Categorical Data Clustering*, December 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-02399640

[58] Q. Brabant, M. Couceiro, D. Dubois, H. Prade, A. Rico.*Learning rule sets and Sugeno integrals for monotonic classification problems*, December 2019, working paper or preprint, https://hal.inria.fr/hal-02427608

[59] F.-É. Calvier, P. Monnin, M. Boland, P. Jarnot, E. Bresso, M. Smaïl-Tabbone, A. Coulet, C. Bousquet.*Providing Molecular Characterization for Unexplained Adverse Drug Reactions : Podium Abstract*, July 2019, Podium Abstract at MedInfo 2019, Lyon, France, https://hal.inria.fr/hal-02196134

[60] M. Couceiro, J. Devillet, J.-L. Marichal, P. Mathonet.*Reducibity of n-ary semigroups: from quasitriviality towards idempotency*, September 2019, working paper or preprint, https://hal.inria.fr/hal-02293908

[61] K. Dalleau, M. Couceiro, M. Smail-Tabbone.*Computing Vertex-Vertex Dissimilarities Using Random Trees: Application to Clustering in Graphs*, November 2019, working paper or preprint, https://hal.inria.fr/hal-02427563

[62] K. DALLEAU, M. COUCEIRO, M. SMAÏL-TABBONE.*Clustering graphs using random trees*, September 2019, working paper or preprint, https://hal.inria.fr/hal-02282207

[63] K. DALLEAU, M. COUCEIRO, M. SMAÏL-TABBONE.*Unsupervised Extra Trees: a stochastic approach to compute similarities in heterogeneous data*, January 2019, working paper or preprint, https://hal.inria.fr/hal-01982232

[64] E. FIMMEL, C. C. MICHEL, F. PIROT, J.-S. SERENI, L. STRÜNGMANN.*Comma-free Codes Over Finite Alphabets*, November 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-02376793

[65] N. JUNIARTA, V. CODOCEDO, M. COUCEIRO, M. KAYTOUE, A. NAPOLI. , D. CRISTEA, F. LE BER, R. MISSAOUI, L. KWUIDA, B. SERTKAYA (editors)*Pattern Structures for Identifying Biclusters with Coherent Sign Changes*, Proceedings of the 15th International Conference on Formal Concept Analysis (Supplementary Proceedings), June 2019, ICFCA 2019 - 15th International Conference on Formal Concept Analysis, https://hal.inria.fr/hal-02166713

[66] N. JUNIARTA, M. COUCEIRO, A. NAPOLI.*Formal Concept Analysis for Identifying Biclusters with Coherent Sign Changes*, July 2019, working paper or preprint, https://hal.inria.fr/hal-02181600

[67] P. MONNIN.*Discovering and Comparing Relational Knowledge, the Example of Pharmacogenomics*, January 2019, Article in Proceedings of the EKAW Doctoral Consortium 2018 co-located with the 21st International Conference on Knowledge Engineering and Knowledge Management (EKAW 2018), https://hal.inria.fr/hal-01955424

[68] F. PIROT, J.-S. SERENI.*Fractional chromatic number, maximum degree and girth*, November 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-02096426

[69] A. ABBOUD, A. LAHMADI, M. RUSINOWITCH, M. COUCEIRO, A. BOUHOULA.*Minimizing Range Rules for Packet Filtering Using a Double Mask Representation*, May 2019, IFIP Networking 2019, Poster, https://hal.inria.fr/hal-02393008

[70] A. ABBOUD, A. LAHMADI, M. RUSINOWITCH, M. COUCEIRO, A. BOUHOULA, S. E. H. AWAINIA, M. AYADI.*Minimizing Range Rules for Packet Filtering Using Double Mask Representation*, April 2019, working paper or preprint, https://hal.inria.fr/hal-02102225

References in notes

[71] C. C. AGGARWAL, C. ZHAI (editors). *Mining Text Data*, Springer, 2012

[72] F. BAADER, D. CALVANESE, D. MCGUINNESS, D. NARDI, P. PATEL-SCHNEIDER (editors). *The Description Logic Handbook*, Cambridge University Press, Cambridge, UK, 2003

[73] M. ALAM, A. BUZMAKOV, V. CODOCEDO, A. NAPOLI.*Mining Definitions from RDF Annotations Using Formal Concept Analysis*, in "International Joint Conference in Artificial Intelligence", Buenos Aires, Argentina, Proceedings of the Twenty-Fourth International Joint Conference on Artificial Intelligence, July 2015, https://hal.archives-ouvertes.fr/hal-01186204

[74] M. ALAM, A. BUZMAKOV, A. NAPOLI.*Exploratory Knowledge Discovery over Web of Data*, in "Discrete Applied Mathematics", 2017, p. 1-25, forthcoming, https://hal.inria.fr/hal-01673439

[75] M. ALAM, T. N. N. LE, A. NAPOLI.*LatViz: A New Practical Tool for Performing Interactive Exploration over Concept Lattices*, in "CLA 2016 - Thirteenth International Conference on Concept Lattices and Their Applications", Moscow, Russia, July 2016, https://hal.inria.fr/hal-01420751

[76] M. ATENCIA, J. DAVID, J. EUZENAT.*Data interlinking through robust linkkey extraction*, in "Proceedings of the 21st European Conference on Artificial Intelligence (ECAI)", T. SCHAUB, G. FRIEDRICH, B. O'SULLIVAN (editors), IOS Press, 2014, p. 15–20, ftp://ftp.inrialpes.fr/pub/exmo/publications/atencia2014b.pdf

[77] J. BAIXERIES, V. CODOCEDO, M. KAYTOUE, A. NAPOLI.*Characterizing Approximate-Matching Dependencies in Formal Concept Analysis with Pattern Structures*, in "Discrete Applied Mathematics", 2018, vol. 249, p. 18-27 [*DOI :* 10.1016/J.DAM.2018.03.073], https://hal.inria.fr/hal-01673441

[78] J. CANO, P. GUTIÉRREZ, B. KRAWCZYK, M. WOZNIAK, S. GARCÍA.*Monotonic classification: An overview on algorithms, performance measures and data sets*, in "Neurocomputing", 2019, vol. 341, p. 168–182

[79] S. DA SILVA, F. LE BER, C. LAVIGNE.*Structures de haies dans un paysage agricole : une étude par chemin de Hilbert adaptatif et chaînes de Markov* , in "EGC 2016 – 16èemes Journées Francophones ”Extraction et Gestion des Connaissances”", Reims, France, Revue des Nouvelles Technologies de l'Information, January 2016, vol. RNTI-E-30, p. 279–290, https://hal.archives-ouvertes.fr/hal-01266344

[80] B. GANTER, S. O. KUZNETSOV.*Pattern Structures and Their Projections*, in "Proceedings of ICCS 2001", LNCS 2120, Springer, 2001, p. 129–142

[81] M. GRABISCH, J.-L. MARICHAL, R. MESIAR, E. PAP.*Aggregation Functions*, Encyclopedia of Mathematics and its Applications, Cambridge University Press, 2009

[82] O. HUDRY, B. MONJARDET.*Consensus Theories. An oriented survey*, in "Mathématiques et Sciences Humaines", 2010, vol. 190, n^{o} 2, p. 139–167

[83] N. JUNIARTA, M. COUCEIRO, A. NAPOLI, C. RAÏSSI.*Sequence Mining within Formal Concept Analysis for Analyzing Visitor Trajectories*, in "SMAP 2018 - 13th International Workshop on Semantic and Social Media Adaptation and Personalization", Zaragoza, Spain, September 2018, https://hal.inria.fr/hal-01887927

[84] N. JUNIARTA, M. COUCEIRO, A. NAPOLI, C. RAÏSSI.*Sequential Pattern Mining using FCA and Pattern Structures for Analyzing Visitor Trajectories in a Museum*, in "CLA 2018 - The 14th International Conference on Concept Lattices and Their Applications", Olomouc, Czech Republic, June 2018, https://hal.inria.fr/hal-01887914

[85] M. KAYTOUE, S. O. KUZNETSOV, A. NAPOLI, S. DUPLESSIS.*Mining gene expression data with pattern structures in formal concept analysis*, in "Information Sciences", 2011, vol. 181, n^{o} 10, p. 1989-2001, https://hal.archives-ouvertes.fr/hal-00541100

[86] J.-F. MARI, A. GOBILLOT, M. BENOÎT.*Time Space Simulation of Land Use changes by stochastic modeling*, in "Revue Internationale de Géomatique", August 2018, vol. 28, n^{o} 2, p. 219–242, https://hal.inria.fr/hal-01662140

[87] J.-P. METIVIER, A. LEPAILLEUR, A. BUZMAKOV, G. POEZEVARA, B. CRÉMILLEUX, S. O. KUZNETSOV, J. LE GOFF, A. NAPOLI, R. BUREAU, B. CUISSART.*Discovering structural alerts for mutagenicity using*

stable emerging molecular patterns, in "Journal of Chemical Information and Modeling", 2015, vol. 55, n^{o} 5, p. 925–940 [*DOI :* 10.1021/CI500611V], https://hal.archives-ouvertes.fr/hal-01186716

[88] G. PERSONENI, M.-D. DEVIGNES, M. SMAÏL-TABBONE, P. JONVEAUX, C. BONNET, A. COULET.*Cooperation of bio-ontologies for the classification of genetic intellectual disabilities : a diseasome approach*, in "Proceedings of the 11th International Conference on Semantic Web Applications and Tools for Healthcare and Life Sciences (SWAT4HCLS 2018)", Antwerp, Belgium, December 2018, https://hal.inria.fr/hal-01925471

[89] N. RAMAKRISHNAN, D. KUMAR, B. MISHRA, M. POTTS, R. F. HELM.*Turning CARTwheels: An Alternating Algorithm for Mining Redescriptions*, in "Proceedings of the Tenth ACM SIGKDD International Conference on Knowledge Discovery and Data Mining", New York, NY, USA, KDD '04, ACM, 2004, p. 266–275

[90] M. ROUANE-HACENE, M. HUCHARD, A. NAPOLI, P. VALTCHEV.*Relational Concept Analysis: Mining Concept Lattices From Multi-Relational Data*, in "Annals of Mathematics and Artificial Intelligence", January 2013, vol. 67, n^{o} 1, p. 81-108 [*DOI :* 10.1007/S10472-012-9329-3], http://hal.inria.fr/lirmm-00816300

Project-Team PESTO

Proof techniques for security protocols

IN COLLABORATION WITH: Laboratoire lorrain de recherche en informatique et ses applications (LORIA)

IN PARTNERSHIP WITH:
CNRS

Université de Lorraine

RESEARCH CENTER
Nancy - Grand Est

THEME
Security and Confidentiality

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Project-Team PESTO

Creation of the Team: 2016 January 01, updated into Project-Team: 2016 November 01

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A4.6. - Authentication
A4.8. - Privacy-enhancing technologies
A7.1. - Algorithms
A7.2. - Logic in Computer Science

Other Research Topics and Application Domains:

B6.3.2. - Network protocols
B6.3.4. - Social Networks
B6.6. - Embedded systems
B9.10. - Privacy

1. Team, Visitors, External Collaborators

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2. Overall Objectives

2.1. Context

The rise of the Internet and the ubiquity of electronic devices have changed our way of life. Many face to face and paper transactions have nowadays digital counterparts: home banking, electronic commerce, e-voting, ... and even partially our social life. This digitalisation of the world comes with tremendous risks for our security and privacy as illustrated by the following examples.

Financial transactions. According to the FEVAD (French federation of remote selling and e-commerce), in France 51.1 billion euros have been spent through e-commerce in 2013 and fraud is estimated to 1.9 billion euros by certissim. [0] As discussed in another white paper [0] by Dave Marcus (Director of Advanced Research and Threat Intelligence, McAfee) and Ryan Sherstobitoff (Threat Researcher, Guardian Analytics) bank fraud has changed dramatically. Fraudsters are aiming to steal increasingly higher amounts from bank accounts (with single transfers over 50,000 euros) and develop fully automated attack tools to do so. As a consequence, protocols need to implement more advanced, multi-factor authentication methods.

Electronic voting. In the last few years several European countries (Estonia, France, Norway and Switzerland) organised *legally binding political elections* that allowed (part of the) voters to cast their votes remotely via the Internet. For example, in June 2012 French people living abroad ("expats") were allowed to vote via the Internet for parliament elections. An engineer demonstrated that it was possible to write a malware that could change the value of a cast vote without any way for the voter to notice. [0] In Estonia in the 2011 parliament election, a similar attack was reported by computer scientist Paavo Pihelgas who conducted a real life experiment with aware consenting test subjects. [0]

Privacy violations. Another security threat is the violation of an individual person's privacy. For instance the use of radio-frequency identification (RFID) technology can be used to trace persons, e.g. in automatic toll-paying devices [0] or in public transportation. Even though security protocols are deployed to avoid tracing by third parties, protocol design errors enabled tracing of European e-passports. [0] Recently, a flaw was identified in the 3G mobile phone protocols that allows a third party, i.e., not only the operator, to trace telephones [39]. Also, anonymised data of social networks has been effectively used to identify persons by comparing data from several social networks. [0]

2.2. Objectives

The aim of the Pesto project is to build formal models and techniques, for computer-aided analysis and design of security protocols (in a broad sense). While historically the main goals of protocols were confidentiality and authentication, the situation has changed. E-voting protocols need to guarantee privacy of votes, while ensuring transparency of the election; electronic devices communicate data by the means of web services; RFID and mobile phone protocols must guarantee that people cannot be traced. Due to malware, security protocols must rely on additional mechanisms, such as trusted hardware components or multi-factor authentication, to guarantee security even if the computing platform is a priori untrusted. Currently existing techniques and tools are however unable to analyse the properties required by these new protocols and to take the newly deployed mechanisms and associated attacker models into account.

[0] Livre Blanc : La fraude dans le e-commerce, certissim.
[0] Dissecting Operation High Roller. https://en.wikipedia.org/wiki/Operation_High_Roller
[0] A video explaining the attack is available at http://www.youtube.com/watch?v=AsvLxY478xc
[0] The Supreme Court dismissed an electoral complaint regarding e-voting security. http://www.nc.ee/?id=1235
[0] A Pass on Privacy? The New York Times, July 17, 2005. http://www.nytimes.com/2005/07/17/magazine/17WWLN.html
[0] Defects in e-passports allow real-time tracking. The Register, January 26, 2010. http://www.theregister.co.uk/2010/01/26/epassport_rfid_weakness/
[0] Social sites dent privacy efforts. BBC, March 27, 2009. http://news.bbc.co.uk/2/hi/technology/7967648.stm

3. Research Program

3.1. Modelling

Before being able to analyse and properly design security protocols, it is essential to have a model with a precise semantics of the protocols themselves, the attacker and its capabilities, as well as the properties a protocol must ensure.

Most current languages for protocol specification are quite basic and do not provide support for global state, loops, or complex data structures such as lists, or Merkle trees. As an example we may cite Hardware Security Modules that rely on a notion of *mutable global state* which does not arise in traditional protocols, see e.g. the discussion by Herzog [53].

Similarly, the properties a protocol should satisfy are generally not precisely defined, and stating the "right" definitions is often a challenging task in itself. In the case of authentication, many protocol attacks were due to the lack of a precise meaning, cf. [52]. While the case of authentication has been widely studied, the recent digitalisation of all kinds of transactions and services, introduces a plethora of new properties, including for instance anonymity in e-voting, untraceability of RFID tokens, verifiability of computations that are out-sourced, as well as sanitisation of data in social networks. We expect that many privacy and anonymity properties may be modelled as particular observational equivalences in process calculi [48], or indistinguishability between cryptographic games [3]; sanitisation of data may also rely on information-theoretic measures.

We also need to take into account that the attacker model changes. While historically the attacker was considered to control the communication network, we may nowadays argue that even (part of) the host executing the software may be compromised through, e.g., malware. This situation motivates the use of secure elements and multi-factor authentication with out-of-band channels. A typical example occurs in e-commerce: to validate an online payment a user needs to enter an additional code sent by the bank via SMS to the user's mobile phone. Such protocols require the possession of a physical device in addition to the knowledge of a password which could have been leaked on an untrusted platform. The fact that data needs to be copied by a human requires these data to be *short*, and hence amenable to brute-force attacks by an attacker or guessing.

3.2. Analysis

3.2.1. Generic proof techniques

Most automated tools for verifying security properties rely on techniques stemming from automated deduction. Often existing techniques do however not apply directly, or do not scale up due to state explosion problems. For instance, the use of Horn clause resolution techniques requires dedicated resolution methods [41] [44]. Another example is unification modulo equational theory, which is a key technique in several tools, e.g. [51]. Security protocols however require to consider particular equational theories that are not naturally studied in classical automated reasoning. Sometimes, even new concepts have been introduced. One example is the finite variant property [46], which is used in several tools, e.g., *Akiss* [44], Maude-NPA [51] and Tamarin [54]. Another example is the notion of asymmetric unification [50] which is a variant of unification used in Maude-NPA to perform important *syntactic* pruning techniques of the search space, even when reasoning modulo an equational theory. For each of these topics we need to design efficient decision procedures for a variety of equational theories.

3.2.2. Dedicated procedures and tools

We design dedicated techniques for automated protocol verification. While existing techniques for security protocol verification are efficient and have reached maturity for verification of confidentiality and authentication properties (or more generally safety properties), our goal is to go beyond these properties and the standard attacker models, verifying the properties and attacker models identified in Section 3.1. This includes techniques that:

- can analyse *indistinguishability* properties, including for instance anonymity and unlinkability properties, but also properties stated in simulation-based (also known as universally composable) frameworks, which express the security of a protocol as an ideal (correct by design) system;
- take into account protocols that rely on a notion of *mutable global state* which does not arise in traditional protocols, but is essential when verifying tamper-resistant hardware devices, e.g., the RSA PKCS#11 standard, IBM's CCA and the trusted platform module (TPM);
- consider attacker models for protocols relying on *weak secrets* that need to be copied or remembered by a human, such as multi-factor authentication.

These goals are beyond the scope of most current analysis tools and require both theoretical advances in the area of verification, as well as the design of new efficient verification tools.

3.3. Design

Given our experience in formal analysis of security protocols, including both protocol proofs and finding of flaws, it is tempting to use our experience to design protocols with security in mind and security proofs. This part includes both provably secure design techniques, as well as the development of new protocols.

3.3.1. General design techniques

Design techniques include *composition results* that allow one to design protocols in a modular way [47], [45]. Composition results come in many flavours: they may allow one to compose protocols with different objectives, e.g. compose a key exchange protocol with a protocol that requires a shared key or rely on a protocol for secure channel establishment, compose different protocols in parallel that may re-use some key material, or compose different sessions of the same protocol.

Another area where composition is of particular importance is Service Oriented Computing, where an "orchestrator" must combine some available component services, while guaranteeing some security properties. In this context, we work on the automated synthesis of the orchestrator or monitors for enforcing the security goals. These problems require the study of new classes of automata that communicate with structured messages.

3.3.2. New protocol design

We also design new protocols. Application areas that seem of particular importance are:

- External hardware devices such as security APIs that allow for flexible key management, including key revocation, and their integration in security protocols. The security *fiasco* of the PKCS#11 standard [43], [49] witnesses the need for new protocols in this area.
- Election systems that provide strong security guarantees. We have been working (in collaboration with the Caramba team) on a prototype implementation of an e-voting system, Belenios (http://belenios.gforge.inria.fr).
- Mechanisms for publishing personal information (e.g. on social networks) in a controlled way.

4. Application Domains

4.1. Cryptographic protocols

Security protocols, such as TLS, Kerberos, ssh or AKA (mobile communication), are the main tool for securing our communications. The aim of our work is to improve their security guarantees. For this, we propose models that are expressive enough to formally represent protocol executions in the presence of an adversary, formal definitions of the security properties to be satisfied by these protocols, and automated tools able to analyse them and possibly exhibit design flaws.

4.2. Automated reasoning

Many techniques for symbolic verification of security are rooted in automated reasoning. A typical example is equational reasoning used to model the algebraic properties of a cryptographic primitive. Our work therefore aims to improve and adapt existing techniques or propose new ones when needed for reasoning about security.

4.3. Electronic voting

Electronic elections have in the last years been used in several countries for politically binding elections. The use in professional elections is even more widespread. The aim of our work is to increase our understanding of the security properties needed for secure elections, propose techniques for analysing e-voting protocols, design of state-of-the-art voting protocols, but also to highlight the limitations of e-voting solutions.

4.4. Privacy in social networks

The treatment of information released by users on social networks can violate a user's privacy. The goal of our work is to allow users to control the information released while guaranteeing their privacy.

5. Highlights of the Year

5.1. Highlights of the Year

5.1.1. Awards

Itsaka Rakotonirina was awarded a Google PhD fellowship in Security and Privacy.

Steve Kremer was granted an ANR Chair of research and teaching in artificial intelligence: ASAP – Tools for automated, symbolic analysis of real-world cryptographic protocols.

6. New Software and Platforms

6.1. Akiss

AKISS - Active Knowledge in Security Protocols

KEYWORDS: Security - Verification

FUNCTIONAL DESCRIPTION: AKISS (Active Knowledge in Security Protocols) is a tool for verifying indistinguishability properties in cryptographic protocols, modelled as trace equivalence in a process calculus. Indistinguishability is used to model a variety of properties including anonymity properties, strong versions of confidentiality and resistance against offline guessing attacks, etc. AKISS implements a procedure to verify equivalence properties for a bounded number of sessions based on a fully abstract modelling of the traces of a bounded number of sessions of the protocols into first-order Horn clauses and a dedicated resolution procedure. The procedure can handle a large set of cryptographic primitives, namely those that can be modeled by an optimally reducing convergent rewrite system, as well as the exclusive or (xor) operator.

- Contact: Steve Kremer
- URL: https://github.com/akiss

6.2. Belenios

Belenios - Verifiable online voting system

KEYWORD: E-voting

FUNCTIONAL DESCRIPTION: Belenios is an open-source online voting system that provides confidentiality and verifiability. End-to-end verifiability relies on the fact that the ballot box is public (voters can check that their ballots have been received) and on the fact that the tally is publicly verifiable (anyone can recount the votes). Confidentiality relies on the encryption of the votes and the distribution of the decryption key.

Belenios builds upon Helios, a voting protocol used in several elections. The main design enhancement of Belenios vs. Helios is that the ballot box can no longer add (fake) ballots, due to the use of credentials. Moreover, Belenios includes a practical threshold decryption system that allows splitting the decryption key among several authorities.

NEWS OF THE YEAR: Since 2015, it has been used by CNRS for remote election among its councils (more than 30 elections every year) and since 2016, it has been used by Inria to elect representatives in the “comités de centre” of each Inria center. In 2018, it has been used to organize about 250 elections (not counting test elections). Belenios is typically used for elections in universities as well as in associations. This goes from laboratory councils (e.g. Irisa, Cran), scientific societies (e.g. SMAI) to various associations (e.g. FFBS - Fédération Française de Baseball et Softball, or SRFA - Société du Rat Francophone et de ses Amateurs).

In 2019, a threshold encryption mode has been added that makes the system more robust to the case where (say) one trustee among three loses her part of the decryption key.

- Participants: Pierrick Gaudry, Stéphane Glondu and Véronique Cortier
- Partners: CNRS - Inria
- Contact: Stéphane Glondu
- URL: http://www.belenios.org/

6.3. Deepsec

DEEPSEC - DEciding Equivalence Properties in SECurity protocols

KEYWORDS: Security - Verification

FUNCTIONAL DESCRIPTION: DEEPSEC (DEciding Equivalence Properties in SECurity protocols) is a tool for verifying indistinguishability properties in cryptographic protocols, modelled as trace equivalence in a process calculus. Indistinguishability is used to model a variety of properties including anonymity properties, strong versions of confidentiality and resistance against offline guessing attacks, etc. DEEPSEC implements a decision procedure to verify trace equivalence for a bounded number of sessions and cryptographic primitives modeled by a subterm convergent destructor rewrite system. The procedure is based on constraint solving techniques. The tool also implements state-of-the-art partial order reductions and allows to distribute the computation on multiple cores and multiple machines.

NEWS OF THE YEAR: In 2019, to improve efficiency for non-determinate processes, we developed new optimisation techniques. This is achieved through a new, stronger equivalence for which partial-order reductions are sound even for non-determinate processes, as well as new symmetry reductions. We demonstrated that these techniques provide a significant (several orders of magnitude) speed-up in practice, thus increasing the size of the protocols that can be analysed fully automatically. Even though the new equivalence is stronger, it is nevertheless coarse enough to avoid false attacks on most practical examples.

- Participants: Steve Kremer, Itsaka Rakotonirina and Vincent Cheval
- Contact: Vincent Cheval
- Publications: Exploiting Symmetries When Proving Equivalence Properties for Security Protocols - Exploiting symmetries when proving equivalence properties for security protocols (Technical report) - DEEPSEC: Deciding Equivalence Properties in Security Protocols Theory and Practice - DEEPSEC: Deciding Equivalence Properties in Security Protocols - Theory and Practice - The DEEPSEC prover
- URL: https://deepsec-prover.github.io/

6.4. Tamarin

TAMARIN prover

KEYWORDS: Security - Verification

FUNCTIONAL DESCRIPTION: The TAMARIN prover is a security protocol verification tool that supports both falsification and unbounded verification of security protocols specified as multiset rewriting systems with respect to (temporal) first-order properties and a message theory that models Diffie-Hellman exponentiation, bilinear pairing, multisets, and exclusive-or (XOR), combined with a user-defined convergent rewriting theory. Its main advantages are its ability to handle stateful protocols and its interactive proof mode. Moreover, it has been extended to verify equivalence properties. The tool is developed jointly by the PESTO team, the Institute of Information Security at ETH Zurich, and the University of Oxford. In a joint effort, the partners wrote and published a user manual in 2016, available from the Tamarin website.

- Contact: Jannik Dreier
- URL: http://tamarin-prover.github.io/

6.5. SAPIC

SAPIC: Stateful Applied Pi Calculus

KEYWORDS: Security - Verification

FUNCTIONAL DESCRIPTION: SAPIC is a plugin of the TAMARIN tool that translates protocols from a high-level protocol description language akin to the applied pi-calculus into multiset rewrite rules, that can then be analysed by the TAMARIN prover. TAMARIN has also been extended with dedicated heuristics that exploit the form of translated rules and favor termination.

SAPIC offers support for the analysis of protocols that include states, for example Hardware Security Tokens communicating with a possibly malicious user, or protocols that rely on databases. It also allows us to verify liveness properties and a notion of location and reporting used for modelling trusted execution environments. It has been successfully applied to several case studies including the Yubikey authentication protocol, and extensions of the PKCS#11 standard. SAPIC also includes support for verifying liveness properties, which are for instance important in fair exchange and contract signing protocols, as well as support for constructions useful when modelling isolated execution environments.

- Contact: Steve Kremer
- URL: http://sapic.gforge.inria.fr/

6.6. TypeEquiv

A type checker for privacy properties

KEYWORDS: Security - Cryptographic protocol - Privacy

FUNCTIONAL DESCRIPTION: TypeEquiv provides a (sound) type system for proving equivalence of protocols (to analyse privacy properties such as vote privacy, anonymity, unlinkability), for both a bounded or an unbounded number of sessions and for the standard cryptographic primitives. TypeEquiv takes as input the specification of a pair of security protocols, written in a dialect of the applied-pi calculus, together with some type annotations. It checks whether the two protocols are in equivalence or not. The tool provides a significant speed-up compared with tools that decide equivalence of security protocols for a bounded number of sessions.

- Partner: Technische Universität Wien
- Contact: Véronique Cortier

7. New Results

7.1. Security protocols

7.1.1. Analysis of Equivalence Properties

Participants: Vincent Cheval, Véronique Cortier, Ivan Gazeau, Steve Kremer, Itsaka Rakotonirina, Christophe Ringeissen.

Automatic tools based on symbolic models have been successful in analyzing security protocols. These tools are particularly well adapted for trace properties (e.g. secrecy or authentication). A wide range of security properties, such as anonymity properties in electronic voting and auctions, unlinkability in RFID protocols and mobile phone protocols, are however naturally expressed in terms of indistinguishability, which is not a trace property. Indistinguishability is naturally formalized as an observational or trace equivalence in cryptographic process calculi, such as the applied pi calculus. While several decision procedures have already been proposed for verifying equivalence properties the resulting tools are often rather limited, and lack efficiency.

Our results are centered around the development of several, complementary verification tools for verifying equivalence properties. These tools are complementary in terms of expressivity, precision and efficiency.

- The *Akiss* tool provides good expressivity as it supports a large number of cryptographic primitives (including the XOR primitive, extremely popular in low energy devices such as RFID tags) and protocols with else branches. It allows verification for a bounded number of protocol sessions. The tool is precise for a class of determinate processes, and can approximate equivalence for other protocols. The tool however suffers from efficiency problems when the number of sessions increases. The computation can be partially distributed on different cores. To overcome these efficiency problems of the *Akiss* tool, Gazeau and Kremer completely revisit the theory underlying *Akiss*. Rather than enumerating the possible traces, the new version directly reasons about partial ordered traces. A new implementation is also in progress and the first results seem extremely promising.
- The DEEPSEC tool is a recent tool that allows for user-defined cryptographic primitives that can be modelled as a subterm convergent rewrite system (slightly more restricted than AKISS), but supports the whole applied pi calculus, except for bounding the number of sessions. It is precise, in that it decides equivalence (without any approximations) and has good efficiency (slightly less than SAT-Equiv) for the class of determinate processes (where partial order reductions apply). To improve efficiency for non-determinate processes, Cheval, Kremer and Rakotonirina [21] develop new optimisation techniques. This is achieved through a new, stronger equivalence for which partial-order reductions are sound even for non-determinate processes, as well as new symmetry reductions. They demonstrate that these techniques provide a significant (several orders of magnitude) speed-up in practice, thus increasing the size of the protocols that can be analysed fully automatically. Even though the new equivalence is stronger, it is nevertheless coarse enough to avoid false attacks on most practical examples.
- The SAT-Equiv tool relies on a “small-attack property”: if there is an attack against trace equivalence, then there is a well-typed attack, that is an attack where the messages follow some a priori given structure. This allows to dramatically reduce the search space. We have recently extended [11] this approach to a class of equational theory, that encompasses all standard cryptographic primitives (including e.g. randomized encryption) as well as theories that are less considered by automatic tools, such as threshold decryption. This result will allow to further extend the SAT-Equiv tool but can also be used more generally to characterize the form of an attack, independently of the considered tool.

From a more foundational point of view, in collaboration with Erbatur (LMU, Germany) and Marshall (Univ Mary Washington, USA), Ringeissen studies decision procedures for the intruder deduction and the static equivalence problems in combinations of subterm convergent rewrite systems and syntactic theories for which it is possible to apply a mutation principle to simplify equational proofs. As a continuation of a work initially presented at UNIF'18, it has been shown that a matching property is applicable to solve both intruder deduction and static equivalence. This matching property can be satisfied when using a matching algorithm known for syntactic theories [29]. A journal paper reporting this result is currently under review.

7.1.2. Decision Procedures for Equational Theories

Participants: Christophe Ringeissen, Michaël Rusinowitch.

Equational theories and unification procedures are widely used in protocol analyzers to model the capabilities of a (passive) intruder. In the context of protocol analysis, many equational theories of practical interest satisfy the finite variant property. This class of theories is indeed a class of syntactic theories admitting a terminating mutation-based unification algorithm. This mutation-based unification algorithm generalizes the syntactic unification algorithm known for the empty theory. In collaboration with Erbatur (LMU, Germany) and Marshall (Univ Mary Washington, USA), this particular unification algorithm has been applied by Ringeissen to get new non-disjoint combination results for the unification problem [23], [32].

In collaboration with Anantharaman (LIFO, Orléans), Hibbs (SUNY Albany & Google, USA), and Narendran (SUNY Albany, USA), Rusinowitch has studied the unification problem in list theories. Decision procedures for various list theories have been investigated in the literature with applications to automated verification. In [17], it has been shown that the unifiability problem for some list theories with a *reverse* operator is NP-complete. A unifiability algorithm is given for the case where the theories are extended with a *length* operator on lists.

Among theories with the finite variant property, the class of theories presented by subterm convergent rewrite systems is particularly remarkable because it satisfies in addition a locality property. For this class of theories, it is thus possible to get a satisfiability procedure based on a reduction to the empty theory via an instantiation with the finitely many terms occurring in the input problem. As an alternative to locality, Ringeissen has investigated a politeness property, in collaboration with Chocron (Insikt Intelligence, Spain) and Fontaine (Veridis project-team). This approach has led to new non-disjoint combination results for the satisfiability problem modulo data structure theories extended with some bridging functions such as the *length* operator on lists [10], [26].

7.1.3. Recast of ProVerif

Participants: Vincent Cheval, Véronique Cortier.

Motivated by the addition of global states in ProVerif, we have started a major revision of the popular tool ProVerif. This revision goes well beyond global states and is conducted in collaboration with Bruno Blanchet, the original and main developer of ProVerif. One of the first main changes is the addition of ProVerif of the notion of "lemmas" and "axioms" that can be added to either encode additional properties (axioms) or help ProVerif to prove the desired properties. It is indeed now possible to specify lemmas, that will significantly reduce the number of considered clauses in the saturation procedure of ProVerif. These lemmas should of course be proved themselves by ProVerif, possibly by induction thanks to a particular care of the order of literals in the saturation procedure. The new approach provides more flexibility in cases where ProVerif was not able to terminate or yield false attacks (e.g. in the presence of global states).

Moreover, even when ProVerif is able to prove security, the tool is suffering from efficiency issues when applied to complex industrial protocols (up to 1 month running time for the analysis of the NoiseExplorer protocol). One reason is the subsumption procedure: a clause shall not be added if it is subsumed by another one (that is, if there exists a more general clause). This is crucial to avoid running into non termination issues. We have started a major rewrite of the subsumption procedure, taking advantage of the recent progress in this domain, in the automated deduction area. Another reason is the translation of processes into Horn clauses: For each conditional in the process, ProVerif generates a Horn clause for each possible result of this conditional.

On complex protocols with many interleaved conditionals, ProVerif is faced with an exponential blowup in the number of generated clauses. We have improved the generation of Horn clauses by avoiding exploring branches that would directly be subsumed by other conditional branches. The first experimental results show significant speed-up on many examples: On average, ProVerif is now 5 to 10 times faster than its current release, with some examples peaking at 50 to 200 times speedup.

7.1.4. Verification of Protocols with Global States

Participants: Jannik Dreier, Lucca Hirschi.

The *TAMARIN* prover is a state-of-the-art verification tool for cryptographic protocols in the symbolic model. Dreier, in collaboration with Hirschi, Sasse (ETH Zurich), and Radomirovic (Dundee), improved the underlying theory and the tool to deal with an equational theory modeling XOR operations. Exclusive-or (XOR) operations are common in cryptographic protocols, in particular in RFID protocols and electronic payment protocols. Although there are numerous applications, due to the inherent complexity of faithful models of XOR, there is only limited tool support for the verification of cryptographic protocols using XOR. This makes *TAMARIN* the first tool to support simultaneously this large set of equational theories, protocols with global mutable state, an unbounded number of sessions, and complex security properties including observational equivalence. We demonstrated the effectiveness of our approach by analyzing several protocols that rely on XOR, in particular multiple RFID-protocols, where we can identify attacks as well as provide proofs. These results were presented at CSF'18, an extended version was accepted in the Journal of Computer Security [12].

7.1.5. Symbolic Methods in Computational Cryptography Proofs

Participants: Charlie Jacomme, Steve Kremer.

Code-based game-playing is a popular methodology for proving the security of cryptographic constructions and side-channel countermeasures. This methodology relies on treating cryptographic proofs as an instance of relational program verification (between probabilistic programs), and decomposing the latter into a series of elementary relational program verification steps. Barthe (MPI on Security and Privacy, Bochum), Grégoire (Inria SAM), Jacomme, Kremer and Strub (LIX, École Polytechnique) develop principled methods for proving such elementary steps for probabilistic programs that operate over finite fields and related algebraic structures. They focus on three essential properties: program equivalence, information flow, and uniformity. We give characterizations of these properties based on deducibility and other notions from symbolic cryptography. They use (sometimes improve) tools from symbolic cryptography to obtain decision procedures or sound proof methods for program equivalence, information flow, and uniformity. Finally, they evaluate their approach using examples drawn from provable security and from side-channel analysis - for the latter, they focus on the masking countermeasure against differential power analysis. A partial implementation of our approach is integrated in EasyCrypt, a proof assistant for provable security, and in MaskVerif, a fully automated prover for masked implementations. This work was presented at CSF [18].

7.1.6. Analysis of Deployed Protocols

Participants: Sergiu Bursuc, Lucca Hirschi, Steve Kremer.

7.1.6.1. New Privacy Threat on 3G, 4G, and Upcoming 5G AKA Protocols

Mobile communications are used by more than two-thirds of the world population who expect security and privacy guarantees. The 3rd Generation Partnership Project (3GPP) responsible for the worldwide standardization of mobile communication has designed and mandated the use of the AKA protocol to protect the subscribers' mobile services. Even though privacy was a requirement, numerous subscriber location attacks have been demonstrated against AKA, some of which have been fixed or mitigated in the enhanced AKA protocol designed for 5G.

We found and reported [9] a new privacy attack against all variants of the AKA protocol, including 5G AKA, that breaches subscriber privacy more severely than known location privacy attacks do. Our attack exploits a new logical vulnerability we uncovered that would require dedicated fixes. We demonstrate the practical feasibility of our attack using low cost and widely available setups. Finally we conduct a security analysis of the vulnerability and discuss countermeasures to remedy our attack.

Our attack has later been considered to be a *key issue in 5G* [38] by 3GPP [0]. Since then, various vendors[0] have proposed countermeasures, which are currently under discussion.

7.1.6.2. Contingent Payments

Bursuc and Kremer study protocols that rely on a public ledger infrastructure, concentrating on protocols for zero-knowledge contingent payment, whose security properties combine diverse notions of fairness and privacy. They argue that rigorous models are required for capturing the ledger semantics, the protocol-ledger interaction, the cryptographic primitives and, ultimately, the security properties one would like to achieve. Our focus is on a particular level of abstraction, where network messages are represented by a term algebra, protocol execution by state transition systems (e.g. multiset rewrite rules) and where the properties of interest can be analyzed with automated verification tools. They propose models for: (1) the rules guiding the ledger execution, taking the coin functionality of public ledgers such as Bitcoin as an example; (2) the security properties expected from ledger-based zero-knowledge contingent payment protocols; (3) two different security protocols that aim at achieving these properties relying on different ledger infrastructures; (4) reductions that allow simpler term algebras for homomorphic cryptographic schemes. Altogether, these models allow us to derive a first automated verification for ledger-based zero-knowledge contingent payment using the Tamarin prover. Furthermore, our models help in clarifying certain underlying assumptions, security and efficiency tradeoffs that should be taken into account when deploying protocols on the blockchain. This work was presented at ESORICS [20].

7.2. E-voting

7.2.1. Definitions for E-Voting

Participants: Sergiu Bursuc, Véronique Cortier, Steve Kremer, Joseph Lallemand.

Existing formal (computational) definitions for privacy in electronic voting make the assumption that the bulletin board which collects the votes behaves honestly: the only ballots on the board are created by voters, all ballots are placed without tampering with them, and no ballots are ever removed. This strong assumption is difficult to enforce in practice and whenever it does not hold vote privacy can be broken. As a consequence, voting schemes are proved secure only against an honest voting server while they are designed and claimed to resist a dishonest one. We have proposed a framework for the analysis of electronic voting schemes in the presence of malicious bulletin boards. We identify a spectrum of notions where the adversary is allowed to tamper with the bulletin board in ways that reflect practical deployment and usage considerations. To clarify the security guarantees provided by the different notions we establish a relationship with simulation-based security with respect to a family of ideal functionalities. The ideal functionalities make clear the set of authorised attacker capabilities which makes it easier to understand and compare the associated levels of security. We then leverage this relationship to show that each distinct level of ballot privacy entails some distinct form of individual verifiability. As an application, we have studied three protocols of the literature (Helios, Belenios, and Civitas) and identified the different levels of privacy they offer. This work has appeared as a part of the PhD thesis [8], defended by Joseph Lallemand in November 2019.

Some modern e-voting systems take into account that the platform used for voting may be corrupted, e.g. infected by malware, yet aiming to ensure privacy and integrity of votes even in that case. Bursuc and Kremer, in collaboration with Dragan (Univ of Surrey) propose a new definition of vote privacy, formalized in the cryptographic model as a computational indistinguishability game. The definition captures both known and novel attacks against several voting schemes, and they propose a scheme that is provably secure in this setting. Moreover the proof is formalized and machine-checked in the EasyCrypt theorem prover [40]. This result has been presented at EuroS&P [19].

[0] 3rd Generation Partnership Project, responsible for the standardization of 3G, 4G, and 5G mobile networks

[0] Qualcomm, Gemalto, China Mobile, Mobile Thales Thales, Nokia Nokia, ZTE ZTE, and Huawei.

7.2.2. Design of E-Voting Protocols

Participants: Véronique Cortier, Jannik Dreier, Joseph Lallemand, Mathieu Turuani.

Most existing voting systems either assume trust in the voting device or in the voting server. Filipiak (Orange Labs), Lallemand, and Cortier proposed a novel Internet voting scheme, BeleniosVS, that achieves both privacy and verifiability against a dishonest voting server as well as a dishonest voting device. In particular, a voter does not leak her vote to her voting device and she can check that her ballot on the bulletin board does correspond to her intended vote. Additionally, our scheme guarantees receipt-freeness against an external adversary. A formal proof of privacy, receipt-freeness, and verifiability has been established using the tool ProVerif, covering a hundred cases of threat scenarios. Proving verifiability required the identification of a set of sufficient conditions, that can be handled by ProVerif [42]. This contribution is of independent interest. This work has been presented at CSF'19 [22].

As a part of a contract with Idemia, we are designing a novel electronic voting system tailored to their needs. The system is made for on-site elections, with the use of smart cards. However, the goal is that the trust should not be placed in one single part of the system, hence smart cards can not be trusted. One originality of the approach is the possibility to re-use existing techniques, in conjunction with the use of smart-cards and paper ballots. In this context, we have designed a novel audit technique [36], which can be seen as a variant to the "cast or audit" approach proposed by Josh Benaloh. One significant advantage of our solution is that voters now audit systematically their ballot (instead of choosing whether they should audit or not) and cast the audited ballot.

7.3. Online Social Networks

7.3.1. Privacy Protection in Social Networks

Participants: Bizhan Alipour, Abdessamad Imine, Michaël Rusinowitch.

Social media such as Facebook provides a new way to connect, interact and learn. Facebook allows users to share photos and express their feelings by using comments. However, Facebook users are vulnerable to attribute inference attacks where an attacker intends to guess private attributes (e.g., gender, age, political view) of target users through their online profiles and/or their vicinity (e.g., what their friends reveal). Given user-generated pictures on Facebook, we show in [16] how to launch gender inference attacks on their owners from pictures meta-data composed of: (i) alt-texts generated by Facebook to describe the content of pictures, and (ii) comments posted by friends, friends of friends or regular users. We assume these two meta-data are the only available information to the attacker. Evaluation results demonstrate that our attack technique can infer the gender with an accuracy of 84% by leveraging only alt-texts, 96% by using only comments, and 98% by combining alt-texts and comments. We compute a set of sensitive words that enable attackers to perform effective gender inference attacks. We show the adversary prediction accuracy is decreased by hiding these sensitive words. To the best of our knowledge, this is the first inference attack on Facebook that exploits comments and alt-texts solely. In subsequent work we have investigated the case where comments are reduced to Emojis.

7.3.2. Compressed and Verifiable Filtering Rules in Software-defined Networking

Participants: Ahmad Abboud, Michaël Rusinowitch.

In a joint project with the Resist research group at Inria Nancy and Numeryx company, we are working on the design, implementation and evaluation of a double-mask technique for building compressed and verifiable filtering rules in Software Defined Networks with the possibility of distributing the workload processing among several packet filtering devices operating in parallel [33], [34].

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

We have several contracts with industrial partners interested in the design of electronic voting systems:

- Since 2014, a collaboration agreement has been signed between Pesto and Scytl, a Spanish company which proposes solutions for the organization of on-line elections, including legally binding elections, in several countries. In this context, a first contract has been signed in 2016 to design a formal proof of both verifiability and privacy of the protocol developed by Scytl, for deployment in Switzerland. In 2018, a new contract has been signed to adapt the previous security proof to the new protocol proposed by Scytl, in order to achieve universal verifiability.
- Docapost signed a 18-month contract in September 2017, with Pesto and Caramba, to enhance the voting solution of Docapost, in particular with respect to verifiability.
- IDEMIA signed a 2-year contract in January 2019, with Pesto and Caramba. The goal is to design a voting protocol adapted to the elections they plan to organize, in various countries. This includes the use of smartcard, yet without having to trust them. Once designed, the protocol will be formally analysed with the tools developed in the team such as ProVerif or Tamarin.

8.2. Bilateral Grants with Industry

A CIFRE contract with Numeryx has started with the Resist research group at Inria Nancy and Pesto, to develop algorithms for optimizing sets of filtering rules in Software Defined Networks.

9. Partnerships and Cooperations

9.1. National Initiatives

9.1.1. ANR

- ANR SEQUOIA *Security properties, process equivalences and automated verification*, duration: 4 years, since October 2014, leader: Steve Kremer, other partners: ENS Cachan, Univ Luxembourg. Most protocol analysis tools are restricted to analyzing reachability properties while many security properties need to be expressed in terms of some process equivalences. The increasing use of observational equivalence as a modeling tool shows the need for new tools and techniques that are able to analyze such equivalence properties. The aims of this project are *(i)* to investigate which process equivalences — among the plethora of existing ones — are appropriate for a given security property, system assumptions and attacker capabilities; *(ii)* to advance the state of the art of automated verification for process equivalences, allowing for instance support for more cryptographic primitives, relevant for case studies; *(iii)* to study protocols that use low-entropy secrets expressed using process equivalences; *(iv)* to apply these results to case studies from electronic voting.
- ANR TECAP *Protocol Analysis — Combining Existing Tools*, duration: 4 years, starting in 2018, leader: Vincent Cheval, other partners: ENS Cachan, Inria Paris, Inria Sophia Antipolis, IRISA, LIX. Despite the large number of automated verification tools, several cryptographic protocols (e.g. stateful protocols) still represent a real challenge for these tools and reveal their limitations. To cope with these limits, each tool focuses on different classes of protocols depending on the primitives, the security properties, etc. Moreover, the tools cannot interact with each other as they evolve in their own model with specific assumptions. The aim of this project is to get the best of all these tools, that is, to improve the theory and implementations of each individual tool towards the strengths of the others and to build bridges that allow the cooperations of the methods/tools. We will focus in

this project on CryptoVerif, EasyCrypt, Scary, ProVerif, *TAMARIN*, *Akiss* and APTE. In order to validate the results obtained in this project, we will apply our results to several case studies such as the Authentication and Key Agreement protocol from the telecommunication networks, the Scytl and Helios voting protocols, and the low entropy 3D-Secure authentication protocol. These protocols have been chosen to cover many challenges that the current tools are facing.

9.2. European Initiatives

9.2.1. FP7 & H2020 Projects

- SPOOC (2015–2020) [0]— ERC Consolidator Grant on Automated Security Proofs of Cryptographic Protocols: Privacy, Untrusted Platforms and Applications to E-voting Protocols.

  The goals of the Spooc project are to develop solid foundations and practical tools to analyze and formally prove security properties that ensure the privacy of users as well as techniques for executing protocols on untrusted platforms. We will

  – develop foundations and practical tools for specifying and formally verifying new security properties, in particular privacy properties;

  – develop techniques for the design and automated analysis of protocols that have to be executed on untrusted platforms;

  – apply these methods in particular to novel e-voting protocols, which aim at guaranteeing strong security guarantees without the need to trust the voter client software.

  Steve Kremer is the leader of the project.

9.3. International Initiatives

9.3.1. Inria International Partners

9.3.1.1. Informal International Partners

- Collaboration with David Basin, Ralf Sasse and Lara Schmid (ETH Zurich), Cas Cremers (Helmholtz Center for Information Security (CISPA)), and Sasa Radomirovic (Univ Dundee) on the improvement of the *TAMARIN* prover
- Collaboration with David Basin and Lara Schmid (ETH Zurich) on the study of the security impact of the bulletin board in e-voting protocols
- Collaboration with Guillaume Girol (CEA), David Basin, Ralf Sasse (ETH Zurich), Dennis Jackson (Univ Oxford), and Cas Cremers (Helmholtz Center for Information Security (CISPA)) on a new security analysis framework for the Noise language
- Collaboration with Ravishankar Borgaonkar (Sintef), Shinjo Park, and Altaf Shaik (TU Berlin) on the study of practical privacy attacks in mobile communication
- Collaboration with Matteo Maffei (Univ Wien) on type systems for e-voting systems
- Collaboration with Bogdan Warinschi (Univ Bristol) on defining game-based privacy for e-voting protocols
- Collaboration with Robert Künnemann (CISPA, Germany) on the development of the SAPIC tool
- Collaboration with Gilles Barthe (MPI for Security and Privacy, Germany) on the automation of computer-aided cryptographic proofs
- Collaboration with Paliath Narendran's group (SUNY Albany) on automated deduction
- Collaboration with Serdar Erbatur (LMU, Germany) and Andrew Marshall (Univ Mary Washington, USA) on decision procedures for combined equational theories

[0] https://members.loria.fr/SKremer/files/spooc/index.html

- Collaboration with Hanifa Boucheneb's group (Polytechnique Montreal) on model-checking of collaborative systems
- Collaboration with John Mullins's group (Polytechnique Montreal) on information hiding

9.4. International Research Visitors

9.4.1. Visits of International Scientists

- Bogdan Warinschi (Univ Bristol), November 2018 and April 2019.
- Ralf Sasse (ETH Zurich), November 2019.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events Organisation

10.1.1.1. General Chair, Scientific Chair

- V. Cortier: vice-chair of the ACM Special Interest Group on Logic and Computation (SigLog); vice-chair of the IFIP Wg-1.7 Foundations of Security Analysis.
- J. Dreier: GRSRD 2019, Grande Region Security and Reliability Day 2019, Nancy, March 2019 (chair)

10.1.2. Scientific Events Selection

10.1.2.1. Member of the Conference Program Committees

- V. Cortier: POST 2019, E-VoteID 2019 (Track chair), S&P 2019, CSF 2019, Voting 2020, Concur 2020, S&P 2020
- V. Cheval: CSF 2020
- J. Dreier: SEC@SAC 2020, 5G-NS 2019, SP5G@ICISSP 2020
- L. Hirschi: SEC@SAC 2020
- A. Imine : ICEIS 2019, DEXA 2019, VLIoT@VLDB 2019, C2SI 2019
- S. Kremer: Euro S&P 2019, Voting 2019, PERR 2019, ESORICS 2019, FSTTCS 2019, CSF 2020, Euro S&P 2020, Voting 2020
- C. Ringeissen: UNIF 2019, FroCoS 2019, WRLA 2020, IJCAR 2020, UNIF 2020
- M. Rusinowitch: IWSPA 2019, STM 2019, CRISIS 2019, IWSPA 2020

10.1.3. Journal

10.1.3.1. Editor in Chief

- V. Cortier: Journal of Computer Security (EiC since November 2019)

10.1.3.2. Member of the Editorial Boards

- V. Cortier: Information & Computation, Journal of Computer Security, ACM Transactions on Privacy and Security (TOPS, previously TISSEC), Foundations and Trends (FnT) in Security and Privacy

10.1.4. Invited Talks

- V. Cortier. Keynote speaker at the ACM SIGSAC 14th Workshop on Programming Languages and Analysis for Security (PLAS 2019), London, UK, November 2019.

- V. Cortier. Keynote speaker at the 24th European Symposium on Research in Computer Security (Esorics 2019), Luxembourg, September 2019.
- V. Cortier. Plenary talk at the 28th edition of Computer Science Logic (CSL 2020), Barcelona, Spain, January 2020.
- S. Kremer. Keynote speaker at the ACM SIGSAC 14th Workshop on Programming Languages and Analysis for Security (PLAS 2019), London, UK, November 2019.
- V. Cheval. Invited talk at the Rendez-vous de la Recherche et de l'Enseignement de la Sécurité des Systèmes d'Information, RESSI 2019, Erquy, France, May 2019.

10.1.5. Scientific Expertise

- V. Cortier: Member of the W&T5ASP panel of the Research Foundation - Flanders (FWO), Belgium
- A. Imine: ANR project expertise
- L. Hirschi: ANR project expertise
- M. Rusinowitch: FNRS project expertises, Belgium

10.1.6. Research Administration

Inria evaluation committee (S. Kremer)
Inria Committee on Gender Equality and Equal Opportunities (S. Kremer, co-chair)
Jury Junior Research Position Inria Paris (S. Kremer)
Computer science commission of the Doctoral School, Univ Lorraine (L. Vigneron, chair)
Jury Associate Professor at IT University Copenhagen (J. Dreier)
Jury Assistant Professor at EISTI school/ETIS laboratory, Cergy (J. Dreier)
Scientific Council of the Computer Science CNRS Institute INS2I (V. Cortier)

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

- Licence:

  V. Cheval, Introduction to Theoretical Computer Science (Logic, Languages, Automata), 38 hours (ETD), TELECOM Nancy

  J. Dreier, Introduction to Theoretical Computer Science (Logic, Languages, Automata), 38 hours (ETD), TELECOM Nancy

  J. Dreier, Awareness for Cybersecurity, 7.5 hours (ETD), TELECOM Nancy

  L. Hirschi, Introduction to Theoretical Computer Science (Logic, Languages, Automata), 38 hours (ETD), TELECOM Nancy
- Master:

  V. Cortier, Security of flows, 16 hours, M2 Computer Science, TELECOM Nancy and Mines Nancy

  V. Cortier, Security of flows, 8 hours, M2 Computer Science, TELECOM Nancy and Mines Nancy

  J. Dreier, Introduction to Cryptography, 42 hours, M1 Computer Science, TELECOM Nancy

  A. Imine, Security for XML Documents, 12 hours (ETD), M1, Univ Lorraine

  S. Kremer, Security Theory, 24 hours (ETD), M2 Computer science, Univ Lorraine

  C. Ringeissen, Decision Procedures for Software Verification, 24 hours (ETD), M2 Computer science, Univ Lorraine

  L. Vigneron, Security of information systems, 32 hours (ETD), M2 Computer science, Univ Lorraine

L. Vigneron, Advanced Security, 28 hours (ETD), Polytech Nancy – Information Systems and Networks, Univ Lorraine

L. Vigneron, Security of information systems, 16 hours (ETD), M2 MIAGE – Audit and Design of Information Systems, Univ Lorraine

- Summer School:

  V. Cortier. Models and Techniques for Analysing Security Protocols, Winter School of the VMCAI 2019 conference, Cascais/Lisbon, Portugal, January 2019.

10.2.2. Supervision

- PhD defended in 2019:

  Joseph Lallemand, Electronic Voting: Definitions and Analysis Techniques [8], November 2019 (V. Cortier)

- PhD in progress:

  Ahmad Abboud, Compressed and Verifiable Filtering Rules in Software-defined Networking, started in August 2018 (A. Lahmadi, M. Rusinowitch and A. Bouhoula)

  Bizhan Alipour, Privacy protection against inference attacks in social networks, started in October 2018 (A. Imine, M. Rusinowitch)

  Charlie Jacomme, Security protocols: new properties, new attackers, new protocols, started in September 2017 (H. Comon and S. Kremer)

  Itsaka Rakotonirina, Efficient verification of equivalence properties in cryptographic protocols, started in October 2017 (V. Cheval and S. Kremer)

10.2.3. Juries

Jury member for J. M. López Becerra, University of Luxembourg (S. Kremer).

Jury president for Hoang-Long Nguyen, University of Lorraine (M. Rusinowitch)

10.3. Popularization

10.3.1. Articles and contents

Véronique Cortier. Some interactions (in collaboration with P. Gaudry and S. Glondu) with France Culture to improve an online article on e-voting.

Steve Kremer co-authored (with L. Mé, D. Rémy and V. Roca) Inria's White Book on Cybersecurity [27].

Steve Kremer In Horizon - The EU Research and Innovation Magazine: Online voting isn't ready for high-stakes elections, Avril 2019.

Steve Kremer, Ludovic Mé, Didier Rémy, and Vincent Roca. In Blog Binaire - Le Monde. La cybersécurité aux multiples facettes.

Steve Kremer. Le vote électronique. Chapter of the book "Treize défis pour la Cybersécurité" édited by CNRS. To appear in January 2020.

Interview with Science & Vie Junior about 5G security (J. Dreier, in "Pourquoi la 5G va tout changer", Science & Vie Junior, Juillet 2019)

Lucca Hirschi, Ralf Sasse, Jannik Dreier in ERCIM News 2019. "Security Issues in the 5G Standard and How Formal Methods Come to the Rescue".

10.3.2. Interventions

Invited conference at the Espace des sciences, Rennes (audience of about 300 people, 5K+ views on Youtube), October, 22nd, 2019 (V. Cortier) “breakfast” in the Senat, on Cybersecurity, organized by OPECST / Académie des sciences / Académie de médecine, June 19th, 2019. (V. Cortier)

How to explain security protocols with Playmobil, group of high school students interns for a week, February 3rd, 2019, (V. Cortier)

11. Bibliography

Major publications by the team in recent years

[1] D. Basin, J. Dreier, L. Hirschi, S. Radomirovic, R. Sasse, V. Stettler.*A Formal Analysis of 5G Authentication*, in "ACM CCS 2018 - 25th ACM Conference on Computer and Communications Security", Toronto, Canada, Proceedings of the 2018 ACM SIGSAC Conference on Computer and Communications Security, CCS 2018, Toronto, ON, Canada, October 15-19, 2018, ACM Press, October 2018, vol. 14 [*DOI :* 10.1145/3243734.3243846], https://hal.archives-ouvertes.fr/hal-01898050

[2] W. Belkhir, Y. Chevalier, M. Rusinowitch.*Parametrized automata simulation and application to service composition*, in "J. Symb. Comput.", 2015, vol. 69, p. 40–60

[3] D. Bernhard, V. Cortier, D. Galindo, O. Pereira, B. Warinschi.*A comprehensive analysis of game-based ballot privacy definitions*, in "Proceedings of the 36th IEEE Symposium on Security and Privacy (S&P'15)", IEEE Computer Society Press, May 2015, p. 499–516

[4] V. Cheval, S. Kremer, I. Rakotonirina.*DEEPSEC: Deciding Equivalence Properties in Security Protocols - Theory and Practice*, in "39th IEEE Symposium on Security and Privacy", San Francisco, United States, May 2018, https://hal.inria.fr/hal-01763122

[5] R. Chrétien, V. Cortier, S. Delaune.*Typing messages for free in security protocols: the case of equivalence properties*, in "Proceedings of the 25th International Conference on Concurrency Theory (CONCUR'14)", Rome, Italy, Lecture Notes in Computer Science, Springer, September 2014, vol. 8704, p. 372-386

[6] S. Erbatur, A. M. Marshall, C. Ringeissen.*Notions of Knowledge in Combinations of Theories Sharing Constructors*, in "26th International Conference on Automated Deduction", Göteborg, Sweden, L. de Moura (editor), Lecture Notes in Artificial Intelligence, Springer, August 2017, vol. 10395, p. 60 - 76 [*DOI :* 10.1007/978-3-319-63046-5_5], https://hal.inria.fr/hal-01587181

[7] H. H. Nguyen, A. Imine, M. Rusinowitch.*Anonymizing Social Graphs via Uncertainty Semantics*, in "Proceedings of the 10th ACM Symposium on Information, Computer and Communications Security, (ASIA CCS'15), 2015", ACM, 2015, p. 495–506

Publications of the year

Doctoral Dissertations and Habilitation Theses

[8] J. Lallemand.*Electronic Voting: Definitions and Analysis Techniques*, Université de Lorraine, November 2019, https://hal.inria.fr/tel-02396851

Articles in International Peer-Reviewed Journal

[9] R. BORGAONKAR, L. HIRSCHI, S. PARK, A. SHAIK.*New Privacy Threat on 3G, 4G, and Upcoming 5G AKA Protocols*, in "Proceedings on Privacy Enhancing Technologies", July 2019, vol. 2019, n^o 3, p. 108-127 [*DOI :* 10.2478/POPETS-2019-0039], https://hal.inria.fr/hal-02368896

[10] P. CHOCRON, P. FONTAINE, C. RINGEISSEN.*Politeness and Combination Methods for Theories with Bridging Functions*, in "Journal of Automated Reasoning", 2019, forthcoming [*DOI :* 10.1007/S10817-019-09512-4], https://hal.inria.fr/hal-01988452

[11] R. CHRÉTIEN, V. CORTIER, A. DALLON, S. DELAUNE.*Typing messages for free in security protocols*, in "ACM Transactions on Computational Logic", 2019, vol. 21, n^o 1, forthcoming [*DOI :* 10.1145/3343507], https://hal.inria.fr/hal-02268400

[12] J. DREIER, L. HIRSCHI, S. RADOMIROVIĆ, R. SASSE.*Verification of Stateful Cryptographic Protocols with Exclusive OR*, in "Journal of Computer Security", 2019, forthcoming, https://hal.archives-ouvertes.fr/hal-02358878

[13] L. HIRSCHI, D. BAELDE, S. DELAUNE.*A method for unbounded verification of privacy-type properties*, in "Journal of Computer Security", June 2019, vol. 27, n^o 3, p. 277-342 [*DOI :* 10.3233/JCS-171070], https://hal.inria.fr/hal-02368832

[14] L. HIRSCHI, R. SASSE, J. DREIER.*Security Issues in the 5G Standard and How Formal Methods Come to the Rescue*, in "ERCIM News", April 2019, https://hal.archives-ouvertes.fr/hal-02268822

Invited Conferences

[15] V. CORTIER, P. GAUDRY, S. GLONDU.*Belenios: a simple private and verifiable electronic voting system*, in "Foundations of Security, Protocols, and Equational Reasoning", Fredericksburg, Virgina, United States, J. D. GUTTMAN, C. E. LANDWEHR, J. MESEGUER, D. PAVLOVIC (editors), LNCS, Springer, 2019, vol. 11565, p. 214-238 [*DOI :* 10.1007/978-3-030-19052-1_14], https://hal.inria.fr/hal-02066930

International Conferences with Proceedings

[16] B. ALIPOUR, A. IMINE, M. RUSINOWITCH.*Gender Inference for Facebook Picture Owners*, in "TrustBus 2019 - 16th International Conference on Trust, Privacy and Security in Digital Business", Linz, Austria, S. GRITZALIS, E. WEIPPL, S. KATSIKAS, G. ANDERST-KOTSIS, A. M. TJOA, I. KHALIL (editors), Lecture Notes in Computer Science, Springer, August 2019, vol. 11711, p. 145–160 [*DOI :* 10.1007/978-3-030-27813-7_10], https://hal.univ-lorraine.fr/hal-02271825

[17] S. ANANTHARAMAN, P. HIBBS, P. NARENDRAN, M. RUSINOWITCH.*Unification modulo Lists with Reverse, Relation with Certain Word Equations*, in "CADE-27 - The 27th International Conference on Automated Deduction", Natal, Brazil, P. FONTAINE (editor), Automated Deduction - CADE 27, Springer International Publishing, August 2019, vol. Springer-Verlag LNCS/LNAI, n^o 11716, p. 1–17 [*DOI :* 10.1007/978-3-030-29436-6_1], https://hal.archives-ouvertes.fr/hal-02123709

[18] G. BARTHE, B. GRÉGOIRE, C. JACOMME, S. KREMER, P.-Y. STRUB.*Symbolic Methods in Computational Cryptography Proofs*, in "CSF2019 - 32nd IEEE Computer Security Foundations Symposium", Hoboken, United States, IEEE, June 2019, p. 136-13615 [*DOI :* 10.1109/CSF.2019.00017], https://hal.archives-ouvertes.fr/hal-02404701

[19] S. BURSUC, C.-C. DRAGAN, S. KREMER.*Private votes on untrusted platforms: models, attacks and provable scheme*, in "EuroS&P 2019 - 4th IEEE European Symposium on Security and Privacy", Stockholm, Sweden, June 2019, https://hal.inria.fr/hal-02099434

[20] S. BURSUC, S. KREMER.*Contingent payments on a public ledger: models and reductions for automated verification*, in "ESORICS 2019 - The 24th European Symposium on Research in Computer Security", Luxembourg, Luxembourg, 2019, https://hal.archives-ouvertes.fr/hal-02269063

[21] V. CHEVAL, S. KREMER, I. RAKOTONIRINA.*Exploiting Symmetries When Proving Equivalence Properties for Security Protocols*, in "CCS'19 - 26th ACM Conference on Computer and Communications Security", London, United Kingdom, November 2019, https://hal.archives-ouvertes.fr/hal-02269043

[22] V. CORTIER, A. FILIPIAK, J. LALLEMAND.*BeleniosVS: Secrecy and Verifiability against a Corrupted Voting Device*, in "CSF 2019 - 32nd IEEE Computer Security Foundations Symposium", Hoboken, United States, June 2019, https://hal.inria.fr/hal-02268399

[23] A. K. EERALLA, S. ERBATUR, A. M. MARSHALL, C. RINGEISSEN.*Rule-Based Unification in Combined Theories and the Finite Variant Property*, in "LATA 2019 - 13th International Conference on Language and Automata Theory and Applications", Saint-Petersbourg, Russia, Language and Automata Theory and Applications - 13th International Conference, LATA 2019, Proceedings., Springer, March 2019, vol. Lecture Notes in Computer Science, n^{o} 11417, p. 356–367 [*DOI :* 10.1007/978-3-030-13435-8_26], https://hal.inria.fr/hal-01988419

[24] L. HIRSCHI, C. CREMERS.*Improving Automated Symbolic Analysis of Ballot Secrecy for E-Voting Protocols: A Method Based on Sufficient Conditions*, in "2019 IEEE European Symposium on Security and Privacy (EuroS&P)", Stockholm, France, IEEE, June 2019, p. 635-650 [*DOI :* 10.1109/EUROSP.2019.00052], https://hal.inria.fr/hal-02368857

Scientific Books (or Scientific Book chapters)

[25] D. BASIN, L. HIRSCHI, R. SASSE.*Symbolic Analysis of Identity-Based Protocols*, in "Foundations of Security, Protocols, and Equational Reasoning", LNCS, Springer, April 2019, vol. Springer, n^{o} 11565, p. 112-134 [*DOI :* 10.1007/978-3-030-19052-1_9], https://hal.inria.fr/hal-02368842

[26] M. P. BONACINA, P. FONTAINE, C. RINGEISSEN, C. TINELLI.*Theory Combination: Beyond Equality Sharing*, in "Description Logic, Theory Combination, and All That - Essays Dedicated to Franz Baader on the Occasion of His 60th Birthday", C. LUTZ, U. SATTLER, C. TINELLI, A.-Y. TURHAN, F. WOLTER (editors), Theoretical Computer Science and General Issues, Springer, June 2019, vol. 11560, p. 57-89, https://hal.inria.fr/hal-02194001

[27] S. KREMER, L. MÉ, D. RÉMY, V. ROCA.*Cybersecurity : Current challenges and Inria's research directions*, Inria white book, Inria, January 2019, n^{o} 3, 172, https://hal.inria.fr/hal-01993308

[28] S. KREMER, L. MÉ, D. RÉMY, V. ROCA.*Cybersécurité : Défis actuels et axes de recherche à l'Inria*, Inria white book, Inria, May 2019, n^{o} 3, 18, https://hal.inria.fr/hal-02414281

[29] C. RINGEISSEN.*Building and Combining Matching Algorithms*, in "Description Logic, Theory Combination, and All That - Essays Dedicated to Franz Baader on the Occasion of His 60th Birthday", C. LUTZ, U. SATTLER, C. TINELLI, A.-Y. TURHAN, F. WOLTER (editors), Lecture Notes in Computer Science,

Springer, June 2019, vol. 11560, p. 523-541 [*DOI :* 10.1007/978-3-030-22102-7_24], https://hal.inria.fr/hal-02187244

Research Reports

[30] S. ANANTHARAMAN, P. HIBBS, P. NARENDRAN, M. RUSINOWITCH.*Unification modulo Lists with Reverse as Solving Simple Sets of Word Equations*, LIFO, Université d'Orléans ; INSA, Centre Val de Loire, August 2019, https://hal.archives-ouvertes.fr/hal-02123648

[31] V. CORTIER, A. FILIPIAK, J. LALLEMAND.*BeleniosVS: Secrecy and Verifiability against a Corrupted Voting Device*, CNRS, Inria, LORIA ; Orange Labs, May 2019, https://hal.inria.fr/hal-02126077

[32] A. K. EERALLA, S. ERBATUR, A. M. MARSHALL, C. RINGEISSEN.*Unification in Non-Disjoint Combinations with Forward-Closed Theories*, Inria Nancy - Grand Est, 2019, n^{o} RR-9252, https://hal.inria.fr/hal-02006179

Other Publications

[33] A. ABBOUD, A. LAHMADI, M. RUSINOWITCH, M. COUCEIRO, A. BOUHOULA.*Minimizing Range Rules for Packet Filtering Using a Double Mask Representation*, May 2019, IFIP Networking 2019, Poster, https://hal.inria.fr/hal-02393008

[34] A. ABBOUD, A. LAHMADI, M. RUSINOWITCH, M. COUCEIRO, A. BOUHOULA, S. E. H. AWAINIA, M. AYADI.*Minimizing Range Rules for Packet Filtering Using Double Mask Representation*, April 2019, working paper or preprint, https://hal.inria.fr/hal-02102225

[35] V. CHEVAL, S. KREMER, I. RAKOTONIRINA.*Exploiting symmetries when proving equivalence properties for security protocols (Technical report)*, 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-02267866

[36] V. CORTIER, J. DREIER, P. GAUDRY, M. TURUANI.*A simple alternative to Benaloh challenge for the cast-as-intended property in Helios/Belenios*, 2019, working paper or preprint, https://hal.inria.fr/hal-02346420

[37] L. HIRSCHI.*Symbolic Abstractions for Quantum Protocol Verification*, December 2019, https://arxiv.org/abs/1904.04186 - working paper or preprint, https://hal.archives-ouvertes.fr/hal-02391308

References in notes

[38] 3GPP.*Study on authentication enhancements in the 5G System (5GS)*, 3rd Generation Partnership Project (3GPP), n^{o} 33.846, http://www.3gpp.org/DynaReport/33849.htm

[39] M. ARAPINIS, L. MANCINI, E. RITTER, M. RYAN, N. GOLDE, K. REDON, R. BORGAONKAR.*New privacy issues in mobile telephony: fix and verification*, in "Proc. 19th ACM Conference on Computer and Communications Security (CCS'12)", ACM Press, 2012, p. 205-216

[40] G. BARTHE, F. DUPRESSOIR, B. GRÉGOIRE, C. KUNZ, B. SCHMIDT, P. STRUB.*EasyCrypt: A Tutorial*, in "Foundations of Security Analysis and Design VII - FOSAD 2012/2013 Tutorial Lectures", A. ALDINI, J. LÓPEZ, F. MARTINELLI (editors), Lecture Notes in Computer Science, Springer, 2013, vol. 8604, p. 146–166

[41] B. BLANCHET.*An Efficient Cryptographic Protocol Verifier Based on Prolog Rules*, in "Proc. 14th Computer Security Foundations Workshop (CSFW'01)", IEEE Comp. Soc. Press, 2001, p. 82–96

[42] B. BLANCHET.*Modeling and Verifying Security Protocols with the Applied Pi Calculus and ProVerif*, in "Foundations and Trends in Privacy and Security", 2016, vol. 1, n^{o} 1-2, p. 1–135

[43] M. BORTOLOZZO, M. CENTENARO, R. FOCARDI, G. STEEL.*Attacking and Fixing PKCS#11 Security Tokens*, in "Proc. 17th ACM Conference on Computer and Communications Security (CCS'10)", ACM Press, 2010, p. 260-269

[44] R. CHADHA, V. CHEVAL, S. CIOBÂCĂ, S. KREMER.*Automated verification of equivalence properties of cryptographic protocols*, in "ACM Transactions on Computational Logic", 2016, vol. 17, n^{o} 4 [*DOI :* 10.1145/2926715], https://hal.inria.fr/hal-01306561

[45] C. CHEVALIER, S. DELAUNE, S. KREMER, M. RYAN.*Composition of Password-based Protocols*, in "Formal Methods in System Design", 2013, vol. 43, p. 369-413

[46] H. COMON-LUNDH, S. DELAUNE.*The finite variant property: How to get rid of some algebraic properties*, in "Proc. of the 16th International Conference on Rewriting Techniques and Applications (RTA'05)", LNCS, Springer, 2005, vol. 3467, p. 294-307

[47] V. CORTIER, S. DELAUNE.*Safely Composing Security Protocols*, in "Formal Methods in System Design", February 2009, vol. 34, n^{o} 1, p. 1-36

[48] S. DELAUNE, S. KREMER, M. RYAN.*Verifying Privacy-type Properties of Electronic Voting Protocols*, in "Journal of Computer Security", July 2009, vol. 17, n^{o} 4, p. 435-487

[49] S. DELAUNE, S. KREMER, G. STEEL.*Formal Analysis of PKCS#11 and Proprietary Extensions*, in "Journal of Computer Security", November 2010, vol. 18, n^{o} 6, p. 1211-1245

[50] S. ERBATUR, D. KAPUR, A. M. MARSHALL, C. MEADOWS, P. NARENDRAN, C. RINGEISSEN.*On Asymmetric Unification and the Combination Problem in Disjoint Theories*, in "Proc. 17th International Conference on Foundations of Software Science and Computation Structures (FoSSaCS'14)", LNCS, Springer, 2014, p. 274-288

[51] S. ESCOBAR, C. MEADOWS, J. MESEGUER.*Maude-NPA: Cryptographic Protocol Analysis Modulo Equational Properties*, in "Foundations of Security Analysis and Design V", LNCS, Springer, 2009, vol. 5705, p. 1-50

[52] D. GOLLMANN.*What do we mean by entity authentication?*, in "Proc. Symposium on Security and Privacy (SP'96)", IEEE Comp. Soc. Press, 1996, p. 46–54

[53] J. HERZOG.*Applying protocol analysis to security device interfaces*, in "IEEE Security & Privacy Magazine", July-Aug 2006, vol. 4, n^{o} 4, p. 84–87

[54] B. SCHMIDT, S. MEIER, C. CREMERS, D. BASIN.*The TAMARIN Prover for the Symbolic Analysis of Security Protocols*, in "Proc. 25th International Conference on Computer Aided Verification (CAV'13)", LNCS, Springer, 2013, vol. 8044, p. 696-701

Team RESIST

Resilience and Elasticity for Security and ScalabiliTy of dynamic networked systems

Inria teams are typically groups of researchers working on the definition of a common project, and objectives, with the goal to arrive at the creation of a project-team. Such project-teams may include other partners (universities or research institutions).

RESEARCH CENTER
Nancy - Grand Est

THEME
Networks and Telecommunications

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Team RESIST

Creation of the Team: 2018 January 01

Keywords:

Computer Science and Digital Science:

A1.1.4. - High performance computing
A1.1.8. - Security of architectures
A1.1.13. - Virtualization
A1.2. - Networks
A1.3. - Distributed Systems
A2.6. - Infrastructure software
A3.1.1. - Modeling, representation
A3.1.3. - Distributed data
A3.1.8. - Big data (production, storage, transfer)
A3.2.2. - Knowledge extraction, cleaning
A3.2.3. - Inference
A3.3. - Data and knowledge analysis
A3.4. - Machine learning and statistics
A4.1. - Threat analysis
A4.4. - Security of equipment and software
A4.9. - Security supervision

Other Research Topics and Application Domains:

B5. - Industry of the future
B6.3.2. - Network protocols
B6.3.3. - Network Management
B6.4. - Internet of things
B6.5. - Information systems
B6.6. - Embedded systems
B9.8. - Reproducibility

1. Team, Visitors, External Collaborators

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2. Overall Objectives

2.1. Context

The increasing number of components (users, applications, services, devices) involved in today's Internet as well as their diversity make **the Internet a very dynamic environment**. Networks and cloud data centers have been becoming vital elements and an integral part of emerging **5G infrastructure**. Indeed, networks continue to play their role interconnecting devices and systems, and clouds are now the de facto technology for hosting services, and for deploying storage and compute resources, and even Network Functions (NFs).

While telecom operators have been historically providing Internet connectivity and managing the Internet infrastructure and services, they are now loosing control to other stakeholders, particularly to Over-the-Top (OTT) content and service providers. Therefore, the delivery of Internet services has increased in complexity to mainly cope with the diversity and exponential growth of network traffic both at the core and at the edge. Intermediate players are multiplying and each of them has been proposing solutions to enhance service access performance.

In the Internet landscape, no single entity can claim a complete view of Internet topology and resources. Similarly, a single authority cannot control all interconnection networks and cloud data centers to effectively manage them and **provide reliable and secure services** to end users and devices at scale. The **lack of clear visibility into Internet operations** is exacerbated by the increasing use of encryption solutions [0] which contributes to traffic opacity.

[0] http://www.arcep.fr/uploads/tx_gsavis/15-0832.pdf, accessed on 09/06/2017

2.2. Challenges

In this context two main challenges stand out:

- **Scalability**: As mentioned above, the Internet ecosystem is continuously expanding in both size and heterogeneity. Scalability was already a challenge in the last decade but solutions mainly focused on scaling one dimension at a time, e.g. increasing the capacity of network links or that of compute resources in order to face peak demand, even if it is infrequent. Such **over-provisioning** however wastes significant resources and **cannot cope with future demand** at a reasonable cost. Several experts warn about major Internet blackouts in the coming years [46], [43]. Scalability must be ensured across multiple dimensions to face of order of magnitude: more users, devices, contents and applications.
- **Security:** Security has gained a lot of popularity in the last few years because the Internet has become a lucrative playground for attackers with large numbers of potential victims and numerous ways to reach them. Advanced Persistent Threats (APT) [48] are the most sophisticated representatives of this evolution. Such **targeted attacks do not rely on generic scenarios**, usually described as a set of signatures. They are **complex by nature** and their investigation requires the **analysis of various sources of data**. At the same time, the generalization of encryption renders all deep packet inspection techniques obsolete and threat hunting becomes an even bigger challenge.

  Additionally, an underground economy has been developed by cyber-criminals. Finally, because many applications are now provided as cloud-based services, physical isolation is also harder with potential attackers able to act directly in the field.

The highly dynamic nature of the Internet ecosystem, the requirement for higher and higher scalability, and the rising security threats have shown the **limitations of traditional approaches to address these challenges**. Resist focuses on two complementary paradigms for achieving security and scalability:

- **Elasticity** refers to the ability of a system to **scale up and down on demand**. Elasticity of compute resources became more accessible with the advent of cloud computing. It has been recently leveraged in support of Network Function Virtualization (NFV) coupled with Software-Defined Networking (SDN). Understanding the dynamics of networked systems is critical in order to benefit from and efficiently orchestrate elasticity at all levels of the network, the system and the applications. On the one hand, elasticity facilitates scalability, as well as security by instantiating virtualized network security functions (e.g., firewall, IDS, DPI, etc.) on demand. On the other hand, it could increase the attack surface. This dilemma must be addressed. Moreover, issues inherent to elasticity such as the dynamic deployment and migration of resources bring new challenges in NFV environments since network functions are different from those of common cloud applications deployed in virtual machines and containers, *e.g.* in terms of network throughput.
- **Resilience** refers to the ability of a system to **adapt itself when facing challenging situations**. It is reasonable to assume that any system may face an attack for which protection mechanisms may fail. A comprehensive approach to resilience that considers not only the network and system resources but also the supported users and applications brings both benefits and challenges since users and applications can be very diverse, ephemeral and mobile. Applications are also deployed in dynamic environments like cloud platforms and are frequently reconfigured.

Resist aspires to make **large-scale** networked systems **more secure and more resilient**, leveraging resource **elasticity** and assuming a highly dynamic environment.

3. Research Program

3.1. Overview

The Resist project aims at designing, implementing and validating novel models, algorithms and tools to **make networked systems elastic and resilient so as to enhance their scalability and security**, assuming users, applications and devices whose volume and heterogeneity will continue to increase.

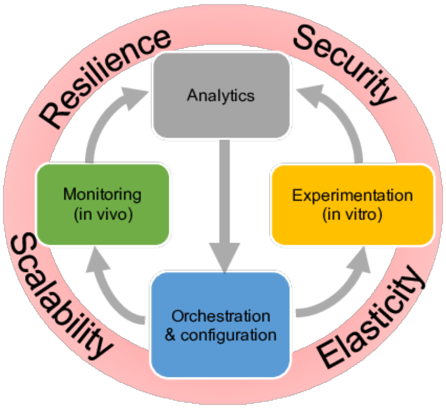

Figure 1. The Resist project

Softwarization of networks and **data analytics** are key enablers to design intelligent methods to orchestrate – *i.e.* configure in a synchronized and distributed manner – both network and system resources. Intelligent **orchestration** leverages relevant data for decision-making using **data analytics**. Input data reflecting the past, current and even future (predicted) states of the system are used to build relevant knowledge. Two approaches are pursued to generate knowledge and to validate orchestration decisions. First, a running system can be **monitored in vivo**. Second, **in vitro experimentation** in a controlled environment (simulators, emulators and experimental platforms) is helpful to reproduce a running system with a high reliability and under different hypotheses. Monitoring and experimentation are steered and configured through orchestration according to the two intertwined loops illustrated in Figure 1.

Accordingly Resist is thus structured into four main research objectives (activities) namely Monitoring, Experimentation, Analytics and Orchestration.

3.2. Monitoring

The evolving nature of the Internet ecosystem and its continuous growth in size and heterogeneity call for a better understanding of its characteristics, limitations, and dynamics, both locally and globally so as to improve application and protocol design, detect and correct anomalous behaviors, and guarantee performance.

To face these scalability issues, **appropriate monitoring models, methods and algorithms are required for data collection, analysis and sharing** from which knowledge about Internet traffic and usage can be extracted. Measuring and collecting traces necessitate user-centered and data-driven paradigms to cover the wide scope of heterogeneous user activities and perceptions. In this perspective, we propose monitoring algorithms and architectures for large scale environments involving mobile and Internet of Things (IoT) devices.

Resist also assesses **the impact of the Internet infrastructure evolution integrating network softwarization on monitoring**, for example the need for dedicated measurement methodologies. We take into account not only the technological specifics of such paradigms for their monitoring but also the ability to use them for collecting, storing and processing monitoring data in an accurate and cost-effective manner.

Crowd-sourcing and third-party involvement are gaining in popularity, paving the way for massively distributed and collaborative monitoring. We thus investigate opportunistic mobile crowdsensing in order to collect user activity logs along with contextual information (social, demographic, professional) to effectively measure end-users' **Quality of Experience**. However, collaborative monitoring raises serious concerns regarding trust and sensitive data sharing (open data). Data anonymization and sanitization need to be carefully addressed.

3.3. Experimentation

Of paramount importance in our target research context is experimental validation using testbeds, simulators and emulators. In addition to using various existing experimentation methodologies, Resist contributes in **advancing the state of the art in experimentation methods and experimental research practices**, particularly focusing on elasticity and resilience.

We develop and deploy testbeds and emulators for **experimentation with new networking paradigms** such as SDN and NFV, to enable large-scale in-vitro experiments combining all aspects of Software-Defined Infrastructures (server virtualization, SDN/NFV, storage). Such fully controlled environments are particularly suitable for our experiments on resilience, as they ease the management of fault injection features.

We are playing a central role in the development of the Grid'5000 testbed [44] and our objective is to reinforce our collaborations with other testbeds, towards a **testbed federation** in order to enable experiments to scale to multiple testbeds, providing a diverse environment reflecting the Internet itself.

Moreover, our research focuses on extending the infrastructure virtualization capabilities of our Distem [47] emulator, which provides a flexible software-based experimental environment.

Finally, methodological aspects are also important for ensuring **trustworthy and reproducible experiments**, and raises many challenges regarding testbed design, experiment description and orchestration, along with automated or assisted provenance data collection [45].

3.4. Analytics

A large volume of data is processed as part of the operations and management of networked systems. These include traditional monitoring data generated by network components and components' configuration data, but also data generated by dedicated network and system probes.

Understanding and predicting security incidents or system ability to scale requires the elaboration of novel **data analytics techniques** capable to cope with large volumes of data generated from various sources, in various formats, possibly incomplete, non-fully described or even encrypted.

We use machine learning techniques (*e.g.* Topological Data Analysis or multilayer perceptrons) and leverage our domain knowledge to fine-tune them. For instance, machine learning on network data requires the definition of new distance metrics capable to capture the properties of network configurations, packets and flows similarly to edge detection in image processing. Resist contributes to developing and making publicly available an **analytics framework dedicated to networked systems** to support Intelligence-Defined Networked Systems.

Specifically, the goal of the Resist analytics framework is to facilitate the extraction of knowledge useful for **detecting, classifying or predicting security or scalability issues**. The extracted knowledge is then leveraged for orchestration purposes to achieve system elasticity and guarantee its resilience. Indeed, predicting when, where and how issues will occur is very helpful in deciding the provisioning of resources at the right time and place. Resource provisioning can be done either reactively to solve the issues or proactively to prepare the networked system for absorbing the incident (resiliency) in a timely manner thanks to its elasticity.

While the current trend is towards centralization where the collected data is exported to the cloud for processing, we seek to extend this model by also developing and evaluating novel approaches in which **data analytics is seamlessly embedded within the monitored systems**. This combination of big data analytics with network softwarization enablers (SDN, NFV) can enhance the scalability of the monitoring and analytics infrastructure.

3.5. Orchestration

The ongoing transformations in the Internet ecosystem including network softwarization and cloudification bring new management challenges in terms of service and resource orchestration. Indeed, the growing sophistication of Internet applications and the complexity of services deployed to support them require novel models, architectures and algorithms for their automated **configuration** and **provisioning**. Network applications are more and more instantiated through the **composition of services, including virtualized hardware and software resources**, that are offered by **multiple providers** and are subject to changes and updates over time. In this dynamic context, efficient orchestration becomes fundamental for ensuring performance, resilience and security of such applications. We are investigating the chaining of different functions for supporting the security protection of smart devices, based on the networking behavior of their applications.

From a resilience viewpoint, this orchestration at the network level allows the dynamic **reconfiguration of resources** to absorb the effects of congestions, such as link-flooding behaviors. The goal is to drastically reduce the effects of these congestions by imposing dynamic policies on all traffic where the network will adapt itself until it reaches a stable state. We also explore mechanisms for **detecting and remediating potential dysfunctions** within a virtualized network. Corrective operations can be performed through dynamically composed VNFs (Virtualized Network Functions) based on available resources, their dependencies (horizontal and vertical), and target service constraints. We also conduct research on verification methods for automatically assessing and validating the composed chains.

From a security viewpoint, this orchestration provides **prevention mechanisms** that capture adversaries' intentions early and **enforces security policies** in advance through the available resources, to be able to proactively mitigate their attacks. We mainly rely on the results obtained in our research activity on security analytics to build such policies, and the orchestration part focuses on the required algorithms and methods for their automation.

4. Application Domains

4.1. Internet

Among the different network types, the Internet is the one to link them all and is consequently our most prominent subject, not to mention its prime importance in today's society. The Internet also exhibits its own challenges due to the scale and diversity of stakeholders, applications and network technologies in use.

From a security perspective, **monitoring and analysing Internet traffic is an important part of threat prevention and predictive security**. Indeed, large network telescopes like the one we use in the High Security Laboratory[0] allow detecting world-wide campaigns of attacks which target a specific exploit in some applications. Moreover the monitoring of the Internet traffic at the **edge** is the best way to quickly detect distributed attacks like DDoS and to mitigate them before they become effective. However, the Internet traffic analysis is made much more complicated since the **massive shift towards encryption** that happened few years ago, which requires new traffic classification methods.

The performance and resilience of services running over the Internet is also a major topic of Resist. In particular, it is very difficult to **diagnose the cause of a degradation of performance among the different actors and technologies** that are used to deliver a service over the Internet (access medium, ISP, CDN, web-browser, etc.). Networked systems deployed at Internet scale are also a natural research subject for Resist. Indeed **decentralized systems** like P2P networks or blockchains are known to be robust and scalable. However, their security and performance have to be carefully assessed because a single flaw in their design can endanger the whole system.

[0] https://lhs.loria.fr

4.2. SDN and Data-Center Networks

As the SDN paradigm and its implementations bring new opportunities that can be leveraged in different contexts, in particular for security and performance, programmable networks are also part of the research scope of Resist. This includes data-plane **programming models and hardware offloading** that enable very flexible programming at the network level. While OpenFlow was initially designed for academic research, SDN in general has then been adopted by industrial players, above all in **data-center networks**. It supports innovations to better share load and optimize resources among processes, in particular for virtualization platforms. Contributing to the development of these technologies is primordial for us as they are key elements for monitoring and enhancing the performance and security of future data-center networks.

When defining or extending SDN technologies, the strongest constraint is to guarantee a satisfactory level of performance, i.e. enabling high flexibility in programming with a **reduced footprint of network throughput**. However, as it may also break isolation principles between multiple tenants, security has to carefully considered, either by adding safeguard mechanisms at run-time or through a priori verification and testing.

4.3. Fog and Cloud computing

Cloud computing has largely evolved in the last years including new networking capabilities as highlighted in the previous section towards the model of XaaS or **everything-as-a-service**. Moreover, cloud computing continues to be more distributed and aims at integrating more heterogeneous resources. One particular example is **fog computing** that consists of a massively distributed number of different resources, including low-performance ones. Large network operators have a great interest in fog computing because they already operate such an infrastructure (e.g. a national operator with regional clouds and setup boxes in end users' homes). Softwarization or virtualization of all functions and services will help them to be competitive by reducing their costs. In general, intelligent orchestration of massively distributed resources will be investigated in various application domains, including **federated cloud infrastructures, fog computing, 5G networks, IoT and big data infrastructures**.

The manageability of such largely distributed systems is a core topic with questions related to monitoring, security and orchestration of resources. Major changes and errors can have dramatic effects on a real system, that actually lead to only minor changes being carried out and slow down innovation and adoption of new propositions. Hence, **controlled and reproducible experiments are vital**.

As shown by our past work, we are able to quickly adjust to experimental needs in most areas of distributed computing and networking, such as *High Performance Computing (HPC)*, *Big Data*, *Peer-to-peer systems*, *Grid computing*, etc. However, in the context of Resist, **we will focus mainly on***Software-Defined Infrastructures*, gathering *cloud computing* for compute and storage resources, *software-defined networking* and *network function virtualization* for networking. Those infrastructures share many common features: need for performance, for scalability, for resilience, all implemented using flexible software components.

Worth mentioning here is our involvement in the international testbed community (FIRE, GENI). We plan to strengthen our existing links with the Chameleon and CloudLab US projects, to leverage the recently accepted Fed4FIRE+ project on a testbed federation, and, at the national level, to contribute to the SILECS initiative for a new large-scale experimental computer science infrastructure.

4.4. Cyber-Physical Systems

Cyber-Physical Systems (CPSs) used to be well isolated and so designed accordingly. In the last decade, they have become **integrated within larger systems** and so accessible through the Internet. This is the case with **industrial systems**, like SCADA, that have been unfortunately exposed to major threats. Furthermore, the **Internet-of-Things (IoT)** has become a reality with numerous protocols, platforms and devices being developed and used to support the growing deployment of smart* services: smart home, transport, health, city... and even rather usual rigid systems such as industry 4.0.

From an academic perspective, the IoT can be seen as an evolution of sensor networks. It thus inherits from the same problems regarding security and scalability, but with a higher order of magnitude both in terms of number of devices and their capabilities, which can be exploited by attackers. Research in this area has focused on developing dedicated protocols or operating systems to guarentee security and performance, Resist aims to tackle identical problems but **assuming a more practical deployment of IoT systems composed of heterogeneous and uncontrolled devices**. Indeed, this ecosystem is very rich and **cannot be controlled by a unique entity**, e.g. services are often developed by third parties, manufacturers of embed devices are different from those providing connectivity.

As a result, managing an IoT system (monitoring, changing configuration, etc.) is very hard to achieve as most of the devices or applications cannot be directly controlled. For instance, many IoT providers rely on their own cloud services, with their own unknown **proprietary protocols** and most of the time through **encrypted channels**. Above all, the use of middle-boxes like gateways hides the IoT end-devices and applications. We will thus need to infer knowledge from **indirect and partial observations**. Likewise, control will be also indirect for example through filtering or altering communications.

5. Highlights of the Year

5.1. Highlights of the Year

The impact of the RESIST team in network and service management community has been highly recognized and awarded this year in recognition of their exceptional contributions and leadership in this research area.

- R. Badonnel has been elected as the chair of the IFIP (International Federation for Information Processing) WG6.6 (Working Group 6.6).
- J. François has been appointed as co-chair of NMRG (Network Management Research Group) of IRTF (Internet Research Task Force).
- T. Cholez gets involved in the new H2020 European project Concordia (section 9.3.1.4).

5.1.1. Awards

- O. Festor has received the *Dan Stokesberry award*.
- J. François has received the *IEEE Young Professional in Network and Service Management award*.

6. New Software and Platforms

6.1. Distem

KEYWORDS: Large scale - Experimentation - Virtualization - Emulation

FUNCTIONAL DESCRIPTION: Distem is a distributed systems emulator. When conducting research on Cloud, P2P, High Performance Computing or Grid systems, it can be used to transform an homogenous cluster (composed of identical nodes) into an experimental platform where nodes have different performance, and are linked together through a complex network topology, making it the ideal tool to benchmark applications targetting such environments, or aiming at tolerating performance degradations or variations which are frequent in the Cloud or in other applications distributed at large scale (P2P for example).

RELEASE FUNCTIONAL DESCRIPTION: New features in Distem 1.3 include: (1) New network emulation parameters: loss, duplication, corruption, reordering and jitter, (2) Support for Debian Stretch, (3) Added many tests, (4) Moved project from GForge to GitHub (https://github.com/madynes/distem).

NEWS OF THE YEAR: New version 1.3

- Participants: Luc Sarzyniec, Lucas Nussbaum and Tomasz Buchert
- Partners: CNRS - Université de Lorraine - Loria - Grid’5000 - Inria
- Contact: Lucas Nussbaum
- URL: http://distem.gforge.inria.fr

6.2. Grid’5000

Grid’5000 testbed

KEYWORDS: HPC - Cloud - Big data - Testbeds

FUNCTIONAL DESCRIPTION: The Grid’5000 experimental platform is a scientific instrument to support computer science research related to distributed systems, including parallel processing, high performance computing, cloud computing, operating systems, peer-to-peer systems and networks. It is distributed on 10 sites in France and Luxembourg. Grid’5000 is a unique platform as it offers to researchers many and varied hardware resources and a complete software stack to conduct complex experiments, ensure reproducibility and ease understanding of results.

NEWS OF THE YEAR: This year’s highlights include the TILECS workshop, and various improvements (update to Debian 10, several new clusters including the addition of 72 GPUs, etc.). More information on https://www.grid5000.fr/w/News

- Participants: Christian Pérez, David Loup, Frédéric Desprez, Laurent Lefèvre, Laurent Pouilloux, Marc Pinhède, Simon Delamare, Lucas Nussbaum, Teddy Valette and Alexandre Merlin
- Contact: Lucas Nussbaum
- URL: https://www.grid5000.fr/

6.3. SCUBA

A Tool Suite for the automated security assessment of IoT environments

KEYWORDS: Cybersecurity - Internet of things - Machine learning - Artificial intelligence

FUNCTIONAL DESCRIPTION: IoT devices are used in different fields of application, not only for the general public, but also in industrial environments. SCUBA is tool suite for the security assessment of industrial and general public IoT devices. It mainly relies on collected information through passive and active scanning of a running IoT device in its exploitation environment to build its Security Knowledge Base (SKB). The knowledge base contains all relevant information of the device regarding its network communications extracted from PCAP files, the enumeration of its used hardware and software represented in the CPE (Common Platform Enumeration) format, the list of its known vulnerabilities in the CVE (Common Vulnerabilities and Exposures) format associated to their CWE (Common Weakness Enumeration) and CAPEC (Common Attack Pattern Enumeration and Classification) descriptions. The SKB is used by SCUBA to predict the intrusion chains associated to an IoT device and its environment. SCUBA tries to be as automated as possible to face the large scale and the great heterogeneity of IoT networks.

NEWS OF THE YEAR: First release

- Participants: Abdelkader Lahmadi, Frédéric Beck, Thomas Lacour and Jérôme François
- Contact: Abdelkader Lahmadi

6.4. Platforms

6.4.1. CPS Security Assessment Platform

NEWS OF THE YEAR :

During 2019, we have extended our IoT (Internet of Things) and CPS (Cyber-Physical Systems) security assessment platform with more IoT devices dedicated to home networks (Alexa and Google Home voice assistants, smart door bell, smart door lock, alarm system). The platform is used for several demonstrations and it is extensively used for the development carried on the SCUBA (see 6.3) tool suite to automate the assessment of the security of IoT and SCADA systems by using ML/AI methods.

- Participants: Abdelkader Lahmadi, Frédéric Beck, Thomas Lacour and Jérôme François
- Contact: Abdelkader Lahmadi

7. New Results

7.1. Monitoring

7.1.1. Encrypted Traffic Analysis

Participants: Jérôme François [contact], Pierre-Olivier Brissaud, Pierre-Marie Junges, Isabelle Chrisment, Thibault Cholez, Olivier François, Olivier Bettan [Thales].

Nowadays, most of Web services are accessed through HTTPS. While preserving user privacy is important, it is also mandatory to monitor and detect specific users' actions, for instance, according to a security policy. Our paper [4] presents a solution to monitor HTTP/2 traffic over TLS. It highly differs from HTTP/1.1 over TLS traffic what makes existing monitoring techniques obsolete. Our solution, H2Classifier, aims at detecting if a user performs an action that has been previously defined over a monitored Web service, but without using any decryption. It is thus only based on passive traffic analysis and relies on random forest classifier. A challenge is to extract representative values of the loaded content associated to a Web page, which is actually customized based on the user action. Extensive evaluations with five top used Web services demonstrate the viability of our technique with an accuracy between 94% and 99%.

We were also interested by Internet of Things (IoT) as related devices become widely used and their control is often provided through a cloud-based web service that interacts with an IoT gateway, in particular for individual users and home automation. Therefore, we propose a technique demonstrating that is possible to infer private user information, i.e., actions performed, by considering a vantage point outside the end-user local IoT network. By learning the relationships between the user actions and the traffic sent by the web service to the gateway, we have been able to establish elementary signatures, one for each possible action, which can be then composed to discover compound actions in encrypted traffic. We evaluated the efficiency of our approach on one IoT gateway interacting with up to 16 IoT devices and showed that a passive attacker can infer user activities with an accuracy above 90%. This work has been published in [16] and is related to the H2020 SecureIoT project (section 9.3.1.2).

7.1.2. Predictive Security Monitoring for Large-Scale Internet-of-Things

Participants: Jérôme François [contact], Rémi Badonnel, Abdelkader Lahmadi, Isabelle Chrisment, Adrien Hemmer.

The Internet-of-Things has become a reality with numerous protocols, platforms and devices being developed and used to support the growing deployment of smart services. Providing new services requires the development of new functionalities, and the elaboration of complex systems that are naturally a source of potential threats. Real cases recently demonstrated that the IoT can be affected by naïve weaknesses. Therefore, security is of paramount importance.

In that context, we have proposed a process mining approach, that is capable to cope with a variety of devices and protocols, for supporting IoT predictive security [14]. We have described the underlying architecture and its components, and have formalized the different phases related to this solution, from the building of behavioral models to the detection of misbehaviors and potential attacks. The pre-processing identifies the states characterizing the IoT-based system, while process mining methods elaborate behavioral models that are compatible with the heterogeneity of protocols and devices [26]. These models are then exploited to analyze monitoring data at runtime and detect misbehaviors and potential attacks preventively. Based on a proof-of-concept prototype, we have quantified the detection performances, as well as the influence of time splitting and clustering techniques. The experimental results clearly show the benefits of our solution combining process mining and clustering techniques. As future work, we are interested in comparing it to other alternative learning techniques, as well as in evaluating to what extent the generated alerts can be exploited to drive the activation of counter-measures.

This work has been achieved in the context of the H2020 SecureIoT project (section 9.3.1.2).

7.1.3. Monitoring of Blockchains' Networking Infrastructure

Participants: Thibault Cholez [contact], Jean-Philippe Eisenbarth, Olivier Perrin.

With the raise of blockchains, their networking infrastructure becomes a critical asset as more and more money and services are made on top of them. However, they are largely undocumented and may be prone to performance issues and severe attacks so that the question of the resiliency of their overlay network arises. With regard to the state of the art on P2P networks security, the fact that a service infrastructure is distributed is not sufficient to assess its reliability, as many bias (for instance, if nodes are concentrated in a given geographical location) and attacks (eclipse, Sybil or partition attacks) are still possible and may severely disturb the network.

Overall, according to the scientific literature, the security provided by the proof of work consensus and the huge size of the main public blockchains seem to protect them well from large scale attacks (51% attack, selfish mining attack, etc.) whose cost to be successful becomes prohibitive and often exceeds the expected gain. However, rather than only focusing on the application level, an attacker could rather try to disturb the underlying P2P network to weaken the consensus in some specific parts of the blockchain network to gain advantage. Our current work uses a third-party crawler to get an accurate view of the Bitcoin overlay network. We are currently analyzing the data with graph theory metrics to identify possible anomalies or flaws that could be exploited by attackers.

7.1.4. Quality of Experience Monitoring

Participants: Isabelle Chrisment [contact], Antoine Chemardin, Frédéric Beck, Lakhdar Meftah [University of Lille], Romain Rouvoy [University of Lille].

We carried on our collaboration with the SPIRALS team (Inria/Université de Lille). Even though mobile crowdsourcing allows industrial and research communities to build realistic datasets, it can also be used to track participants' activity and to collect insightful reports from the environment (e.g., air quality, network quality). While data anonymization for mobile crowdsourcing is commonly achieved *a posteriori* on the server side, we have proposed a decentralized approach, named Fougere [19], which introduces an *a priori* data anonymization process. In order to validate our privacy preserving proposal, two testing frameworks (ANDROFLEET and PEERFLEET [20]) have been designed and implemented. They allows developers to automate reproducible testing of nearby peer-to-peer (P2P) communications.

In the context of both ANR BottleNet (section 9.2.1.1) and IPL BetterNet (section 9.2.5.1) projects, we continued to work on our open measurement platform for the quality of mobile Internet access (i.e., setup and manage the backend infrastructure for data collection and analysis). This platform is hosted by the High Security Laboratory [0] located at Inria Nancy Grand-Est. A collect campaign has been performed with a small set of volunteer users selected by the INSEAD-Sorbonne Université Behavioural Lab [0].

[0] https://lhs.loria.fr
[0] https://www.insead.edu/centres/insead-sorbonne-universite-lab-en

7.2. Experimentation

This section covers our work on experimentation on testbeds (mainly Grid'5000), on emulation (mainly around the Distem emulator), and on Reproducible Research.

7.2.1. Grid'5000 Design and Evolutions

Participants: Benjamin Berard [SED], Luke Bertot, Alexandre Merlin, Lucas Nussbaum [contact], Nicolas Perrin, Patrice Ringot [SISR LORIA], Teddy Valette [SED].

The team was again heavily involved in the evolutions and the governance of the Grid'5000 testbed.

Technical team management. Since the beginning of 2017, Lucas Nussbaum serves as the *directeur technique* (CTO) of Grid'5000 in charge of managing the global technical team (10 FTE). He is also a member of the *Bureau* of the GIS Grid'5000.

SILECS project. We are also heavily involved in the ongoing SILECS project, that aims to create a new infrastructure on top of the foundations of Grid'5000 and FIT in order to meet the experimental research needs of the distributed computing and networking communities.

SLICES ESFRI proposal. At the European level, we are involved in a ESFRI proposal submission. We submitted a *Design Study* project in November 2019, and are in the final stages of submitting the ESFRI proposal itself in early 2020.

TILECS workshop. We participated in the organization of the TILECS workshop. TILECS (*Towards an Infrastructure for Large-Scale Experimental Computer Science*, https://www.silecs.net/tilecs-2019/) gathered about 80 members (mostly faculty) of the testbeds designers and users community in France, to discuss the future plans for research infrastructures in the networking and distributed computing fields. During that workshop, Lucas Nussbaum presented Grid'5000 [32].

Group storage. A technical contribution from the team is the addition of a *group storage* service that allows groups of users to share data, with improved security and performance compared to what was previously available.

Support for Debian 10. Another notable technical contribution from the team is the work of Teddy Valette on supporting Debian 10 in the set of Grid'5000 system environments made available to users.

New clusters available in Nancy: graffiti, gros, grue. Finally, the team was also heavily involved in the purchase and installation of several new clusters in the Nancy site, gathering funding from CPER LCHN, CPER Entreprises, MULTISPEECH team, LARSEN team. This greatly increases the resources available locally, both for GPUs (graffiti and grue), and for large-scale experiments (gros).

7.2.2. Involvement in the Fed4FIRE Testbeds Federation

Participants: Luke Bertot, Lucas Nussbaum [contact].

In the context of the Fed4FIRE+ project (section 9.3.1.1), Grid'5000 was officially added to the Fed4FIRE federation at the beginning of 2019. In 2019, we implemented on-demand *stitching* between Grid'5000 experiments and other testbeds of the federation (through VLANs provided by GEANT and RENATER), allowing experiments that combine resources from Grid'5000 and other testbeds [27]. We are also improving our implementation of an SFA Aggregate Manager in order to allow the use of Grid'5000 through Fed4FIRE tools, such as the jFed GUI.

We also worked on the issue of classifying and presenting the set of testbeds available in the federation. This was the subject of a presentation at the GEFI collaboration workshop [31].

7.2.3. I/O Emulation Support in Distem

Participants: Alexandre Merlin, Abdulqawi Saif, Lucas Nussbaum [contact].

We finished the work on adding I/O emulation support in Distem, in order to experiment how Big Data solution can handle degraded situations [22].

7.2.4. Distributing Connectivity Management in Cloud-Edge infrastructures

Participant: Lucas Nussbaum [contact].

In the context of David Espinel's PhD (CIFRE Orange, co-supervised with Adrien Lebre and Abdelhadi Chari), we worked on distributing connectivity management in Cloud-Edge infrastructures [38]. The classic approach of deploying large data centers to provide Cloud services is being challenged by the emerging needs of Internet of Things applications, Network Function Virtualization services or Mobile edge computing. A massively distributed Cloud-Edge architecture could better fit the requirements and constraints of these new trends by deploying on-demand Infrastructure as a Service in different locations of the Internet backbone (i.e, network point of presences). A key requirement in this context is the establishment of connectivity among several virtual infrastructure managers in charge of operating each site. In this work, we analyzed the requirements and challenges raised by the inter-site connectivity management in a Cloud-Edge infrastructure.

7.2.5. NDN Experimentation

Participants: Thibault Cholez [contact], Xavier Marchal, Olivier Festor.

While ICN is a promising technology, we currently lack experiments carrying real user traffic. This also highlights the difficulty of making the link between the new NDN world and the current IP world. To address this issue, we designed and implemented an HTTP/NDN gateway (composed of ingress and egress gateways) that can seamlessly transport the traffic of regular web users over an NDN island, making them benefit from the good properties of the protocol to deliver content (request mutualization, caching, etc.). The gateway itself is part of a wider architecture that aims to use NFV to deploy NDN and benefit from its orchestration capability to address performance and security issues inherent to new network architectures.

To validate the whole architecture, a testbed involving real users was made. The gateway was used by dozens of users for a few weeks to prove that running a NDN network over NFV is a viable solution to address the transition between both worlds. Users accessed many websites through the NDN network in a very satisfying way. The results have been published in IEEE Communications Magazine [5].

7.3. Analytics

7.3.1. CPS Security Analytics

Participants: Abdelkader Lahmadi [contact], Mingxiao Ma, Isabelle Chrisment.

During 2019, we evaluated a novel type of attack, named Measurement as Reference attack (MaR), on the cooperative control and communication layers in microgrids, where the attacker targets the communication links between distributed generators (DGs) and manipulates the reference voltage data exchanged by their controllers. We assessed its impact on reference voltage synchronization at the different control layers of a microgrid. Results and the development of an experimental platform are presented in [18] to demonstrate this attack, in particular the maximum voltage deviation and inaccurate reference voltage synchronization it causes in a microgrid. ML algorithms are also applied on the collected datasets from this platform for the detection of this attack.

7.3.2. Optimal and Verifiable Packet Filtering in Software-Defined Networks

Participants: Abdelkader Lahmadi [contact], Ahmad Abboud, Michael Rusinowitch [Pesto team], Miguel Couceiro [Orpailleur team], Adel Bouhoula [Numeryx].

Packet filtering is widely used in multiple networking appliances and applications, in particular, to block malicious traffic (protection of network infrastructures through firewalls and intrusion detection systems). It is also widely deployed on routers, switches and load balancers for packet classification. This mechanism relies on the packet's header fields to filter such traffic by using range rules of IP addresses or ports. However, the set of packet filters has to handle a growing number of connected nodes and many of them are compromised and used as sources of attacks. For instance, IP filter sets available in blacklists may reach several millions of entries, and may require large memory space for their storage in filtering appliances. In [40], [39], we proposed a new method based on a double mask IP prefix representation together with a linear transformation algorithm to build a minimized set of range rules. We have formally defined the double mask representation over range rules and proved that the number of required masks for any range is at most $2w-4$, where w is the length of a field. This representation makes the network more secure, reliable and easier to maintain and configure. We show empirically that the proposed method achieves an average compression ratio of 11% on real-life blacklists and up to 74% on synthetic range rule sets. Finally, we add support of double mask into a real SDN network.

7.3.3. Port Scans Analysis

Participants: Jérôme François [contact], Frederic Beck, Sofiane Lagraa [University of Luxembourg], Yutian Chen [Telecom Nancy], Laurent Evrard [University of Namur], Jean-Noël Colin [University of Namur].

TCP/UDP port scanning or sweeping is one of the most common technique used by attackers to discover accessible and potentially vulnerable hosts and applications. Although extracting and distinguishing different port scanning strategies is a challenging task, the identification of dependencies among probed ports is primordial for profiling attacker behaviors, with as a final goal to better mitigate them. In [6], we proposed an approach that allows us to track port scanning behavior patterns among multiple probed ports and identify intrinsic properties of observed group of ports. Our method is fully automated and based on graph modeling and data mining techniques including text mining. It provides to security analysts and operators relevant information about services that are jointly targeted by attackers. This is helpful to assess the strategy of the attacker, such that understanding the types of applications or environment she targets. We applied our method to data collected through a large Internet telescope (or Darknet).

In addition, we decided to leverage this knowledge for improving data analysis techniques applied to network traffic monitoring. Network traffic monitoring is primordial for network operations and management for many purposes such as Quality-of-Service or security. However, one major difficulty when dealing with network traffic data (packets, flows...) is the poor semantic of individual attributes (number of bytes, packets, IP addresses, protocol, TCP/UDP port number...). Many attributes can be represented as numerical values but cannot be mapped to a meaningful metric space. Most notably are application port numbers. They are numerical but comparing them as integers is meaningless. In [13], [12], we propose a fine grained attacker behavior-based network port similarity metric allowing traffic analysis to take into account semantic relations between port numbers. The behavior of attackers is derived from passive observation of a Darknet or telescope, aggregated in a graph model, from which a semantic dissimilarity function is defined. We demonstrated the veracity of this function with real world network data in order to pro-actively block 99% of TCP scans.

7.4. Orchestration

7.4.1. Mutualization of Monitoring Functions in Edge Computing

Participants: Jérôme François [contact], Mohamed Abderrahim [Orange Labs], Meryem Ouzzif [Orange Labs], Karine Guillouard [Orange Labs], Adrien Lebre [STACK Inria team, IMT Atlantique], Charles Prud'Homme [IMT Atlantique], Xavier Lorca [IMT Mines Albi, France].

By relying on small sized and massively distributed infrastructures, the edge computing paradigm aims at supporting the low latency and high bandwidth requirements of the next generation services that will leverage IoT devices (e.g., video cameras, sensors). To favor the advent of this paradigm, management services, similar to the ones that made the success of cloud computing platforms, should be proposed. However, they should be designed in order to cope with the limited capabilities of the resources that are located at the edge. In that sense, they should mitigate as much as possible their footprint. Among the different management services that need to be revisited, we investigated in [10] the monitoring one. Monitoring functions tend to become compute-, storage-and network-intensive, in particular because they will be used by a large part of applications that rely on real-time data. To reduce as much as possible the footprint of the whole monitoring service, we proposed to mutualize identical processing functions among different tenants while ensuring their quality-of-service (QoS) expectations. We formalized our approach as a constraint satisfaction problem and show through micro-benchmarks its relevance to mitigate compute and network footprints.

This work has been achieved in the context of the Inria-Orange joint lab (section 9.2.2.1).

7.4.2. Software-Defined Security for Clouds

Participants: Rémi Badonnel [contact], Olivier Festor, Maxime Compastié.

Cloud infrastructures provide new facilities to build elaborated added-value services by composing and configuring a large variety of computing resources, from virtualized hardware devices to software products. They are however further exposed to security attacks than traditional environments. We have pursued our efforts on a software-defined security strategy based on the TOSCA language, in order to support the protection of cloud resources using unikernel techniques [11]. This language enables the specification of cloud services and their orchestration. We have extended it to drive the integration and configuration of security mechanisms within cloud resources, at the design and operation phases, according to different security levels. We rely on unikernel techniques to elaborate cloud resources using a minimal set of libraries, in order to reduce the attack surface. We have designed a framework to interpret this extended language and to generate and configure protected unikernel virtual machines, in accordance with contextual changes. The adaptation is typically performed through the regeneration of protected unikernel virtual machines in a dynamic manner. We have quantified the benefits and limits of this approach through extensive series of experiments. As future work, we are interested in investigating security issues specifically related to cloud resource migrations, and evaluating to what extent our hardening techniques can be complemented by security chains.

This word has been achieved in the context of the Inria-Orange joint lab (section 9.2.2.1).

7.4.3. Chaining of Security Functions

Participants: Rémi Badonnel [contact], Abdelkader Lahmadi, Stephan Merz, Nicolas Schnepf.

Software-defined networking offers new opportunities for protecting end users and their applications. It enables the elaboration of security chains that combines different security functions, such as firewalls, intrusion detection systems, and services for preventing data leakage. In that context, we have continued our efforts on the orchestration and verification of security chains, in collaboration with Stephan Merz from the VeriDis project-team at Inria Nancy, and concretized with the PhD defense of Nicolas Schnepf in September 2019 [3]. In particular, we have proposed this year an approach for automating the merging of security chains in software-defined networks [24]. This method complements the inference-based generation techniques that we proposed in [9]. The merging algorithms are designed to compose several security chains into a single one, in order to minimize the number of security functions and rules, while preserving the semantics of the initial chains. The algorithms have been implemented in Python and have been integrated into a proof-of-concept prototype that also contains the learning and inference components [23]. The performance of this implementation has been evaluated through extensive experiments. In particular, we have compared different approaches to merging security chains in terms of the complexity of the resulting chains, their accuracy, and the overhead incurred in computing the combined chains. The proposed solution is able to minimize the number of security functions and rules. It also facilitates the building of security chains at runtime, through a decoupling from the generation of individual chains.

7.4.4. Software-Defined Traffic Engineering to Absorb Influx of Network Traffic

Participants: Jérôme François [contact], Abdelkader Lahmadi, Romain Azais [MOSAIC team], Benoit Henry [IMT Lille Douai], Shihabur Chowdhury [University of Waterloo], Raouf Boutaba [University of Waterloo].

Existing shortest path-based routing in wide area networks or equal cost multi-path routing in data center networks do not consider the load on the links while taking routing decisions. As a consequence, an influx of network traffic stemming from events such as distributed link flooding attacks and data shuffle during large scale analytics can congest network links despite the network having sufficient capacity on alternate paths to absorb the traffic. This can have several negative consequences, service unavailability, delayed flow completion, packet losses, among others. In this regard and under the context of NetMSS associate team (section 9.4.1.1), we proposed SPONGE [15], a traffic engineering mechanism for handling sudden influx of network traffic. SPONGE models the network as a stochastic process, takes the switch queue occupancy and traffic rate as inputs, and leverages the multiple available paths in the network to route traffic in a way that minimizes the overall packet loss in the network. We demonstrated the practicality of SPONGE through an OpenFlow based implementation, where we periodically and pro-actively reroute network traffic to the routes computed by SPONGE. Mininet emulations using real network topologies show that SPONGE is capable of reducing packet drops by 20% on average even when the network is highly loaded because of an ongoing link flooding attack.

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Grants with Industry

- Thales (Palaiseau, France):
  - CIFRE PhD (Pierre-Olivier Brissaud, supervised by Isabelle Chrisment and Jérôme François)
  - Encrypted network traffic analysis (HTTP2 over TLS)
- Orange Labs (Issy-Les-Moulineaux, France):
  - CIFRE PhD (Paul Chaignon, supervised by Olivier Festor and Jérôme François)
  - Software Datapaths for Multi-Tenant Packet Processing
- Orange Labs (Issy-Les-Moulineaux, France):
  - CIFRE PhD (Matthews Jose, supervised by Olivier Festor and Jérôme François)
  - Complex arithmetic operation for in-network computing using hardware dataplanes
- Numeryx Technologies (Paris, France):
  - CIFRE PhD (Ahmad Abboud, supervised by Michael Rusinowitch, Abdelkader Lahmadi and Adel Bouhoula)
  - Compressed and Verifiable Filtering Rules in Software-defined Networking

9. Partnerships and Cooperations

9.1. Regional Initiatives

Olivier Festor is leading the Grand Est PACTE initiative on cyber-security. This initiative led to a total funding of 400 K€ to acquire, develop and operate the first Cyber Range in the Grand Est. This unique equipment is deployed at TELECOM Nancy and serves as the main platform for cyber-security training in the Grand Est region for both civil and military staff.

9.2. National Initiatives

9.2.1. ANR

9.2.1.1. ANR BottleNet

Participants: Isabelle Chrisment [contact], Antoine Chemardin, Thibault Cholez.

- Acronym: BottleNet
- Title: Understanding and Diagnosing End-to-End Communication Bottlenecks of the Internet
- Coordinator: Inria
- Duration: October 2015 - extended to September 2020
- Others Partners: Inria Muse, Inria Diana, Lille1 University, Telecom Sud-Paris, Orange, IP-Label.

- Abstract: The Quality of Experience (QoE) when accessing the Internet, on which more and more human activities depend on, is a key factor for today's society. The complexity of Internet services and of users' local connectivity has grown dramatically in the last years with the proliferation of proxies and caches at the core and access technologies at the edge (home wireless and 3G/4G access), making it difficult to diagnose the root causes of performance bottlenecks. The objective of BottleNet is to deliver methods, algorithms, and software systems to measure end-to-end Internet QoE and to diagnose the cause of the experienced issues. The result can then be used by users, network and service operators or regulators to improve the QoE.

9.2.1.2. ANR FLIRT

Participants: Rémi Badonnel [contact], Olivier Festor, Thibault Cholez, Jérôme François, Abdelkader Lahmadi, Laurent Andrey.

- Acronym: FLIRT
- Title: Formations Libres et Innovantes Réseaux et Télécoms
- Coordinator: Institut Mines-Télécom (Pierre Rolin)
- Duration: January 2016-Décembre 2020
- Others Partners: TELECOM Nancy, Institut Mines-Télécom, Airbus, Orange, the MOOC Agency, Isograd
- Site: http://flirtmooc.wixsite.com/flirt-mooc-telecom
- Abstract: FLIRT (Formations Libres et Innovantes Réseaux & Télécom) is an applied research project leaded by the Institut Mines-Télécom, for an (extended) duration of 5 years. It includes 14 academic partners (engineering schools including Telecom Nancy), industrial partners (Airbus, Orange) and innovative startups (the MOOC agency, and Isograd). The project is to build a collection of 10 MOOCs (Massive Open Online Courses) in the area of networks and telecommunications, three training programmes based on this collection, as well as several innovations related to pedagogical efficiency (such as virtualization of practical labs, management of student cohorts, and adaptative assessment). The RESIST team is leading a working group dedicated to the building and operation of a MOOC on network and service management. This MOOC covers the fundamental concepts, architectures and protocols of the domain, as well as their evolution in the context of future Internet (e.g. network programming, flow monitoring). It corresponds to a training program of 5 weeks. The main targeted skills are to understand the challenges of network and service management, to know the key methods and techniques related to this area, and to get familiar with the usage and parameterization of network management solutions.

9.2.1.3. ANR MOSAICO

Participants: Thibault Cholez [contact], Olivier Festor.

- Acronym: MOSAICO
- Title: Multi-layer Orchestration for Secured and low lAtency applICatiOns
- Coordinator: Orange Labs
- Start: 01/12/2019
- Duration: 4 years
- Others Partners: Orange Labs, Montimage, ICD-UTT
- Abstract:

  For several years, programmability has become increasingly important in network architectures. The last trend is to finely split services into micro-services. The expected benefits relies on an easier development and maintenance, better quality, scalability and responsiveness to new scenarios than monolithic approaches, while offering more possibilities for operators and management facilities through orchestration. As a consequence, it appears that network functions, such as routing, filtering, etc. can be split in several micro-services, implemented through different means, according to the software environments, and at different topological locations, thus opening the way to fully end-to-end programmable networks. This need for multi-level and multi-technology orchestration is even more important with the emergence of new services, such as immersive services, which exhibit very strong quality of service constraints (i.e. latency cannot exceed a few milliseconds), while preserving end-to-end security. The MOSAICO project proposes to design, implement and validate a global and multi-layer orchestration solution, able to control several underlying network programmability technologies (SDN, NFV, P4) to compose micro-services forming the overall network service. To reach this objective, the project will follow an experimental research methodology in several steps including the definition of the micro-services and of the global architecture, some synthetic benchmarking, the design of orchestration rules and the evaluation against the project use-case of a low latency network application.

The kick-off meeting of MOSAICO took place the 03/12/2019 in Orange Gardens. Our current work consists in surveying the latest technologies around NFV and Open Networking.

9.2.2. Inria joint Labs

9.2.2.1. Inria-Orange Joint Lab

Participants: Jérôme François [contact], Olivier Festor, Matthews Jose, Paul Chaignon.

- Acronym: IOLab
- Title: Inria - Orange Joint Laboratory
- Duration: September 2015 - August 2020
- Abstract: The challenges addressed by the Inria-Orange joint laboratory relate to the virtualization of communication networks, the convergence between cloud computing and communication networks, and the underlying software-defined infrastructures. Our work concerns in particular monitoring methods for software-defined infrastructures, and management strategies for supporting software-defined security in multi-tenant cloud environnements.

9.2.3. Technological Development Action (ADT)

9.2.3.1. ADT SCUBA

Participants: Abdelkader Lahmadi [Contact], Jérôme François, Thomas Lacour, Frédéric Beck.

- Acronym: SCUBA
- Duration: January 2018-January 2020
- Abstract: The goal of this ADT is to develop a tool suite to evaluate the security of industrial and general public IoT devices in their exploitation environment. The Tool suite relies on a set of security probes to collect information through passive and active scanning of a running IoT device in its exploitation environment to build its Security Knowledge Base (SKB). The knowledge base contains all relevant information of the device regarding its network communications, the enumeration of its used hardware and software, the list of its known vulnerabilities in the CVE format associated to their Common Weakness Enumeration (CWE) and Common Attack Pattern Enumeration and Classification (CAPEC) descriptions. The collected information is used to evaluate the devices associated with their usage scenarios and to identify intrusion chains in an automated way.

9.2.4. FUI

9.2.4.1. FUI PACLIDO

Participants: Abdelkader Lahmadi [contact], Mingxiao Ma, Isabelle Chrisment, Jérôme François.

- Acronym: PACLIDO
- Title: Lightweight Cryptography Protocols and Algorithms for IoT (Protocoles et Algorithmes Cryptographiques Légers pour l'Internet des Objets)
- Coordinator: ADS (Airbus Defence and Space)

- Duration: September 2017- August 2020
- Others Partners: Sophia Conseil, Université de Limoges, Cea tech, Trusted Objects, Rtone, Saint Quentin En Yvelines.
- Abstract: The goal of PACLIDO is to propose and develop lightweight cryptography protocols and algorithms to secure IoT communications between devices and servers. The implemented algorithms and protocols will be evaluated in multiple use cases including smart home and smart city applications. PACLIDO develops in addition an advanced security monitoring layer using machine learning methods to detect anomalies and attacks while traffic is encrypted using the proposed algorithms.

9.2.5. Inria Project Lab

9.2.5.1. IPL BetterNet

Participants: Isabelle Chrisment [contact], Antoine Chemardin, Frederic Beck, Thibault Cholez.

- Acronym: BetterNet
- Coordinator: RESIST (Isabelle Chrisment)
- Duration: October 2016-August 2020
- Others Partners: Inria MiMove, Inria Diana, Inria Spirals, Inria Dionysos, ENS-ERST and IP-Label
- Site: https://project.inria.fr/betternet
- Abstract: BetterNet's goal is to build and deliver a scientific and technical collaborative observatory to measure and improve the Internet service access as perceived by users. We will propose new user-centered measurement methods, which will associate social sciences to better understand Internet usage and the quality of services and networks. Tools, models and algorithms will be provided to collect data that will be shared and analyzed to offer valuable service to scientists, stakeholders and the civil society.

9.2.5.2. IPL Discovery

Participant: Lucas Nussbaum [contact].

- Coordinator: Adrien Lebre (STACK)
- End: June 2019
- Site: http://beyondtheclouds.github.io
- Others Partners: Orange, RENATER
- Abstract: To accommodate the ever-increasing demand for Utility Computing (UC) resources, while taking into account both energy and economical issues, the current trend consists in building larger and larger Data Centers in a few strategic locations. Although such an approach enables UC providers to cope with the actual demand while continuing to operate UC resources through a centralized software system, it is far from delivering sustainable and efficient UC infrastructures for future needs.

  The DISCOVERY initiative aims at exploring a new way of operating Utility Computing (UC) resources by leveraging any facilities available through the Internet in order to deliver widely distributed platforms that can better match the geographical spread of users as well as the ever increasing demand. Critical to the emergence of such locality-based UC (also referred as Fog/Edge Computing) platforms is the availability of appropriate operating mechanisms. The main objective of DISCOVERY is to design, implement, demonstrate and promote a new kind of Cloud Operating System (OS) that will enable the management of such a large-scale and widely distributed infrastructure in an unified and friendly manner.

9.3. European Initiatives

9.3.1. H2020 Projects

9.3.1.1. Fed4Fire+ (2017-2022)

Title: Federation for FIRE Plus

Program: H2020

Duration: January 2017 - December 2021

Coordinator: Interuniversitair Micro-Electronica centrum Imec VZW

Partners:

Universidad de Malaga; National Technical University of Athens - NTUA; The Provost, Fellows, Foundation Scholars & the other members of board of the College of the Holy & Undivided Trinity of Queen Elizabeth Near Dublin; Ethniko Kentro Erevnas Kai Technologikis Anaptyxis; GEANT LImited; Institut Jozef Stefan; Mandat International Alias Fondation Pour la Cooperation Internationale; Universite Pierre et Marie Curie - Paris 6; Universidad De Cantabria; Fundacio Privada I2CAT, Internet I Innovacio Digital A Catalunya; EURESCOM-European Institute For Research And Strategic Studies in Telecommunications GMBH; Nordunet A/S; Technische Universitaet Berlin; Instytut Chemii Bioorganicznej Polskiej Akademii Nauk; Fraunhofer Gesellschaft zur Foerderung Der Angewandten Forschung E.V.; Universiteit Van Amsterdam; University of Southampton; Martel GMBH; Atos Spain SA; Institut National de Recherche en Informatique et automatique.

Inria contact: David Margery (for RESIST: Lucas Nussbaum)

Abstract: Fed4FIRE+ is a successor project to Fed4FIRE. In Fed4FIRE+, we more directly integrate Grid’5000 into the wider eco-system of experimental platforms in Europe and beyond using results we developped in Fed4FIRE. We will also provide a generalised proxy mechanisms to allow users with Fed4FIRE identities to interact with services giving access to different testbeds but not designed to support Fed4FIRE identities. Finally, we will work on orchestration of experiments in a federation context.

9.3.1.2. SecureIoT

Title: Predictive Security for IoT Platforms and Networks of Smart Objects

Duration: December 2017 - December 2020

Coordinator: INTRASOFT International SA

Partners:

Fujitsu Technology Solutions GMBH; Atos Spain S.A; Siemens SRL; Singularlogic S.A.; IDIADA Automotive Technology SA; P@SSPORT Holland B.V.; UBITECH LIMITED; Innovation Sprint Sprl; DWF Germany Rechtsanwaltsgesellschaft mbH; LuxAI S.A.; Institut National de Recherche en Informatique et automatique; it’s OWL Clustermanagement GmbH; Research and Education Laboratory in Information Technologies – Athens Information Technology (AIT).

Inria contact: Jérôme François

Url : http://secureiot.eu

Abstract: SecureIoT is a a joint effort of global leaders in IoT services and IoT cybersecurity to secure the next generation of dynamic, decentralized IoT systems, that span multiple IoT platforms and networks of smart objects, through implementing a range of predictive IoT security services. SecureIoT will integrate its security services in three different application scenarios in the areas of: Digital Automation in Manufacturing (Industry 4.0), Socially assistive robots for coaching and healthcare and Connected cars and Autonomous Driving.

Emerging cross-platform interactions and interactions across networks of smart objects require more dynamic, scalable, decentralized and intelligent IoT security mechanisms. Such mechanisms are highly demanded by the industry in order to secure a whole new range of IoT applications that transcend the boundaries of multiple IoT platforms, while involving autonomous interactions between intelligent CPS systems and networks of smart objects. In this direction, the main objectives of the project are to predict and anticipate the behavior of IoT systems, facilitate compliance to security and privacy regulations and provide APIs and tools for trustworthy IoT solutions.

9.3.1.3. SPARTA

Title: Strategic programs for advanced research and technology in Europe

Program: H2020

Duration: February 2019 - January 2022

Coordinator: Commissariat à l'Energie Atomique et aux Energies Alternatives

Partners: see web site

Inria contact: Jérôme François

Url : http://www.sparta.eu

Abstract: Cybersecurity is an urgent and major societal challenge. In correlation with the digitization of our societies, cyberthreats are having an increasing impact on our lives: it is essential to ensure digital security and strategic autonomy of the EU by strengthening its cybersecurity capacities. This challenge will require the coordination of Europe's best competences, along with strong international cooperations, towards common research and innovation goals.

SPARTA is a novel cybersecurity competence network, with the objective to collaboratively develop and implement top-tier research and innovation actions. Strongly guided by concrete challenges forming an ambitious Cybersecurity Research & Innovation Roadmap, SPARTA will tackle hard innovation challenges, leading the way in building transformative capabilities and forming a world-leading cybersecurity competence network across the EU. Four initial research and innovation programs will push the boundaries to deliver advanced solutions to cover emerging issues, with applications from basic human needs to economic activities, technologies, and sovereignty.

9.3.1.4. CONCORDIA

Participants: Thibault Cholez [contact], Rémi Badonnel, Olivier Festor.

Acronym: CONCORDIA

Title: Cyber security cOmpeteNCe fOr Research anD InnovAtion

Program: H2020

Start: 01/01/2019

Duration: 4 years

Coordinator: Research Institute CODE (Munich, Germany)

Partners: 52 partners, 26 academic and 26 industrial, from 19 countries (please see https://www.concordia-h2020.eu/consortium)

Url : https://www.concordia-h2020.eu/

Abstract: CONCORDIA is one of the 4 pilot projects whose goal is to structure and develop a network of cybersecurity competences across Europe. CONCORDIA has a research program to develop next-generation cybersecurity solutions by taking a holistic end-to-end data-driven approach from data acquisition, data transport and data usage, and addressing device-centric, network-centric, software-centric, system-centric, data-centric and user-centric security. The solutions will be integrated in sector-specific (vertical) and cross-sector (horizontal) industrial pilots with building incubators. Vertical pilots include Telecom, Finance, e-Health, Defence and e-Mobility, while horizontal pilots are about two European-scale federated platforms that are the DDoS clearing house and the Threat Intelligence platform . CONCORDIA also develops a CONCORDIA ecosystem by providing lab infrastructures, platforms, tools as "Living Labs" as well as advanced cybersecurity courses on cyber-ranges.

The project kick-off took place in Munich the 28/01/2019. The team is mainly involved in three tasks (research, education and European dimension). On the research side, we begun our work on assessing the reliability of blockchains' networking infrastructure (see section 7.1.3). Regarding the education in cybersecurity, we set up a cyber-range at TELECOM Nancy which was officially launched the 24/09/2019 and is already used by our M1 and M2 students to be trained in cybersecurity. We worked also for the task "Liaison with stakeholders" and were in particular the main editor of the 1st year deliverable of this task.

9.4. International Initiatives

9.4.1. Inria Associate Teams Not Involved in an Inria International Labs

9.4.1.1. NetMSS

Title: NETwork Monitoring and Service orchestration for Softwarized networks

International Partner (Institution - Laboratory - Researcher):

University of Waterloo (Canada), David R. Cheriton School of Computer Science - Raouf Boutaba

Start year: 2018

Duration: 3 years

See also: https://team.inria.fr/netmss/

Evolution towards softwarized networks are greatly changing the landscape in networking. In the last years, effort was focused on how to integrate network elements in cloud-based models. This lead to the advent of network function virtualization primarily relying on regular virtualization technologies and on some advances in network programmability. Several architectural models have been proposed and, even if no full consensus has been reached yet, they highlight the major components. Among them, monitoring and orchestration are vital elements in order to ensure a proper assessment of the network conditions (network monitoring) serving as the support for the decision when deploying services (orchestration). With softwarization of networks, these elements can benefit from a higher flexibility but the latter requires new methods to be efficiently handled. For example, monitoring softwarized networks necessitates the collection of heterogeneous information, regarding the network but also cloud resources, from many locations. Targeting such a holistic monitoring will then support better decision algorithms, to be applied in a scalable and efficient manner, taking advantage of the advanced capabilities in terms of network configuration and programmability. In addition, real-time constraints in networking are very strong due to the transient nature of network traffic and are faced with high throughputs, especially in data-center networks where softwarization primarily takes place. Therefore, the associate team will promote (1) line-rate and accurate monitoring and (2) efficient resource uses for service orchestration leveraging micro-services.

9.4.2. Inria International Partners

9.4.2.1. Declared Inria International Partners

The team is actively involved in the international program of LUE (Lorraine Université d'Excellence):

Prof. Raouf Boutaba (University of Waterloo): Inria International Chair and Professor@Lorraine

Abir Laraba: international PhD grant in cooperation with University of Waterloo

Mehdi Zakroum: international PhD grant in cooperation with International University of Rabat

9.4.2.2. Informal International Partners

Since 2019, we have started a collaboration with Sonia Mettali from the CRISTAL Lab at the ENSI engineering school (Tunisia) on the development of reinforcement learning methods for the monitoring of IoT. The work is done in the context of the PhD of Mohamed Said Frikha, jointly co-supervised by Sonia Mettali and Abdelkader Lahmadi.

9.4.3. Participation in Other International Programs

9.4.3.1. ThreatPredict

- Title: ThreatPredict, From Global Social and Technical Big Data to Cyber Threat Forecast
- Coordinator: Inria
- Duration: December 2017 - November 2020
- Others Partners: International University of Rabat (IUR), Carnegie Mellon University
- Funding: North Atlantic Treaty Organization
- Abstract: Predicting attacks can help to prevent them or at least reduce their impact. Nowadays, existing attack prediction methods make accurate predictions only hours in advance or cannot predict geo-politically motivated attacks. ThreatPredict aims to predict different attack types days in advance. It develops machine-learning algorithms that capture the spatio-temporal dynamics of cyber-attacks and global social, geo-political and technical events. Various sources of information are collected, enriched and correlated such as honeypot data, darknet, GDELT, Twitter, and vulnerability databases. In addition to warning about attacks, this project will improve our understanding of the effect of global events on cyber-security.

9.5. International Research Visitors

9.5.1. Visits of International Scientists

Professor Adel Bouhoula from SUP'COM (Tunisia) from June 2019 until July 2019 in collaboration with PESTO team to develop methods for optimal and verifiable security policies for software-defined networks.

Dashi Kondo, Assistant Professor in Osaka Prefecture University for two weeks in November 2019 to develop new scientific cooperation on network security.

9.5.1.1. Internships

Anthony Samer Abou Jaoude, from March 2019 until May 2019.

Tarek Nsiri, from June 2019 until September 2019.

9.5.2. Visits to International Teams

9.5.2.1. Research Stays Abroad

Abdelkader Lahmadi visited the team of Professor Raouf Boutaba in the University of Waterloo for two weeks during the month of June 2019. During this visit, he provided an IEEE seminar on the topic of Self-Driving Networks.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events: Organisation

10.1.1.1. General Chair, Scientific Chair

Olivier Festor: IEEE Conference on Network Softwarization (NetSoft 2019), general co-chair.

Isabelle Chrisment: IEEE/IFIP International Workshop on Analytics for Network and Service Management (AnNet 2020), general co-chair.

10.1.1.2. Member of the Organizing Committees

Laurent Andrey: IEEE Conference on Network Softwarization (NetSoft 2019), web chair.

Rémi Badonnel: IEEE International Symposium on Integrated Network Management (IM 2019); IFIP International Conference on Networking (Networking 2020); IEEE/IFIP Network Operations and Management Symposium (NOMS 2020).

Olivier Festor: IEEE International Symposium on Integrated Network Management (IM 2019), member of the steering committee & Publications co-chair; IEEE/IFIP Network Operations and Management Symposium (NOMS 2020), tutorial co-chair; IFIP International Conference on Networking (Networking 2020), patrons co-chair.

Thibault Cholez: IEEE/IFIP Workshop on Security for Emerging Distributed Network Technologies (DISSECT 2020).

Isabelle Chrisment: Rendez-vous de la Recherche et de l'Enseignement de la Sécurité des Systèmes d'Information (RESSI 2019), member of the steering committee.

Jérôme François: Rendez-vous de la Recherche et de l'Enseignement de la Sécurité des Systèmes d'Information (RESSI 2019), member of the steering committee; IEEE International Conference on Blockchain and Cryptocurrency (ICBC 2019), demonstration co-chair.

Abdelkader Lahmadi : IEEE International Symposium on Integrated Network Management (IM 2019), co-chair of the workshop HotNSM; IEEE/IFIP Network Operations and Management Symposium (NOMS 2020), publicity co-chair.

Lucas Nussbaum: TILECS workshop.

10.1.2. Scientific Events: Selection

10.1.2.1. Chair of Conference Program Committees

Rémi Badonnel: IEEE/IFIP/In Coop. with ACM SIGCOMM International Conference on Network and Service Management (CNSM 2019), technical program committee co-chair; IEEE International Symposium on Integrated Network Management (IM 2019), experience program committee co-chair; IEEE/IFIP Network Operations and Management Symposium (NOMS 2020), experience program committee co-chair.

Olivier Festor: IEEE International Symposium on Integrated Network Management (IM 2019), Tutorial chair; IEEE Conference on Network Softwarization (NetSoft 2019), Technical Program Committee co-chair; IEEE/IFIP/In Coop. with ACM SIGCOMM International Conference on Network and Service Management (CNSM 2019).

Isabelle Chrisment: IFIP, in-cooperation with ACM SIGCOMM Network Traffic Measurement and Analysis Conference (TMA 2019).

Jérôme François: IEEE International Symposium on Integrated Network Management (IM 2019); IEEE/IFIP Workshop on Security for Emerging Distributed Network Technologies (DISSECT 2019); IEEE Workshop on Emerging Trends in Softwarized Networks (ETSN 2019).

10.1.2.2. Member of the Conference Program Committees

Laurent Andrey: IEEE Conference on Network Softwarization (NetSoft 2019).

Rémi Badonnel: IEEE/IFIP/In Coop. with ACM SIGCOMM International Conference on Network and Service Management (CNSM 2019); IEEE International Symposium on Integrated Network Management (IM 2019); IEEE Conference on Network Softwarization (NetSoft 2019); IEEE/IFIP International Workshop on Analytics for Network and Service Management (AnNet 2019); IEEE Global Information Infrastructure and Networking Symposium (GIIS 2019); IEEE International Conference on Communications (ICC 2020); IEEE/IFIP Network Operations and Management Symposium (NOMS 2020).

Isabelle Chrisment: IEEE/IFIP/In Coop. with ACM SIGCOMM International Conference on Network and Service Management (CNSM 2019); IEEE International Symposium on Integrated Network Management (IM 2019); IEEE/IFIP International Workshop on Analytics for Network and Service Management (AnNet 2019); Rencontres Francophones sur la Conception de Protocoles, l'Évaluation de Performance et l'Expérimentation des Réseaux de Communication (CoRes 2019); IEEE/IFIP Network Operations and Management Symposium

(NOMS 2020); ACM/IEEE International Conference on Internet of Things Design and Implementation (IoTDI 2020);

Thibault Cholez: IEEE International Conference on Blockchain and Cryptocurrency (ICBC 2019); IEEE International Conference on Cloud Networking (CloudNet 2019); IEEE International Symposium on Integrated Network Management (IM 2019); IEEE/IFIP Workshop on Security for Emerging Distributed Network Technologies (DISSECT 2019); IEEE/IFIP International Workshop on Managing and Managed by Blockchain (Man2block 2019); IEEE/IFIP Network Operations and Management Symposium (NOMS 2020).

Olivier Festor: IEEE/IFIP/In Coop. with ACM SIGCOMM International Conference on Network and Service Management (CNSM 2019); IEEE International Symposium on Integrated Network Management (IM 2019); IEEE Conference on Network Softwarization (NetSoft 2019); IEEE/IFIP Network Operations and Management Symposium (NOMS 2020); IEEE/IFIP/In Coop. with ACM SIGCOMM International Conference on Network and Service Management (CNSM 2020); IEEE Conference on Network Softwarization (NetSoft 2020); IFIP International Conference on Networking (Networking 2020).

Jérôme François: IFIP, in-cooperation with ACM SIGCOMM Network Traffic Measurement and Analysis Conference (TMA 2019); IEEE INFOCOM Workshop on Cryptocurrencies and Blockchains for Distributed Systems (CryBlock 2019); Conference on Blockchain Research & Applications for Innovative Networks and Services (BRAINS 2019); IEEE/IFIP International Workshop on Managing and Managed by Blockchain (Man2block 2019).

Abdelkader Lahmadi: IEEE INFOCOM Workshop on Cryptocurrencies and Blockchains for Distributed Systems (CryBlock 2019); IEEE/IFIP International Workshop on Managing and Managed by Blockchain (Man2block 2019); IEEE/IFIP Network Operations and Management Symposium (NOMS 2020); IEEE International Symposium on Integrated Network Management (IM 2019); IEEE Conference on Network Softwarization (NetSoft 2019); Cyber Security in Networking Conference (CSNet 2019); IEEE Workshop on Emerging Trends in Softwarized Networks (ETSN 2019).

Lucas Nussbaum: International Conference on Enabling Technologies: Infrastructure for Collaborative Entreprises (WETICE 2019); 39^{th} IEEE International Conference on Distributed Computing System (ICDCS 2019); 16^{th} International Conference on Mining Software Repositories (MSR 2019 – FOSS award); 11^{th} IEEE International Conference on Cloud Computing Technology and Science (CloudCom 2019). 5^{th} International Workshop on Serverless Computing (WoSC 2019); 54^{th} IEEE International Conference on Communications (ICC) – NGNI Symposium; IEEE Global Information Infrastructure and Networking Symposium (GIIS 2019).

10.1.2.3. Reviewer

The permanent team members made many reviews for the conferences the team is involved in.

10.1.3. Journal

10.1.3.1. Member of the Editorial Boards

Rémi Badonnel: Associate Editor for the Wiley International Journal of Network Management (IJNM), Associate Editor for the Springer Journal of Network and System Management (JNSM)and guest editor for the IEEE Transactions on Network and Service Management (TNSM).

Isabelle Chrisment: Associate Editor for the IEEE Transactions on Network and Service Management (TNSM).

Abdelkader Lahmadi : Associate Editor for the Wiley International Journal of Network Management (IJNM)and Guest Editor for a special issue of Springer Journal of Network and System Management (JNSM).

Jérôme François: Associate Editor-In-Chief for the Wiley International Journal of Network Management (IJNM).

10.1.3.2. Reviewer - Reviewing Activities

Rémi Badonnel: IEEE Transactions on Network and Service Management (TNSM), IEEE Journal on Selected Areas in Communications (JSAC), Springer Journal of Network and System Management (JNSM), IEEE Communications Magazine (COMMAG), Wiley International Journal of Network Management (IJNM) and Elsevier Journal of Industrial Information Integration (JIII).

Thibault Cholez: IEEE Transactions on Network and Service Management (TNSM), IEEE Communications Magazine (COMMAG), Elsevier Journal on Communication Networks (COMNET)and SIGCOMM Computer Communication Review.

Isabelle Chrisment: IEEE Transactions on Network and Service Management (TNSM).

Laurent Andrey: Springer Journal of Network and System Management (JNSM) and Wiley International Journal of Network Management (IJNM).

Jérôme François: IEEE Transactions on Network and Service Management (TNSM), IEEE Journal on Selected Areas in Communications (JSAC) and Wiley International Journal of Network Management (IJNM).

Abdelkader Lahmadi : IEEE Transactions on Network and Service Management (TNSM), IEEE Journal on Selected Areas in Communications (JSAC), Wiley International Journal of Network Management (IJNM), Springer Journal of Network and System Management (JNSM), IEEE Communications Magazine (COMMAG) and Elsevier Journal Computer Communications (COMCOM).

Lucas Nussbaum: International Journal of Grid and Utility Computing (IJGUC).

10.1.4. Invited Talks

Abdelkader Lahmadi provided a keynote on "Toward Self-driving Networks: Network Management and Security Challenges" in the IEEE/IFIP Workshop on Security for Emerging Distributed Network Technologies (DISSECT), 8 April, 2019, Washington D.C., USA.

Isabelle Chrisment provided a talk on "Experimentation in Cybersecurity: from Requirements to Platforms" in the TILECS (Towards an Infrastructure for Large-Scale Experimental Computer Science) workshop, 3-4 July 2019, Grenoble, France.

Olivier Festor gave a keynote on the coupling of Information Centric Networks and Programmable Networks at the Orange Network of the Future workshop in may 2019. He also gave a talk at the Distinguished Experts Panel of IEEE/IFIP IM'2019 in Washington on Intelligent Management and gave a short invited presentation entitled “Opening the Network for More Secure Services” at the SecSoft 2019 workshop in Paris on June 24th, 2019.

10.1.5. Leadership within the Scientific Community

Rémi Badonnel has been elected as the chair of the IFIP (International Federation for Information Processing) WG6.6 (Working Group 6.6) dedicated to the management of networks and distributed systems.

Isabelle Chrisment has been a co-chair of the Allistene cybersecurity working group, whose main goal is to help drive the French cybersecurity research and innovation.

Olivier Festor is a member of the IEEE/IFIP NISC (NOMS IM Stering Committee) which manages the set of conferences in the area of network and service management for both IEE and IFIP scientific communities worldwide.

Jérôme François has been appointed as co-chair of NMRG (Network Management Research Group) of IRTF (Internet Research Task Force).

10.1.6. Scientific Expertise

Isabelle Chrisment served as an expert of the HCERES (High Council for Evaluation of Research and Higher Education) committee for the LISTIC Laboratory. She was a member of the GDR RSD/ASF selection committee for the thesis award. She is also a member of the AFNIC's Scientific Council.

Abdelkader Lahmadi served as reviewer for ANRT (CIFRE PhD). Abdelkader Lahmadi has contributed to the writing of a document about the protection of critical infrastructures in transport and energy within the working group "enjeux 2025" of CoFIS (Comité de la Filière industrielle de sécurité).

Olivier Festor is a member of the Scientific Council of Orange and Director of TELECOM Nancy, the graduate Engineering School of Computer Science at the University of Lorraine. He is also contributing to the HCERES national scientific evaluation board.

Jérôme François and Rémi Badonnel serve as reviewers for ANRT (CIFRE PhD). Jérôme François is in the advisory board of the Interreg TERMINAL project (2019-2021).

10.1.7. Research Administration

Thibault Cholez is a member of the executive council of the Digitrust project (I-Site project of the Université de Lorraine to foster research on trust and security in IT).

Isabelle Chrisment is also an elected member of the scientific pole AM2I (Automatique, Mathématiques, Informatique et leurs Interaction) at Université de Lorraine. She is a member of the COMIPERS at Inria Nancy Grand Est. She is also involved in the CMI (Commission de la Mention Informatique) board, which is a part of the doctoral school IAEM.

Abdelkader Lahmadi is a member of the CDT of Inria Nancy Grand Est.

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Olivier Festor is the Director of the TELECOM Nancy Engineering School.

Rémi Badonnel is heading the Internet Systems and Security specialization of the 2nd and 3rd years at the TELECOM Nancy engineering school, and is coordinating the Security Pathway Program at the same school, elaborated in the context of the International Master of Science in Security of Computer Systems built with the Mines Nancy school.

Thibault Cholez is in charge of the organization of professional projects for the three years of TELECOM Nancy students in apprenticeship.

Team members are teaching the following courses:

Rémi Badonnel 242 hours - L3, M1, M2 - Networks, Systems and Services, Software Design and Programming, Cloud Computing, Network and Security Management - TELECOM Nancy, Université de Lorraine

Thibault Cholez 290 hours - L3, M1, M2 - Computer Networks, Object-Oriented Programming, Network Services, Constraint development on small Connected Objects, Mobile applications and Internet of Things, IT tools for Project Management - TELECOM Nancy, Université de Lorraine

Isabelle Chrisment 220 hours -L3, M1, M2 -C and Shell Programming, Computer Networking, Operating Systems, Network Security. - TELECOM Nancy, Université de Lorraine

Jérôme François 70 hours - M1, M2 -Network security, Big Data - TELECOM Nancy, Université de Lorraine

Abdelkader Lahmadi 280 hours - L3, M1, M2 - Real time and Embedded Systems Programming, Distributed Systems and Algorithms, Green IT, Algorithms and Advanced Programming, Security of Cyber Physical Systems - ENSEM Engineering School, Université de Lorraine

Lucas Nussbaum 200 hours - L2, Licence Pro (L3), M1 - several courses about systems administration, monitoring, virtualization, configuration management, networking, operating systems. - IUT Nancy-Charlemagne

E-learning

MOOC *Supervision de Réseaux et Services (Session 2)*, FUN Project, Université de Lorraine, Ingénieur, formation initiale et continue, Thibault Cholez, Rémi Badonnel, Laurent Andrey, Olivier Festor, Abdelkader Lahmadi, Jérôme François, January-March 2019, over 6000 from 77 countries, and 347 certificates of achievement. Each MOOC Resist participant contributed to the 2019 maintenance for a third opening on January 2020.

10.2.2. Supervision

PhD in progress: Ahmad Abboud, *Compressed and verifiable filtering rules in Software-defined Networking*, since September 2018, supervised by Michael Rusinowitch, Abdelkader Lahmadi, and Adel Bouhoula.

PhD in progress: Pierre-Olivier Brissaud, *Encrypted traffic analysis*, since July 2016, supervised by Isabelle Chrisment, Jérôme François and Thibault Cholez.

PhD in progress: Jean-Philippe Eisenbarth, *Securing the future blockchain-based security services*, since May 2019, supervised by Thibault Cholez and Olivier Perrin (Coast team).

PhD in progress: David Espinel, *SDN solution for Massively Distributed Cloud Infrastructure*, since February 2018, supervised by Lucas Nussbaum, Adrien Lebre and Abdelhadi Chari.

PhD in progress: Adrien Hemmer, *Predictive Security Monitoring for Large-Scale Internet-of-Things*, since October 2018, supervised by Isabelle Chrisment and Rémi Badonnel.

PhD in progress: Pierre-Marie Junges, *Internet-wide automated assessment of the exposure of the IoT devices to security risks*, since October 2018 supervised by Olivier Festor and Jérôme François.

PhD in progress: Mingxiao Ma, *Cyber-Physical Systems defense through smart network configuration*, since Novemeber 2017, supervised by Isabelle Chrisment, Abdelkader Lahmadi.

PhD in progress: Abdulqawi Saif, *Open Science for the scalability of a new generation search technology*, since December 2015, supervised by Ye-Qiong Song & Lucas Nussbaum.

PhD in progress: Matthews Jose, *Programming model for new flow-based network monitoring*, since January 2019, supervised by Olivier Festor & Jérôme François.

PhD in progress: Data-Driven Intelligent Monitoring for Software-Defined Networks, *Programming model for new flow-based network monitoring*, since October 2018, supervised by Isabelle Chrisment, Raouf Boutaba & Jérôme François.

PhD in progress: Abir Laraba, *Data-Driven Intelligent Monitoring for Software-Defined Networks*, since October 2018, supervised by Isabelle Chrisment, Raouf Boutaba & Jérôme François.

PhD in progress: Mehdi Zakroum, *Forecasting cyberthreats from exogeneous data*, since October 2019, supervised by Isabelle Chrisment & Jérôme François.

PhD: Paul Chaignon, *Software Datapaths for Multi-Tenant Packet Processing*, supervised by Olivier Festor, Jérôme François and Kahina Lazri [1].

PhD: Xavier Marchal, Secure operation of virtualized Named Data Networks, supervised by Olivier Festor & Thibault Cholez [2].

PhD: Nicolas Schnepf, *Orchestration and Verification of Security Functions for Smart Environments*, supervised by Stephan Merz, Rémi Badonnel and Abdelkader Lahmadi [3].

PhD: Lakhdar Meftah, *Towards Privacy-sensitive Mobile Crowdsourcing*, supervised by Romain Rouvoy (University of Lille) and Isabelle Chrisment.

10.2.3. Juries

Team members participated to the following Ph.D. defense committees:

- Damien Crémilleux, PhD in Computer Science from CentraleSupélec, Rennes, France. Title: Visualization for information system security monitoring, February 2019 – (Isabelle Chrisment as president).

- Philippe Pittoli, PhD in Computer Science from the University of Strasbourg, France.Title: Influence d'une architecture de type maître-esclave dans les problématiques de l'Internet des Objets. May 2019 – (Isabelle Chrisment as reviewer).
- Kallol Krishna Karmakar, PhD in Computer Science from the University of Newcastle, Australia. Title: Techniques for Securing Software Defined Networks and Services, June 2019 – (Isabelle Chrisment as reviewer).
- Pierre-Marie Bajan, Phd in Computer Science from Télécom SudParis, France. Title: Simulation d'attaque et d'activité : application à la cyber-défense, July 2019 – (Isabelle Chrisment as examiner).
- Muhammad Jawad Khokhar, PhD in Computer Science from the University of Nice-Sophia Antipolis, France. Title: Modeling Quality of Experience of Internet Video Streaming by Controlled Experimentation and Machine Learning, October 2019 - (Isabelle Chrisment as examiner).
- François Boutigny, Phd in Computer Science from Télécom SudParis, France. Title: Multidomain Virtual Network Embedding under Security-oriented Requirements applied to 5G Networks Slices, November 2019 – (Isabelle Chrisment as examiner).
- Fetia Bannour, PhD in Computer Science and Electrical Engineering from the Paris-Est Créteil University, France. Title: Contributions pour le contrôle distribué dans les réseaux SDN, November 2019 - (Olivier Festor as reviewer).
- Danilo Cerovic, PhD in Computer Science from Sorbonne Université, Paris, France. Title: Architecture réseau résiliente et hautement performante pour les datacenters virtualisés, February 2019 - (Olivier Festor as reviewer).

Team members participated to the following Habilitation Degree committees:

- Nozar Kheir, Habilitation Degree in Computer Science from Université Paris-Saclay, France. Title : From Cyber-secure to Cyber-resilient Computer Systems - The way forward, May 2019 - (Olivier Festor as reviewer).

10.3. Popularization

10.3.1. Articles and contents

Abdelkader Lahmadi and Frédéric Beck provided a podcast about the security of connected devices available at Interstices (https://interstices.info/des-outils-pour-evaluer-la-securite-des-objets-connectes/)

Thibault Cholez gave an interview for the *factuel* (newsletter of the University of Lorraine) to present the H2020 project CONCORDIA (https://factuel.univ-lorraine.fr/node/11394). He also wrote a blog entry entitled "Assessing blockchains' network infrastructure: why it matters for cybersecurity" for the CONCORDIA website (https://www.concordia-h2020.eu/blog-post/assessing-blockchains-network-infrastructure-why-it-matters-for-cybersecurity/).

Isabelle Chrisment contributed to the ARCEP Report entitled "The State of the Internet in France", June 2019, page 19, https://www.arcep.fr/uploads/tx_gspublication/rapport-etat-internet-2019-270619.pdf (French version) or https://en.arcep.fr/uploads/tx_gspublication/report-state-internet-2019-eng-270619.pdf (English version).

Jérôme François has been interviewed by France 3 Lorraine to present how cyberthreat can be predicted in the context of ThreatPredict (section 9.4.3.1). He also gave an introduction to network security in the context of FAN (https://fan.inria.fr/)

10.3.2. Education

Isabelle Chrisment participated in the SNT (Sciences Numériques et Technologie) MOOC, more especially in the design of a video entitled "Internet IP, a universal protocol?" in the module "Internet and Networks. The SNT MOOC is a FUN Project dedicated to the teachers in high schools to help them within the context of the high school reform.

10.3.3. Internal action

Jérôme François presented ThreatPredict (section 9.4.3.1) at the “Café des Sciences” in Inria Rocquencourt Center.

11. Bibliography

Publications of the year

Doctoral Dissertations and Habilitation Theses

[1] P. CHAIGNON.*Software Datapaths for Multi-Tenant Packet Processing*, Université de Lorraine, May 2019, https://hal.univ-lorraine.fr/tel-02315651

[2] X. MARCHAL.*Architectures and advanced functions for a progressive deployment of Information-Centric Networking*, Université de Lorraine, June 2019, https://hal.univ-lorraine.fr/tel-02315611

[3] N. SCHNEPF.*Orchestration and verification of security functions for smart devices*, Université de Lorraine, September 2019, https://hal.univ-lorraine.fr/tel-02351769

Articles in International Peer-Reviewed Journal

[4] P.-O. BRISSAUD, J. FRANÇOIS, I. CHRISMENT, T. CHOLEZ, O. BETTAN.*Transparent and Service-Agnostic Monitoring of Encrypted Web Traffic*, in "IEEE Transactions on Network and Service Management", September 2019, vol. 16, n^{o} 3, p. 842-856 [*DOI :* 10.1109/TNSM.2019.2933155], https://hal.inria.fr/hal-02316644

[5] G. DOYEN, T. CHOLEZ, W. MALLOULI, B. MATHIEU, H.-L. MAI, X. MARCHAL, D. KONDO, M. AOUADJ, A. PLOIX, E. MONTES DE OCA, O. FESTOR.*An Orchestrated NDN Virtual Infrastructure transporting Web Traffic: Design, Implementation and First Experiments with Real End-Users*, in "IEEE Communications Magazine", June 2019, vol. 57, n^{o} 6 [*DOI :* 10.1109/MCOM.2019.1800730], https://hal.inria.fr/hal-02353861

[6] S. LAGRAA, Y. CHEN, J. FRANÇOIS.*Deep Mining Port Scans from Darknet*, in "International Journal of Network Management", February 2019, https://hal.inria.fr/hal-02403715

[7] D. MARS, S. METTALI GAMMAR, A. LAHMADI, L. AZOUZ SAIDANE.*Using Information Centric Networking in Internet of Things: A Survey*, in "Wireless Personal Communications", March 2019, vol. 105, n^{o} 1, p. 87-103 [*DOI :* 10.1007/s11277-018-6104-8], https://hal.inria.fr/hal-02393632

[8] T. NGUYEN, H.-L. MAI, R. COGRANNE, G. DOYEN, W. MALLOULI, L. NGUYEN, M. EL AOUN, E. MONTES DE OCA, O. FESTOR.*Reliable Detection of Interest Flooding Attack in Real Deployment of Named Data Networking*, in "IEEE Transactions on Information Forensics and Security", September 2019, vol. 14, n^{o} 9, p. 2470-2489 [*DOI :* 10.1109/TIFS.2019.2899247], https://hal.archives-ouvertes.fr/hal-02068457

[9] N. SCHNEPF, R. BADONNEL, A. LAHMADI, S. MERZ.*Rule-Based Synthesis of Chains of Security Functions for Software-Defined Networks*, in "Electronic Communications of the EASST", 2019, vol. 076, https://hal.inria.fr/hal-02397981

Invited Conferences

[10] M. ABDERRAHIM, M. OUZZIF, K. GUILLOUARD, J. FRANÇOIS, A. LEBRE, C. PRUD'HOMME, X. LORCA.*Efficient Resource Allocation for Multi-tenant Monitoring of Edge Infrastructures*, in "PDP 2019 - 27th Euromicro International Conference on Parallel, Distributed and Network-Based Processing", Pavie, Italy, 27th Euromicro International Conference on Parallel, Distributed and Network-Based Processing, IEEE, 2019, p. 1-8 [*DOI :* 10.1109/EMPDP.2019.8671621], https://hal.inria.fr/hal-01987946

International Conferences with Proceedings

[11] M. COMPASTIÉ, R. BADONNEL, O. FESTOR, R. HE.*A TOSCA-Oriented Software-Defined Security Approach for Unikernel-Based Protected Clouds*, in "NetSoft 2019 - IEEE Conference on Network Softwarization", Paris, France, IEEE, June 2019, p. 151-159 [*DOI :* 10.1109/NETSOFT.2019.8806623], https://hal.archives-ouvertes.fr/hal-02271520

[12] L. EVRARD, J. FRANÇOIS, J.-N. COLIN, F. BECK.*port2dist: Semantic Port Distances for Network Analytics*, in "IFIP/IEEE Symposium on Integrated Network and Service Management (IM 2019) - Demo session", Washington, United States, April 2019, https://hal.inria.fr/hal-02345491

[13] L. EVRARD, J. FRANÇOIS, J.-N. COLIN.*Attacker Behavior-Based Metric for Security Monitoring Applied to Darknet Analysis*, in "IFIP/IEEE Symposium on Integrated Network and Service Management (IM 2019)", Washington, United States, April 2019, https://hal.inria.fr/hal-02345457

[14] A. HEMMER, R. BADONNEL, I. CHRISMENT.*A Process Mining Approach for Supporting IoT Predictive Security*, in "Network Operations and Management Symposium", Budapest, Hungary, April 2020, https://hal.inria.fr/hal-02402986

[15] B. HENRY, S. R. CHOWDHURY, A. LAHMADI, R. AZAÏS, J. FRANÇOIS, R. BOUTABA.*SPONGE: Software-Defined Traffic Engineering to Absorb Influx of Network Traffic*, in "44th IEEE Conference on Local Computer Networks (LCN)", Osnabrück, Germany, October 2019, https://hal.archives-ouvertes.fr/hal-02403616

[16] P.-M. JUNGES, J. FRANCOIS, O. FESTOR.*Passive Inference of User Actions through IoT Gateway Encrypted Traffic Analysis*, in "IFIP/IEEE Symposium on Integrated Network and Service Management (IM 2019) Workshop: 5th International Workshop on Security for Emerging Distributed Network Technologies (DISSECT 2019)", Washington, United States, April 2019, https://hal.inria.fr/hal-02331783

[17] S. LAGRAA, M. CAILAC, S. RIVERA, F. BECK, R. STATE.*Real-time attack detection on robot cameras: A self-driving car application*, in "IEEE IRC 2019 - Third IEEE International Conference on Robotic Computing", Naples, Italy, February 2019, https://hal.inria.fr/hal-02063304

[18] M. MA, A. LAHMADI, I. CHRISMENT.*Demonstration of Synchronization Attacks on Distributed and Cooperative Control in Microgrids*, in "The 16th IFIP/IEEE Symposium on Integrated Network and Service Management (IM 2019)", Washington DC, United States, April 2019, https://hal.archives-ouvertes.fr/hal-02389307

[19] L. MEFTAH, R. ROUVOY, I. CHRISMENT.*FOUGERE: User-Centric Location Privacy in Mobile Crowdsourcing Apps*, in "19th IFIP International Conference on Distributed Applications and Interoperable Systems (DAIS)", Kongens Lyngby, Denmark, J. PEREIRA, L. RICCI (editors), Distributed Applications and Interop-

erable Systems, Springer International Publishing, 2019, vol. LNCS-11534, p. 116-132 [*DOI :* 10.1007/978-3-030-22496-7_8], https://hal.inria.fr/hal-02121311

[20] L. MEFTAH, R. ROUVOY, I. CHRISMENT.*Testing Nearby Peer-to-Peer Mobile Apps at Large*, in "MOBILESoft 2019 - 6th IEEE/ACM International Conference on Mobile Software Engineering and Systems", Montréal, Canada, D. POSHYVANYK, I. MALAVOLTA (editors), May 2019, https://hal.inria.fr/hal-02059088

[21] P. ROLIN, D. MOALIC, R. BADONNEL, O. BERGER, J. FOUZAI.*A collection of MOOCs to create digital programs*, in "OOFHEC 2019: the Online, Open and Flexible Higher Education Conference", Madrid, Spain, October 2019, p. 86-99, https://conference.eadtu.eu/download2527, https://hal.archives-ouvertes.fr/hal-02398007

[22] A. SAIF, A. MERLIN, O. DAUTRICOURT, M. HOUBRE, L. NUSSBAUM, Y.-Q. SONG.*Emulation of Storage Performance in Testbed Experiments with Distem*, in "CNERT 2019 - IEEE INFOCOM International Workshop on Computer and Networking Experimental Research using Testbeds", Paris, France, April 2019, 6, https://hal.inria.fr/hal-02078301

[23] N. SCHNEPF, R. BADONNEL, A. LAHMADI, S. MERZ.*A Tool Suite for the Automated Synthesis of Security Function Chains*, in "IFIP/IEEE IM 2019 - IFIP/IEEE International Symposium on Integrated Network Management", Washington, United States, April 2019, https://hal.inria.fr/hal-02111658

[24] N. SCHNEPF, R. BADONNEL, A. LAHMADI, S. MERZ.*Automated Factorization of Security Chains in Software-Defined Networks*, in "IFIP/IEEE IM 2019 - IFIP/IEEE International Symposium on Integrated Network Management", Washington, United States, April 2019, https://hal.inria.fr/hal-02111656

[25] W. M. SHBAIR, M. STEICHEN, J. FRANÇOIS, R. STATE.*BlockZoom: Large-Scale Blockchain Testbed*, in "2019 IEEE International Conference on Blockchain and Cryptocurrency (ICBC) - Demo", Seoul, South Korea, IEEE, May 2019, p. 5-6 [*DOI :* 10.1109/BLOC.2019.8751230], https://hal.inria.fr/hal-02403717

[26] A. VULPE, A. PAIKAN, R. CRACIUNESCU, P. ZIAFATI, S. KYRIAZAKOS, A. HEMMER, R. BADONNEL.*IoT Security Approaches in Social Robots for Ambient Assisted Living Scenarios*, in "The 22nd International Symposium on Wireless Personal Multimedia Communications", Lisbon, Portugal, November 2019, https://hal.inria.fr/hal-02402950

National Conferences with Proceeding

[27] D. DELABROYE, S. DELAMARE, D. LOUP, L. NUSSBAUM.*Remplacer un routeur par un serveur Linux : retour d'expérience des passerelles d'accès à Grid'5000*, in "JRES - Journées Réseaux de l'Enseignement et de la Recherche", Dijon, France, December 2019, https://hal.inria.fr/hal-02401684

Conferences without Proceedings

[28] S. HADDAD-VANIER, C. GICQUEL, L. BOUKHATEM, K. LAZRI, P. CHAIGNON.*Virtual network functions placement for defense against distributed denial of service attacks*, in "8th International Conference on Operations Research and Enterprise Systems ICORES 2019", Praque, Czech Republic, February 2019, https://hal.archives-ouvertes.fr/hal-02421693

[29] M. LAURENT, O. PAUL, G. BLANC, B. CARRON, N. CHARBONNIER, I. CHRISMENT, J. FRANÇOIS, D. HOTZ, P. JAILLON, R. KHATOUN, C. KIENNERT, M. LAZRAG, S. MASMOUDI.*MOOC Sécurité des réseaux: un apprentissage massif de la sécurité par la théorie et la pratique*, in "RESSI 2019: Rendez-vous de

la Recherche et de l'Enseignement de la Sécurité des Systèmes d'Information", Erquy, France, RESSI 2019 Rendez-vous de la Recherche et de l'Enseignement de la Sécurité des Systèmes d'Information, 2019, p. 1-4, https://hal.archives-ouvertes.fr/hal-02437172

[30] H.-L. MAI, M. AOUADJ, G. DOYEN, W. MALLOULI, E. MONTES DE OCA, O. FESTOR.*Toward Content-Oriented Orchestration: SDN and NFV as Enabling Technologies for NDN*, in "IM 2019 - IFIP/IEEE Symposium on Integrated Network and Service Management (IM)", Arlington, United States, IEEE, April 2019, https://hal-utt.archives-ouvertes.fr/hal-02274785

[31] L. NUSSBAUM.*An overview of Fed4FIRE testbeds – and beyond?*, in "GEFI - Global Experimentation for Future Internet Workshop", Coimbra, Portugal, November 2019, https://hal.inria.fr/hal-02401738

[32] L. NUSSBAUM.*SILECS/Grid'5000: le volet data-center de SILECS : Présentation et exemples d'expériences*, in "TILECS - Towards an Infrastructure for Large-Scale Experimental Computer Science", Grenoble, France, July 2019, https://hal.inria.fr/hal-02401836

Scientific Books (or Scientific Book chapters)

[33] *5th IEEE Conference on Network Softwarization, NetSoft 2019, Paris, France*, June 2019, https://hal.archives-ouvertes.fr/hal-02296176

[34] *TMA 2019 - Proceedings of the 3rd Network Traffic Measurement and Analysis Conference*, IEEE, Paris, France, June 2019, https://hal.archives-ouvertes.fr/hal-02296177

[35] *Proceedings of the 15th International Conference on Network and Service Management (CNSM 2019)*, October 2019, https://hal.archives-ouvertes.fr/hal-02398019

[36] J. BETSER, C. FUNG, A. CLEMM, J. FRANÇOIS, A. SHINGO, R. BADONNEL, G. M. MOURA. , IEEE (editor)*16th IFIP/IEEE International Symposium on Integrated Network Management (IM 2019) - Experience Session*, IEEE, April 2019, https://hal.archives-ouvertes.fr/hal-02398024

Research Reports

[37] A. SAIF, L. NUSSBAUM, Y.-Q. SONG.*On the Impact of I/O Access Patterns on SSD Storage*, Inria, January 2020, n° RR-9319, https://hal.inria.fr/hal-02430564

Scientific Popularization

[38] D. ESPINEL SARMIENTO, A. LEBRE, L. NUSSBAUM, A. CHARI.*Distributing connectivity management in Cloud-Edge infrastructures : Challenges and approaches*, in "COMPAS 2019 - Conférence d'informatique en Parallélisme, Architecture et Système", Anglet, France, June 2019, p. 1-7, https://hal.inria.fr/hal-02133606

Other Publications

[39] A. ABBOUD, A. LAHMADI, M. RUSINOWITCH, M. COUCEIRO, A. BOUHOULA.*Minimizing Range Rules for Packet Filtering Using a Double Mask Representation*, May 2019, IFIP Networking 2019, Poster, https://hal.inria.fr/hal-02393008

[40] A. ABBOUD, A. LAHMADI, M. RUSINOWITCH, M. COUCEIRO, A. BOUHOULA, S. E. H. AWAINIA, M. AYADI.*Minimizing Range Rules for Packet Filtering Using Double Mask Representation*, April 2019, working paper or preprint, https://hal.inria.fr/hal-02102225

[41] M. BERMAN, T. FRIEDMAN, A. GOSAIN, K. KEAHEY, R. MCGEER, I. MOERMAN, A. NAKAO, L. NUSSBAUM, K. RAUSCHENBACH, V. SYROTIUK, M. VEERARAGHAVAN, N. YAMANAKA.*Report of the Third Global Experimentation for Future Internet (GEFI 2018) Workshop*, January 2019, https://arxiv.org/abs/1901.02929 - working paper or preprint, https://hal.inria.fr/hal-01978579

[42] D. MARGERY, L. NUSSBAUM.*Estimation of Costs and Pay per Use on a Large-scale Shared Computer Science Testbed: the Grid'5000 Case*, February 2019, working paper or preprint, https://hal.inria.fr/hal-02011425

References in notes

[43] J. ARON.*The internet is almost full*, in "New Scientist", 2015, vol. 226, n^{o} 3022, 20

[44] D. BALOUEK, A. CARPEN-AMARIE, G. CHARRIER, F. DESPREZ, E. JEANNOT, E. JEANVOINE, A. LÈBRE, D. MARGERY, N. NICLAUSSE, L. NUSSBAUM, O. RICHARD, C. PÉREZ, F. QUESNEL, C. ROHR, L. SARZYNIEC.*Adding Virtualization Capabilities to the Grid'5000 Testbed*, in "Cloud Computing and Services Science", I. IVANOV, M. SINDEREN, F. LEYMANN, T. SHAN (editors), Communications in Computer and Information Science, Springer International Publishing, 2013, vol. 367, p. 3-20 [*DOI :* 10.1007/978-3-319-04519-1_1], https://hal.inria.fr/hal-00946971

[45] T. BUCHERT, C. RUIZ, L. NUSSBAUM, O. RICHARD.*A survey of general-purpose experiment management tools for distributed systems*, in "Future Generation Computer Systems", 2015, vol. 45, p. 1-12 [*DOI :* 10.1016/J.FUTURE.2014.10.007], https://hal.inria.fr/hal-01087519

[46] D. J. RICHARDSON.*Filling the Light Pipe*, in "Science", 2010, vol. 330, n^{o} 6002, p. 327–328

[47] L. SARZYNIEC, T. BUCHERT, E. JEANVOINE, L. NUSSBAUM.*Design and Evaluation of a Virtual Experimental Environment for Distributed Systems*, in "PDP2013 - 21st Euromicro International Conference on Parallel, Distributed and Network-Based Processing", Belfast, United Kingdom, February 2013, https://hal.inria.fr/hal-00724308

[48] C. TANKARD.*Advanced Persistent threats and how to monitor and deter them*, in "Network Security", 2011, vol. 2011, n^{o} 8, p. 16-19

Project-Team SEMAGRAMME

Semantic Analysis of Natural Language

IN COLLABORATION WITH: Laboratoire lorrain de recherche en informatique et ses applications (LORIA)

IN PARTNERSHIP WITH:
CNRS

Université de Lorraine

RESEARCH CENTER
Nancy - Grand Est

THEME
Language, Speech and Audio

Table of contents

Project-Team SEMAGRAMME

Creation of the Team: 2011 January 01, updated into Project-Team: 2013 July 01

Keywords:

Computer Science and Digital Science:

A5.8. - Natural language processing
A7.2. - Logic in Computer Science
A9.4. - Natural language processing

Other Research Topics and Application Domains:

B9.6.8. - Linguistics

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2. Overall Objectives

2.1. Scientific Context

Computational linguistics is a discipline at the intersection of computer science and linguistics. On the theoretical side, it aims to provide computational models of the human language faculty. On the applied side, it is concerned with natural language processing and its practical applications.

From a structural point of view, linguistics is traditionally organized into the following sub-fields:

- Phonology, the study of language abstract sound systems.
- Morphology, the study of word structure.
- Syntax, the study of language structure, i.e., the way words combine into grammatical phrases and sentences.
- Semantics, the study of meaning at the levels of words, phrases, and sentences.
- Pragmatics, the study of the ways in which the meaning of an utterance is affected by its context.

Computational linguistics is concerned by all these fields. Consequently, various computational models, whose application domains range from phonology to pragmatics, have been developed. Among these, logic-based models play an important part, especially at the "highest" levels.

At the level of syntax, generative grammars may be seen as basic inference systems, while categorial grammars are based on substructural logics specified by Gentzen sequent calculi. Finally, model-theoretic grammars amount to sets of logical constraints to be satisfied.

At the level of semantics, the most common approaches derive from Montague grammars, which are based on the simply typed λ-calculus and Church's simple theory of types. In addition, various logics (modal, hybrid, intensional, higher-order...) are used to express logical semantic representations.

At the level of pragmatics, the situation is less clear. The word *pragmatics* has been introduced by Morristo designate the branch of philosophy of language that studies, besides linguistic signs, their relation to their users and the possible contexts of use. The definition of pragmatics was not quite precise, and, for a long time, several authors have considered (and some authors are still considering) pragmatics as the wastebasket of syntax and semantics. Nevertheless, as far as discourse processing is concerned (which includes pragmatic problems such as pronominal anaphora resolution), logic-based approaches have also been successful. In particular, Kamp's Discourse Representation Theorygave rise to sophisticated 'dynamic' logics. The situation, however, is less satisfactory than it is at the semantic level. On the one hand, we are facing a kind of logical "tower of Babel". The various pragmatic logic-based models that have been developed, while sharing underlying mathematical concepts, differ in several respects and are too often based on *ad hoc* features. As a consequence, they are difficult to compare and appear more as competitors than as collaborative theories that could be integrated. On the other hand, several phenomena related to discourse dynamics (e.g., context updating, presupposition projection and accommodation, contextual reference resolution...) are still lacking deep logical explanations. We strongly believe, however, that this situation can be improved by applying to pragmatics the same approach Montague applied to semantics, using the standard tools of mathematical logic.

Accordingly:

> *The overall objective of the Sémagramme project is to design and develop new unifying logic-based models, methods, and tools for the semantic analysis of natural language utterances and discourses. This includes the logical modeling of pragmatic phenomena related to discourse dynamics. Typically, these models and methods will be based on standard logical concepts (stemming from formal language theory, mathematical logic, and type theory), which should make them easy to integrate.*

The project is organized along three research directions (i.e., *syntax-semantics interface*, *discourse dynamics*, and *common basic resources*), which interact as explained below.

2.2. Syntax-Semantics Interface

The Sémagramme project intends to focus on the semantics of natural languages (in a wider sense than usual, including some pragmatics). Nevertheless, the semantic construction process is syntactically guided, that is, the constructions of logical representations of meaning are based on the analysis of the syntactic structures. We do not want, however, to commit ourselves to such or such specific theory of syntax. Consequently, our approach should be based on an abstract generic model of the syntax-semantic interface.

Here, an important idea of Montague comes into play, namely, the "homomorphism requirement": semantics must appear as a homomorphic image of syntax. While this idea is almost a truism in the context of mathematical logic, it remains challenged in the context of natural languages. Nevertheless, Montague's idea has been quite fruitful, especially in the field of categorial grammars, where van Benthem showed how syntax and semantics could be connected using the Curry-Howard isomorphism. This correspondence is the keystone of the syntax-semantics interface of modern type-logical grammars. It also motivated the definition of our own Abstract Categorial Grammars [37].

Technically, an Abstract Categorial Grammar simply consists of a (linear) homomorphism between two higher-order signatures. Extensive studies have shown that this simple model allows several grammatical formalisms to be expressed, providing them with a syntax-semantics interface for free [39],[3].

We intend to carry on with the development of the Abstract Categorial Grammar framework. At the foundational level, we will define and study possible type theoretic extensions of the formalism, in order to increase its expressive power and its flexibility. At the implementation level, we will continue the development of an Abstract Categorial Grammar support system.

As said above, considering the syntax-semantics interface as the starting point of our investigations allows us not to be committed to some specific syntactic theory. The Montagovian syntax-semantics interface, however, cannot be considered to be universal. In particular, it does not seem to be well adapted to dependency and model-theoretic grammars. Consequently, in order to be as generic as possible, we intend to explore alternative models of the syntax-semantics interface. In particular, we will explore relational models where several distinct semantic representations can correspond to the same syntactic structure.

2.3. Discourse Dynamics

It is well known that the interpretation of a discourse is a dynamic process. Take a sentence occurring in a discourse. On the one hand, it must be interpreted according to its context. On the other hand, its interpretation affects this context, and must therefore result in an updating of the current context. For this reason, discourse interpretation is traditionally considered to belong to pragmatics. The cut between pragmatics and semantics, however, is not that clear.

As we mentioned above, we intend to apply to some aspects of pragmatics (mainly, discourse dynamics) the same methodological tools Montague applied to semantics. The challenge here is to obtain a completely compositional theory of discourse interpretation, by respecting Montague's homomorphism requirement. We think that this is possible by using techniques coming from programming language theory, in particular, continuation semantics, and the related theories of functional control operators.

We have indeed successfully applied such techniques in order to model the way quantifiers in natural languages may dynamically extend their scope [38]. We intend to tackle, in a similar way, other dynamic phenomena (typically, anaphora and referential expressions, presupposition, modal subordination...).

What characterizes these different dynamic phenomena is that their interpretations need information to be retrieved from a current context. This raises the question of the modeling of the context itself. At a foundational level, we have to answer questions such as the following. What is the nature of the information to be stored in the context? What are the processes that allow implicit information to be inferred from the context? What are the primitives that allow a context to be updated? How does the structure of the discourse and the discourse relations affect the structure of the context? These questions also raise implementation issues. What are the appropriate datatypes? How can we keep the complexity of the inference algorithms sufficiently low?

2.4. Common Basic Resources

Even if our research primarily focuses on semantics and pragmatics, we nevertheless need syntax. More precisely, we need syntactic trees to start with. We consequently need grammars, lexicons, and parsing algorithms to produce such trees. During the last years, we have developed the notion of interaction grammar [32] and graph rewriting [1], [2] as models of natural language syntax. This includes the development of grammars for French [33], together with morpho-syntactic lexicons. We intend to continue this line of research and development. In particular, we want to increase the coverage of our grammars for French, and provide our parsers with more robust algorithms.

Further primary resources are needed in order to put at work a computational semantic analysis of utterances and discourses. As we want our approach to be as compositional as possible, we must develop lexicons annotated with semantic information. This opens the quite wide research area of lexical semantics.

Finally, when dealing with logical representations of utterance interpretations, the need for inference facilities is ubiquitous. Inference is needed in the course of the interpretation process, but also to exploit the result of the interpretation. Indeed, an advantage of using formal logic for semantic representations is the possibility of using logical inference to derive new information. From a computational point of view, however, logical inference may be highly complex. Consequently, we need to investigate which logical fragments can be used efficiently for natural language oriented inference.

3. Research Program

3.1. Overview

The research program of Sémagramme aims to develop models based on well-established mathematics. We seek two main advantages from this approach. On the one hand, by relying on mature theories, we have at our disposal sets of mathematical tools that we can use to study our models. On the other hand, developing various models on a common mathematical background will make them easier to integrate, and will ease the search for unifying principles.

The main mathematical domains on which we rely are formal language theory, symbolic logic, and type theory.

3.2. Formal Language Theory

Formal language theory studies the purely syntactic and combinatorial aspects of languages, seen as sets of strings (or possibly trees or graphs). Formal language theory has been especially fruitful for the development of parsing algorithms for context-free languages. We use it, in a similar way, to develop parsing algorithms for formalisms that go beyond context-freeness. Language theory also appears to be very useful in formally studying the expressive power and the complexity of the models we develop.

3.3. Symbolic Logic

Symbolic logic (and, more particularly, proof-theory) is concerned with the study of the expressive and deductive power of formal systems. In a rule-based approach to computational linguistics, the use of symbolic logic is ubiquitous. As we previously said, at the level of syntax, several kinds of grammars (generative, categorial...) may be seen as basic deductive systems. At the level of semantics, the meaning of an utterance is captured by computing (intermediate) semantic representations that are expressed as logical forms. Finally, using symbolic logics allows one to formalize notions of inference and entailment that are needed at the level of pragmatics.

3.4. Type Theory and Typed λ-Calculus

Among the various possible logics that may be used, Church's simply typed λ-calculus and simple theory of types (a.k.a. higher-order logic) play a central part. On the one hand, Montague semantics is based on the simply typed λ-calculus, and so is our syntax-semantics interface model. On the other hand, as shown by Gallin, the target logic used by Montague for expressing meanings (i.e., his intensional logic) is essentially a variant of higher-order logic featuring three atomic types (the third atomic type standing for the set of possible worlds).

4. Application Domains

4.1. Deep Semantic Analysis

Our applicative domains concern natural language processing applications that rely on a deep semantic analysis. For instance, one may cite the following ones:

- textual entailment and inference,
- dialogue systems,
- semantic-oriented query systems,
- content analysis of unstructured documents,
- text transformation and automatic summarization,
- (semi) automatic knowledge acquisition.

4.2. Text Transformation

Text transformation is an application domain featuring two important sub-fields of computational linguistics:

- parsing, from surface form to abstract representation,
- generation, from abstract representation to surface form.

Text simplification or automatic summarization belong to that domain.

We aim at using the framework of Abstract Categorial Grammars we develop to this end. It is indeed a reversible framework that allows both parsing and generation. Its underlying mathematical structure of λ-calculus makes it fit with our type-theoretic approach to discourse dynamics modeling.

5. New Software and Platforms

5.1. ACGtk

Abstract Categorial Grammar Development Toolkit

KEYWORDS: Natural language processing - NLP - Syntactic analysis - Semantics

SCIENTIFIC DESCRIPTION: Abstract Categorial Grammars (ACG) are a grammatical formalism in which grammars are based on typed lambda-calculus. A grammar generates two languages: the abstract language (the language of parse structures), and the object language (the language of the surface forms, e.g., strings, or higher-order logical formulas), which is the realization of the abstract language.

ACGtk provides two software tools to develop and to use ACGs: acgc, which is a grammar compiler, and acg, which is an interpreter of a command language that allows one, in particular, to parse and realize terms.

FUNCTIONAL DESCRIPTION: ACGtk provides softwares for developing and using Abstract Categorial Grammars (ACG).

RELEASE FUNCTIONAL DESCRIPTION: This version removes the dependency to obsolete packages. It also provides a better handling of the command line interface.

NEWS OF THE YEAR: The new version removes dependencies to obsolete libraries. It improves the command line interface and prepares the integration of new functionalities and optimizations.

- Participants: Philippe de Groote, Jiri Marsik, Sylvain Pogodalla and Sylvain Salvati
- Contact: Sylvain Pogodalla
- Publications: A syntax-semantics interface for Tree-Adjoining Grammars through Abstract Categorial Grammars - ACGTK: un outil de développement et de test pour les grammaires catégorielles abstraites - Discourse Modeling with Abstract Categorial Grammars - On the expressive power of Abstract Categorial Grammars: Representing context-free formalisms - Towards abstract categorial grammars
- URL: http://acg.loria.fr/

5.2. Dep2pict

KEYWORDS: Syntactic analysis - Semantics

FUNCTIONAL DESCRIPTION: Dep2pict is a program for drawing graphical representation of dependency structures of natural language sentences. Dep2pict takes into account the modified format mixing surface and deep syntactic information used in deep-sequoia.

- Contact: Bruno Guillaume
- URL: http://dep2pict.loria.fr/

5.3. Grew

Graph Rewriting

KEYWORDS: Semantics - Syntactic analysis - Natural language processing - Graph rewriting

FUNCTIONAL DESCRIPTION: Grew is a Graph Rewriting tool dedicated to applications in NLP. Grew takes into account confluent and non-confluent graph rewriting and it includes several mechanisms that help to use graph rewriting in the context of NLP applications (built-in notion of feature structures, parametrization of rules with lexical information).

NEWS OF THE YEAR: In 2019, the Grew software was enriched with a new syntax for edges (it is now possible to use feature structures as edge labels).

The Grew-match tool (http://match.grew.fr) is an online service available where a user can query different corpora with graph matching requests. All UD corpora (157 in 90 different languages in v2.5) are available and data from several other projects can also be queried. In the last 12 months (December 2018 to November 2019), 32,465 requests were received on the Grew-match server. The number of requests has increased in the last months (7,948 in November 2019).

An experiment was conducted to test the usage of the matching part of Grew on larger graphs. In the internship of Axel Didier, we experiment graph query on the French lexical network, RL-Fr.

- Participants: Bruno Guillaume, Guy Perrier and Guillaume Bonfante
- Contact: Bruno Guillaume
- Publications: Application de la réécriture de graphes au traitement automatique des langues - Application of Graph Rewriting to Natural Language Processing
- URL: http://grew.fr/

5.4. ZombiLingo

KEYWORDS: Syntactic analysis - Natural language processing - Lexical resource - Collaborative science

FUNCTIONAL DESCRIPTION: ZombiLingo is a prototype of a GWAP (Game With A Purpose) where gamers have to give linguistic information about the syntax of natural language sentences, currently in French, and later to other languages.

NEWS OF THE YEAR: Karën Fort and Bruno Guillaume proposed a new version of ZombiLingo this year. It is named ZombiLudik (https://zombiludik.org) and the main difference is that the linguistic data used are now based on the Universal Dependencies (UD) framework. Due to the recent success of the UD project, this format is now used for data in 90 different languages and we hope to find new collaborations to work on a similar games for some foreign languages. A first demonstration version was built on English data (https://en.zombiludik.org). Karën Fort and Bruno Guillaume presented the English version of the game in June during the NIEUW consortium meeting in London.

- Authors: Bruno Guillaume, Karën Fort, Nicolas Lefebvre and Valentin Stern
- Contact: Karën Fort
- URL: http://zombilingo.org/

6. New Results

6.1. Syntax-Semantics Interface

Participants: Philippe de Groote, Sylvain Pogodalla, William Babonnaud.

6.1.1. Abstract Categorial Grammars

We have worked on implementing parsing optimization to the Abstract Categorial Grammar tool kit. These optimizations are based on Datalog program rewriting techniques, in particular a general version of Magic Sets [27], [36]. Theses optimizations rely on the tree isomorphism between derivation trees resulting from parsing with a given abstract categorial grammar, and proofs of facts in a corresponding Datalog program. Because magic rewriting breaks the isomorphism, a transformation of proofs back to derivation trees has been proposed.

6.1.2. Lexical Semantics

The lexicon model underlying Montague semantics is an enumerative model that would assign a meaning to each atomic expression. This model does not exhibit any interesting strucuture. In particular, polysemy problems are considered as homonymy phenomena: a word has as many lexical entries as it has senses, and the semantic relations that might exist between the different meanings of a same word are ignored. To overcome these problems, models of generative lexicons have been proposed in the literature. Implementing these generative models in the realm of the typed λ-calculus necessitates a calculus with notions of subtyping and type coercion. In this context, we have investigated several ways of expressing coercion using record types, and intersection types. In addition, William Babonnaud has shown how the structure of a generative lexicon may be formalized in type theory, using the categorical notion of a topos [10].

6.2. Discourse Dynamics

Participants: Maxime Amblard, Clément Beysson, Maria Boritchev, Philippe de Groote, Bruno Guillaume, Pierre Ludmann, Michel Musiol.

6.2.1. Dynamic Logic

We have enriched our type-theoretic dynamic logic in several directions in order to take into account more dynamic phenomena. In particular, we have continued to study the dynamic properties of determiners in order to systematically capture their semantics by defining an appropriate notion of dynamic generalized quantifier. To this end, Clement Beysson has studied several issues raised by the modeling of plural determiners, which necessitates to introduce plural discourse referents that can be formalized as second-order bound variables.

6.2.2. Dialogue Modeling

Maxime Amblard and Maria Boritchev have developed a dynamic model of dialogue. We have focused on the relation between question and answers and on building a resource based on settlers of Catan game records (the DiNG corpus).

We presented in [12] research on a compositional treatment of questions in a neo-Davidsonian event semantics style. [28] presented a dynamic neo-Davidsonian compositional treatment of declarative sentences. Starting from complex formal examples, we enriched Champollion’s framework with ways of handling phenomena specific to question-answer pair representation. Maria Boritchev gave two presentations on these issues [16], [21].

In [9], we presented a taxonomy of questions and answers based on real-life data extracted from spontaneous dialogue corpora. This classification allowed us to build a fine-grained annotation scheme, which we applied to several languages: English, French, Italian and Chinese. In [13], we presented an annotation scheme for classifying the content and discourse contribution of question-answer pairs. We proposed detailed guidelines for using the scheme and applied them to dialogues in English, Spanish, and Dutch. Finally, we have reported on initial machine learning experiments for automatic annotation.

In another direction, Maxime Amblard has started a common work with Chloé Braud on Formal and Statistical Modelling of dialogue. To this end, we have started with Chuyuan Li to design a dialogue model to structure the different necessary linguistic informations for interaction. This model will be implemented in a tool that finely manages interaction through formal and learning strategies.

6.2.3. Pathological Discourse Modelling

Michel Musiol has obtained a full-time delegation in the Semagramme team. This proximity makes it possible to set up a more active collaboration on the issue of pathological discourse modeling. He has worked on the development of the possibility of testing his conjectures on the cognitive and psychopathological profile of the interlocutors, in addition to information provided by the model of ruptures and incongruities in pathological discourse. This methodological system makes it possible to discuss, or even evaluate, the heuristic potential of the computational models developed on the basis of empirical facts.

As part of the work carried out in the SLAM project, Maxime Amblard, Michel Musiol and Manuel Rebuschi (*Archives Henri-Poincaré, Université de Lorraine*) continue to work on modelling interactions with schizophrenic patients. We published an article about the corpus [20]. We are writing a book on these issues, in particular, we wrote a long introduction [19]. Maxime Amblard and Michel Musiol were awarded by an Inria Exploratory Action on this issues ODiM. This year we recruited the project's collaborators. In addition, we started the constitution of a new resource.

6.3. Common Basic Resources

Participants: Maxime Amblard, Clément Beysson, Philippe de Groote, Bruno Guillaume, Guy Perrier, Sylvain Pogodalla, Karën Fort.

6.3.1. Corpus Annotation

The Universal Dependencies project (UD) aims at building a syntactic dependency scheme which allows for similar analyses for several different languages. Bruno Guillaume and Guy Perrier are active in the UD community, and participate to the development and the improvement of the French data in this international initiative. Bruno Guillaume converted a new French treebank into UD: the French Question Bank (FQB), developped by Djamé Seddah and Marie Candito [35]. With the conversion system described in [2], the corpus UD_French-FQB was introduced in version 2.4 of UD in May 2019.

Bruno Guillaume, Marie-Catherine de Marneffe (Ohio State University, Columbus, Ohio, USA) and Guy Perrier improved the consistency of two French corpora annotated with the UD scheme [6]. They improved the annotations of the two French corpora to render them closer to the UD scheme, and evaluated the changes done to the corpora in terms of closeness to the UD scheme as well as of internal corpus consistency.

Bruno Guillaume and Guy Perrier developed and popularized the use of the GREW tool for various language applications and more particularly the pattern matching module Grew-match [22], [26], [17].

SUD is an annotation scheme for syntactic dependency treebanks, that is almost isomorphic to UD (Universal Dependencies). Contrary to UD, it is based on syntactic criteria (favoring functional heads) and the relations are defined on distributional and functional bases. In [14], Kim Gerdes (Sorbonne nouvelle, Paris 3), Bruno Guillaume, Sylvain Kahane (*Université Paris Nanterre*) and Guy Perrier recalled and specified the general principles underlying SUD, presented the updated set of SUD relations, discussed the central question of Multiword Expressions, and introduced an orthogonal layer of deep-syntactic features converted from the deep-syntactic part of the UD scheme.

6.3.2. FR-FraCas

Maxime Amblard, Clement Beysson, Philippe de Groote, Bruno Guillaume, Sylvain Pogodalla and Karën Fort carried on the development of FR-FraCas, a French version of the FraCas test suite [31] which is an inference test suite, in English, for evaluating the inferential competence of different NLP systems and semantic theories. There currently exists a multilingual version of the resource for Farsi, German, Greek, and Mandarin. Sémagramme completed the first translation into French of the test suite. The latter has been publicly released [0]. We also ran an experiment in order to test both the translation and the logical semantics underlying the problems of the test suite. The experiment was run with 18 French native speakers. Such an experiment provides a way of checking the hypotheses made by formal semanticists against the actual semantic capacity of speakers (in the present case, French speakers), and allows us to compare the results we obtained with the ones of similar experiments that have been conducted for other languages [30], [29].

7. Bilateral Contracts and Grants with Industry

7.1. Industry Partner

As a follow-up to a Cifre PhD thesis [34] on the use of Abstract Categorial Grammars in an industrial context, the team worked on a common road-map with the Yseop company and proposed common master internships as a first step towards formalizing the partnership.

After a master internship supervised by Bruno Guillaume, a discussion opened on the use of Abstract Categorial Grammars in the industrial context. C&S - Communication and Systems - has tool specifications that need to be verified, which can be achieved through semantic representation. A Cifre PhD thesis is currently being prepared for early 2020.

8. Partnerships and Cooperations

8.1. Regional Initiatives

CPER LCHN

Langues, Connaissances et Humanités Numériques (Languages, Knowledge and Digital Humanities)

Duration: 2015 - 2020 Coordinator: Bruno Guillaume

Other partners: Université de Lorraine, Région Grand-Est, France

Participants: Maxime Amblard, Karën Fort, Bruno Guillaume

Abstract: This initiative is an interdisciplinary project which involves several laboratories in the Université de Lorraine. It aims to strengthen the University de Lorraine University in the areas of management and access to digital content. A huge part of the project concerns researches on language. The initiative combines national and regional funding which mainly supports equipment purchase. It proposes to set up scientific experimentation platforms to strengthen cooperation between Lorraine's partners thus enabling Lorraine to acquire significant visibility through national platforms for the dissemination of resources. Most of the online tools built in the team (https://zombiludik.org, http://match.grew.fr for instance) are available through virtual machines funded by the CPER.

8.2. National Initiatives

ODiM

Outils informatisés d'aide au Diagnostic des Maladies mentales

2019 - 2022

Coordinator: Maxime Amblard

Participants: Maxime Amblard, Vincent-Thomas Barrouillet, Samuel Buchel, Amandine Lecomte, Chuyuan Li, Michel Musiol

Abstract:

[0] https://gitlab.inria.fr/semagramme-public-projects/resources/french-fracas

ODiM is an interdisciplinary project, at the interface of psychiatry-psychopathology, linguistics, formal semantics and digital sciences. It aims to replace the paradigm of Language and Thought Disorders (LTD) as used in the Mental Health sector with a semantic-formal and cognitive model of Discourse Disorders (DD). These disorders are translated into pathognomonic signs, making them complementary diagnostic tools as well as screening for vulnerable people before the psychosis's trigger. The project has three main components.

The work is based on real data from interviews with patients with schizophrenia. A data collection phase in partner hospitals and with a control group, consisting of interviews and neuro-cognitive tests, is therefore necessary.

The data collection will allow the development of the theoretical model, both in psycholinguistic and semantic formalization for the identification of diagnostic signs. The success of such a project requires the extension of the analysis methodology in order to increase the model's ability to identify sequences with symptomatic discontinuities.

If the general objective of the project is to propose a methodological framework for defining and understanding diagnostic clues associated with psychosis, we also wish to equip these approaches by developing software to automatically identify these clues, both in terms of discourse and language behaviour.

8.3. European Initiatives

8.3.1. Collaborations in European Programs, Except FP7 & H2020

EnetCollect

European Network for Combining Language Learning with Crowdsourcing Techniques

2015- 2025

Coordinator: Lionel Nicolas and Verena Lyding (Chair & Grant Holder)

Participants: Karën Fort, Bruno Guillaume

Abstract:

Karën Fort and Bruno Guillaume participate in the EnetCollect [0] COST action. EnetCollect aims at performing the groundwork to set into motion a Research and Innovation trend combining the well-established domain of Language Learning with recent and successful crowdsourcing approaches.

- Karën Fort co-organized with Rodrigo Agerri (Univ. of the Basque Country) the first Hackathon (named Crowdfest) in January in Brussels,
- Karën Fort and Bruno Guillaume participated in the 3rd Annual Action meeting in Lisbon in March,
- Karën Fort participated to a Workgroup meeting in Malta in November.

Karën Fort pariticipates in the COST action NexusLinguarum [0]. The main aim of this action is to promote synergies across Europe between linguists, computer scientists, terminologists, and other stakeholders in industry and society, in order to investigate and extend the area of linguistic data science.

8.4. International Initiatives

8.4.1. Participation in other International Programs

Common work and a common workshop was held in Gothenburg with the Centre for Linguistic Theory and Studies in Probability (CLASP, University of Gothenburg, Sweden), especially with Robin Cooper, Ellen Breitholtz and Chris Howes on the topic of dialogical reasoning in patients with schizophrenia and formal approaches to (in)coherence and dynamics in dialogue. The visit was supported by the French Institute in Sweden (*Programme Galan*).

[0] https://enetcollect.eurac.edu/
[0] https://www.cost.eu/actions/CA18209

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. Scientific Events: Organisation

9.1.1.1. Member of the Organizing Committees

- Karën Fort co-organized of the first enetCollect (European Network for Combining Language Learning with Crowdsourcing Techniques) hackathon

9.1.2. Scientific Events: Selection

9.1.2.1. Chair of Conference Program Committees

- Philippe de Groote: Chair of the 16th Meeting on the Mathematics of Language [24].
- Sylvain Pogodalla: co-chair of FG 2019*23rd Conference on Formal Grammar* [23].

9.1.2.2. Member of the Conference Program Committees

- Philippe de Groote: Senior PC member of: IJCAI 2019, the 28th International Joint Conference on Artificial Intelligence; PC member of: SCiL 2020, the third meeting of the Society for Computation in Linguistics; WOLLIC 2019, the 26th Workshop on Logic, Language, Information and Computation; IWCS 2019, the 13th International Conference on Computational Semantics ; FG'19, the 24th Conference on Formal Grammar; SPE 11, the 11th Semantics and Philosophy in Europe Colloquium.

9.1.2.3. Reviewer

- Maxime Amblard: 13th International Conference on Computational Semantics (IWCS 2019), IJCAI 2019, TALN 2019, JPC2019.
- Karën Fort: ACL 2019, NAACL 2019, TALN 2019, CJC-Praxiling 2019. *La fabrique de la participation culturelle. Plateformes numériques et enjeux démocratiques*
- Sylvain Pogodalla: 13th International Conference on Computational Semantics (IWCS 2019), Logic and Engineering of Natural Language Semantics 16 (LENLS16).

9.1.3. Journal

9.1.3.1. Member of the Editorial Boards

- Maxime Amblard: Member of the editorial board of the journal *Traitement Automatique des Langues*, in charge of the hard copy editorial process,
- Philippe de Groote: area editor of the *FoLLI-LNCS series*.
- Sylvain Pogodalla: Member of the editorial board of the journal *Traitement Automatique des Langues*, in charge of the *Résumés de thèses* section.

9.1.3.2. Reviewer - Reviewing Activities

- Maxime Amblard: Logic and Algorithms in Computational Linguistics, Springer series Studies in Computational Intelligence (SCI)
- Philippe de Groote: Journal of Language, Logic and Information; Journal of Logic and Computation; Logical Methods in Computer Science.
- Sylvain Pogodalla: Journal of Language, Logic and Information.

9.1.4. Invited Talks

- Karën Fort:
  - *La production participative (crowdsourcing) : miroir grossissant sur l'annotation manuelle.* Inria Almanach. Paris, France. October 11th 2019

   - *Productions participatives de corpus annotés : des modèles encore incertains.* Colloque Jeunes Chercheurs PRAXILING 2019
   - with Denis Maurel. *Regards croisés sur la linguistique informatique.* Colloque Décrire une langue : objectifs et méthodes. Sorbonne Université, Paris, France. September 13th 2019
- Michel Musiol:
   - *Improving the investigation of conversational discontinuities using the support of eye-tracking methods.* Workshop on Incoherence of Dialogue, University of Göteborg, 2019, october 9-10th
   - *Approche différentielle des registres communicationnels de l'interlocuteur schizophrène dans l'entretien clinique*, Faculté de Médecine and Centre Hospitalo-Universitaire of Tizi Ouzou, Algeria, June 13th.
- Bruno Guillaume:
   - *Rigor Mortis* EnetCollect 3rd Annual Action meeting in Lisbon, March 14th. The game Rigor Mortis ((http://rigor-mortis.org) is a crowdsourcing projet when users have to find Multi-Word expression.

9.1.5. Leadership within the Scientific Community

- Maxime Amblard: Management Committee of the OLKI project (*Lorraine Université d'Excellence* project - PIA), co-leader of the workpackage 2 on NLP activities.
- Karën Fort:
   - Management Committee member of the COST Action CA16105 "European Network for Combining Language Learning with Crowdsourcing Techniques" (http://www.cost.eu/COST_Actions/ca/CA16105).
   - Management Committee Substitute member of the COST Action CA18209 "European network for Web-centred linguistic data science" (http://www.cost.eu/COST_Actions/ca/CA18209).
   - in charge with G. Wisniewski of axis 2 of GDR LIFT (*Linguistique informatique, formelle et de terrain*) : *Linguistique et évaluation des systèmes de traitement automatique des langues*. Kick off meeting at the end of Nov., Orléans, France, co-organized (with A. Millour, SU) a working group on variations in GDR LIFT
- Philippe de Groote: president of SIGMOL, *Association for Mathematics of Language, a Special Interest Group of the Association for Computational Linguistics*; member of the LACL steering committee.
- Bruno Guillaume: Management Committee Substitute member of the COST Action CA16105 "European Network for Combining Language Learning with Crowdsourcing Techniques" (http://www.cost.eu/COST_Actions/ca/CA16105).
- Sylvain Pogodalla: member of the LACL steering committee; member of the Formal Grammar standing committee.

9.1.6. Scientific Expertise

- Philippe de Groote: member of the scientific council of the AREN e-FRAN project, *ARgumentation Et Numérique*.
- Sylvain Pogodalla: expert for the Research Executive Agency (REA) of the EU.

9.1.7. Research Administration

- Maxime Amblard:
   - Member of *conseil scientifique* of *Université de Lorraine*
   - Standing invitee at the *pôle scientifique* AM2I of *Université de Lorraine*

  - Member of the *Sénat Académique* of *Université de Lorraine*
  - Member of the progress commission of *Université de Lorraine*
  - Member of the administration council of the *Institut des sciences du digital, management et cognition*
  - Member of the board of the *Maison des sciences de l'homme*, MSH-Lorraine
  - Head of the master in Natural Language Processing (master 1 and 2)
- Philippe de Groote:
  - Member of the *bureau du comité des projets d'Inria Nancy – Grand Est*.
  - Member of the scientific council of the LIRMM, *Laboratoire d'Informatique, de Robotique et de Microélectronique de Montpellier*
- Bruno Guillaume:
  - Head of the Loria department NLPKD (Natural Language Processing and Knowledge Discovery).
  - Leader of the CPER 2015-2020 project *Langues, Connaissances et Humanités Numériques* (Languages, Knowledge and Digital Humanities) in which ten laboratories of *Université de Lorraine* participate.
  - Member of the Comipers (committee for PhD and Post-doctoral selection).
- Michel Musiol:
  - Member of the McF selection committee 1231/4381 (section 16), *Université de Reims Champagne-Ardenne*
  - Member of the McF selection committee 739 (section 16), *Aix-Marseille Université*
- Sylvain Pogodalla:
  - Elected member of the *comité de centre d'Inria Nancy – Grand Est*,
  - in charge of the *commission IES (information et édition scientifique du centre d'Inria Nancy – Grand Est*.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Licence:

Maxime Amblard, NLP Introduction, 4h, L1, Université de Lorraine, France

Maxime Amblard, Linguistic engineering, 20h, L3, Université de Lorraine, France

Maria Boritchev, Formalisms and reasoning representations , 20h, L3, Université de Lorraine, France

Maria Boritchev, Algorithmic 1, 22h, L1, Université de Lorraine, France

Master:

Maxime Amblard, Python Programming (english), 30h, M1 NLP, Université de Lorraine, France.

Maxime Amblard, Methods for NLP (english), 36h, M1 NLP, Université de Lorraine, France.

Maxime Amblard, Formalisms (english), 24h, M2 NLP, Université de Lorraine, France.

Maxime Amblard, Discourse and Dialogue (english), 18h, M2 NLP, Université de Lorraine, France.

Philippe de Groote, Formal Logic, 22h, M1 NLP, Université de Lorraine, France.

Philippe de Groote, Formal languages, 22h, M1 NLP, Université de Lorraine, France.

Philippe de Groote, Computational Semantics, 18h, M2 NLP, Université de Lorraine, France.

Philippe de Groote, Computational structures and logics for natural language modeling, 18h, M2 NLP, Université Paris Diderot – Paris 7, France.

Bruno Guillaume, Written Corpora TAL (english), 30h, M1 NLP, Université de Lorraine, France.

9.2.2. Supervision

PhD defended:

- Timothée Bernard, *Approches formelles de l'analyse du discours : relations discursives et verbes d'attitude propositionnelle*, September 1st 2019

PhD in progress:

William Babonnaud, *Lexical semantics, compositionality and type coercion*, since September 2018, Philippe de Groote.

Clement Beysson, *Dynamic generalized quantifiers for discourse analysis*, since September 2015, Philippe de Groote and Bruno Guillaume.

Maria Boritchev, *Dialogue Dynamics Modeling in the Simple Theory of Types*, since September 2017, Maxime Amblard and Philippe de Groote.

Pierre Ludmann, *Dynamic construction of discursive structures*, since September 2017, Philippe de Groote and Sylvain Pogodalla.

Chuyuan Li, *Formal and statistical modeling of dialogue*, since October 2019, Maxime Amblard and Chloé Braud.

Vincent-Thomas Barrouillet, *Towards an automated formalization of logical deviations of pathological discourse from schizophrenic patients*, since October 2019, Maxime Amblard and Michel Musiol.

Samuel Buchel, *Linguistic, semantic and cognitive modelling of dialogical incongruities and discontinuities in the interaction with the schizophrenic patients*, since December 2019, Maxime Amblard and Michel Musiol.

9.2.3. Juries

- Karën Fort was member of the jury PhD thesis of:
  - Claire Wolfarth, Université Grenoble Alpes. December 9th.
  - Arne Skjærholt, Oslo University. First opponent. December 4th.
  - Ivan Garrido Marquez, Université Paris 13. February 8th.
- Michel Musiol
  - Yann Auxemery, Université de Lorraine, October 15th
  - Aurore Morel, Université de Lyon 1 Claude Bernard, December 20th

9.3. Popularization

9.3.1. Internal or external Inria responsibilities

Maxime Amblard is the vice head of editorial board of Interstices.info

9.3.2. Articles and contents

- Karën Fort: 3 articles in volume 140 of *Culture et Recherche* (Journal of the Ministry of Culture):
  - Ouvrir le dédale des données des recherches myriadisées (with Lisa Chupin, Université Paris-Descartes)

– Les jeux ayant un but : des sciences participatives ? (with Bruno Guillaume)
– Sciences participatives et diversité linguistique : retours d'expériences (with Alice Millour, Sorbonne Université)

9.3.3. Interventions

Maxime Amblard was an organizer of the *Forum des Sciences Cognitives* in Nancy

Maxime Amblard organized a Diabolo Science presentation with Marie Duflot-Kremer for PintOf-Science

Maxime Amblard gave a presentation for high school students in the laboratory

Karën Fort: ethics and citizen science class at the Museum national d'histoire naturelle (3h)

9.3.4. Creation of media or tools for science outreach

Maxime Amblard was the leader of the project Happy Family Cards Game, which aimed to develop such a game for promoting computer science as a scientific field. 20 000 copies have been printed and are currently being distributed. The project was presented at the Fête de la Science panel in Paris.

Maxime Amblard designed an unplugged activity on syntactic parsing (about rabbits and carrots), [25].

Karën Fort: participation in the Sorbonne Université portal for citizen science with ZombiLUDik and Recettes (with A. Millour) : https://www.science-ensemble.org/

10. Bibliography

Major publications by the team in recent years

[1] G. BONFANTE, B. GUILLAUME.*Non-size increasing Graph Rewriting for Natural Language Processing*, in "Mathematical Structures in Computer Science", 2018, vol. 28, n° 08, p. 1451–1484 [*DOI :* 10.1017/S0960129518000178], https://hal.inria.fr/hal-00921038

[2] G. BONFANTE, B. GUILLAUME, G. PERRIER.*Application of Graph Rewriting to Natural Language Processing*, Logic, Linguistics and Computer Science Set, ISTE Wiley, 2018, vol. 1, 272, https://hal.inria.fr/hal-01814386

[3] S. POGODALLA.*A syntax-semantics interface for Tree-Adjoining Grammars through Abstract Categorial Grammars*, in "Journal of Language Modelling", 2017, vol. 5, n° 3, p. 527–605 [*DOI :* 10.15398/JLM.V5I3.193], https://hal.inria.fr/hal-01242154

[4] P. DE GROOTE, M. KANAZAWA.*A Note on Intensionalization*, in "Journal of Logic, Language and Information", 2013, vol. 22, n° 2, p. 173-194 [*DOI :* 10.1007/S10849-013-9173-9], https://hal.inria.fr/hal-00909207

Publications of the year

Doctoral Dissertations and Habilitation Theses

[5] T. BERNARD.*Formal approaches to discourse analysis : Discourse relations and attitude verbs*, Université Sorbonne Paris Cité, January 2019, https://hal.inria.fr/tel-02150106

Articles in International Peer-Reviewed Journal

[6] B. GUILLAUME, M.-C. DE MARNEFFE, G. PERRIER.*Conversion et améliorations de corpus du français annotés en Universal Dependencies*, in "Traitement Automatique des Langues", 2019, vol. 60, n^{o} 2, p. 71-95, https://hal.inria.fr/hal-02267418

Invited Conferences

[7] K. FORT.*La production participative (crowdsourcing) : miroir grossissant sur l'annotation manuelle*, in "Séminaire de l'équipe Inria ALMANACH", Paris, France, October 2019, https://hal.inria.fr/hal-02418852

[8] K. FORT.*Productions participatives de corpus annotés : des modèles encore incertains*, in "Colloque Jeunes Chercheurs PRAXILING", Montpellier, France, November 2019, https://hal.inria.fr/hal-02418826

International Conferences with Proceedings

[9] M. AMBLARD, M. BORITCHEV, M. CARLETTI, L. DIEUDONAT, Y. TSAI.*A Taxonomy of Real-Life Questions and Answers in Dialogue*, in "SemDial 2019 - LondonLogue - 23rd Workshop on the semantics and pragmatics of dialogue", London, United Kingdom, September 2019, https://hal.inria.fr/hal-02269609

[10] W. BABONNAUD.*A Topos-Based Approach to Building Language Ontologies*, in "Formal Grammar. 24th International Conference, FG 2019", Riga, Latvia, R. BERNARDI, G. KOBELE, S. POGODALLA (editors), Lecture notes in Computer Science, July 2019, vol. 11668, p. 18-34 [*DOI :* 10.1007/978-3-662-59648-7_2], https://hal.inria.fr/hal-02418029

[11] T. BERNARD.*Negation in event semantics with actual and nonactual events*, in "ConSOLE 2018 - 26th Conference of the Student Organization of Linguistics in Europe", London, United Kingdom, 2019, p. 350-366, https://hal.inria.fr/hal-01931273

[12] M. BORITCHEV, M. AMBLARD.*A compositional view of questions*, in "WiNLP - Widening NLP - ACL Workshop", Florence, Italy, July 2019, https://hal.inria.fr/hal-02269603

[13] M.-A. CRUZ-BLANDÓN, G. MINNEMA, A. NOURBAKHSH, M. BORITCHEV, M. AMBLARD.*Toward Dialogue Modeling: A Semantic Annotation Scheme for Questions and Answers*, in "LAW XIII 2019 - The 13th Linguistic Annotation Workshop", Florence, Italy, August 2019, https://arxiv.org/abs/1908.09921 , https://hal.inria.fr/hal-02269613

[14] K. GERDES, B. GUILLAUME, S. KAHANE, G. PERRIER.*Improving Surface-syntactic Universal Dependencies (SUD): surface-syntactic relations and deep syntactic features*, in "TLT 2019 - 18th International Workshop on Treebanks and Linguistic Theories", Paris, France, August 2019, https://hal.inria.fr/hal-02266003

[15] P. MULLER, C. BRAUD, M. MOREY.*ToNy: Contextual embeddings for accurate multilingual discourse segmentation of full documents*, in "Proceedings of the Workshop on Discourse Relation Parsing and Treebanking 2019", Minneapolis, United States, Proceedings of the Workshop on Discourse Relation Parsing and Treebanking 2019, Association for Computational Linguistics, June 2019, p. 115-124 [*DOI :* 10.18653/v1/W19-2715], https://hal.archives-ouvertes.fr/hal-02374091

Conferences without Proceedings

[16] M. BORITCHEV.*Thé, café et licornes – Traitement de la structure conversationnelle dans la théorie dynamique des types*, in "EJCIM 2019 - École Jeunes Chercheurs et Chercheuses en Informatique Mathématique", Marseille, France, March 2019, https://hal.inria.fr/hal-02071515

[17] B. GUILLAUME.*Graph Matching for Corpora Exploration*, in "JLC 2019 - 10èmes Journées Internationales de la Linguistique de corpus", Grenoble, France, November 2019, https://hal.inria.fr/hal-02267475

[18] D. MAUREL, K. FORT.*Regards croisés sur la linguistique informatique*, in "Colloque Décrire une Langue : Objectifs et Méthodes. Université de la Sorbonne", Paris, France, September 2019, https://hal.archives-ouvertes.fr/hal-02290423

Scientific Books (or Scientific Book chapters)

[19] M. AMBLARD, M. MUSIOL, M. REBUSCHI.*Discourse coherence - From psychology to linguistics and back again*, in "(In)coherence of discourse - Formal and Conceptual issues of Language", M. AMBLARD, M. MUSIOL, M. REBUSCHI (editors), Springer, 2019, Language, Cognition and Mind, forthcoming, https://hal.inria.fr/hal-02269640

[20] M. AMBLARD, M. REBUSCHI, M. MUSIOL.*Corpus et pathologie mentale : particularités dans la constitution et l'analyse d'une ressource*, in "Les corpus en sciences humaines et sociales", M. REBUSCHI, C. BENZITOUN (editors), Presses Universitaires de Nancy, 2019, forthcoming, https://hal.inria.fr/hal-02269622

[21] M. BORITCHEV, M. AMBLARD.*Picturing Questions and Answers - a formal approach to SLAM*, in "(In)coherence of discourse - Formal and Conceptual issues of Language", M. AMBLARD, M. MUSIOL, M. REBUSCHI (editors), (In)coherence of discourse Formal and Conceptual issues of Language, Springer, 2019, Language, Cognition and Mind, forthcoming, https://hal.inria.fr/hal-02269631

[22] B. GUILLAUME, G. PERRIER.*Leçons de l'annotation linguistique en de´pendances de corpus e´crits du français*, in "Les corpus en sciences humaines et sociales", Presses Universitaires de Nancy, 2019, forthcoming, https://hal.inria.fr/hal-02267428

Books or Proceedings Editing

[23] R. BERNARDI, G. KOBELE, S. POGODALLA (editors). *Formal Grammar : 24th International Conference, FG 2019, Riga, Latvia, August 11, 2019, Proceedings*, Lecture Notes in Computer Science, Springer, Riga, Latvia, 2019, vol. 11668 [*DOI :* 10.1007/978-3-662-59648-7], https://hal.inria.fr/hal-02267405

[24] P. DE GROOTE, F. DREWES, G. PENN (editors). *Proceedings of the 16th Meeting on the Mathematics of Language*, Association for Computational Linguistics, Toronto, Canada, 2019, https://hal.inria.fr/hal-02268054

Other Publications

[25] M. AMBLARD.*Les lapins magiciens*, December 2019, working paper or preprint, https://hal.inria.fr/hal-02414345

[26] G. PERRIER, B. GUILLAUME.*GREW, a tool for annotating corpora and exploiting annotated corpora*, November 2019, 73, Journe´es scientifiques "Linguistique informatique, formelle de terrain", Poster, https://hal.inria.fr/hal-02388693

References in notes

[27] S. ABITEBOUL, R. HULL, V. VIANU.*Foundations of Databases*, Assison-Wesley, 1995, http://webdam.inria.fr/Alice/pdfs/all.pdf

[28] L. CHAMPOLLION.*Quantification and negation in event semantics*, in "Formal Semantics and Pragmatics: Discourse, Context, and Models", 2011, p. 1-23

[29] S. CHATZIKYRIAKIDIS, R. COOPER, S. DOBNIK, S. LARSSON.*An overview of Natural Language Inference Data Collection: The way forward?*, in "Proceedings of the Computing Natural Language Inference Workshop", 2017, https://www.aclweb.org/anthology/W17-7203

[30] R. COOPER, S. CHATZIKYRIAKIDIS, S. DOBNIK.*Testing the FraCaS test suite*, 2016, Presentation at the Unshared Task "Theory and System analysis with FraCaS, MultiFraCaS and JSeM Test Suites" of Logical Engineering of Natural Language Semantics 13 (LENLS 13)

[31] R. COOPER, D. CROUCH, J. VAN EIJCK, C. FOX, J. VAN GENABITH, J. JASPARS, H. KAMP, D. MILWARD, M. PINKAL, M. POESIO, S. PULMAN, T. BRISCOE, H. MAIER, K. KONRAD.*Using the framework*, The FraCaS Consortium, 1996, n^o Technical Report LRE 62-051 D-16

[32] B. GUILLAUME, G. PERRIER.*Interaction Grammars*, in "Research on Language & Computation", 2009, vol. 7, p. 171–208

[33] G. PERRIER.*A French Interaction Grammar*, in "International Conference on Recent Advances in Natural Language Processing - RANLP 2007", Borovets, Bulgarie, G. ANGELOVA, K. BONTCHEVA, R. MITKOV, N. NICOLOV, K. SIMOV (editors), INCOMA Ltd, Shoumen, Bulgaria, 2007, p. 463-467, http://hal.inria.fr/inria-00184108/en/

[34] R. SALMON.*Natural language generation using abstract categorial grammars*, Université Paris Diderot, 2017

[35] D. SEDDAH, M. CANDITO.*Hard Time Parsing Questions: Building a QuestionBank for French*, in "Tenth International Conference on Language Resources and Evaluation (LREC 2016)", Portorož, Slovenia, Proceedings of the 10th edition of the Language Resources and Evaluation Conference (LREC 2016), May 2016, https://hal.archives-ouvertes.fr/hal-01457184

[36] J. D. ULLMAN.*Principles of Database and Knowledge-Base Systems: Volume II: The New Technologies*, W. H. Freeman & Co., New York, NY, USA, 1990

[37] P. DE GROOTE.*Towards abstract categorial grammars*, in "Association for Computational Linguistics, 39th Annual Meeting and 10th Conference of the European Chapter", Toulouse, France, Association for Computational Linguistics, July 2001, p. 148-155, Colloque avec actes et comité de lecture. internationale, http://hal.inria.fr/inria-00100529/en

[38] P. DE GROOTE.*Towards a Montagovian Account of Dynamics*, in "16th Semantics and Linguistic Theory conference - SALT2006", Tokyo, Japan, M. GIBSON, J. HOWELL (editors), 2006, https://journals.linguisticsociety.org/proceedings/index.php/SALT/article/view/2952/0

[39] P. DE GROOTE, S. POGODALLA.*On the expressive power of abstract categorial grammars: Representing context-free formalisms*, in "Journal of Logic, Language and Information", 2004, vol. 13, n^{o} 4, p. 421–438

Project-Team SPHINX

Heterogeneous Systems: Inverse Problems, Control and Stabilization, Simulation

IN COLLABORATION WITH: Institut Elie Cartan de Lorraine (IECL)

IN PARTNERSHIP WITH:
CNRS

Université de Lorraine

RESEARCH CENTER
Nancy - Grand Est

THEME
Optimization and control of dynamic systems

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Project-Team SPHINX

Creation of the Team: 2015 January 01, updated into Project-Team: 2016 May 01

Keywords:

Computer Science and Digital Science:

A6. - Modeling, simulation and control
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A6.1.1. - Continuous Modeling (PDE, ODE)
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Other Research Topics and Application Domains:

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Céline Cordier [Inria, Administrative Assistant]

2. Overall Objectives

2.1. Overall Objectives

In this project, we investigate theoretical and numerical mathematical issues concerning heterogeneous physical systems. The heterogeneities we consider result from the fact that the studied systems involve subsystems of different physical nature. In this wide class of problems, we study two types of systems: **fluid-structure interaction systems (FSIS)** and **complex wave systems (CWS)**. In both situations, one has to develop specific methods to take the coupling between the subsystems into account.

(FSIS) Fluid-structure interaction systems appear in many applications: medicine (motion of the blood in veins and arteries), biology (animal locomotion in a fluid, such as swimming fishes or flapping birds but also locomotion of microorganisms, such as amoebas), civil engineering (design of bridges or any structure exposed to the wind or the flow of a river), naval architecture (design of boats and submarines, researching into new propulsion systems for underwater vehicles by imitating the locomotion of aquatic animals). FSIS can be studied by modeling their motions through Partial Differential Equations (PDE) and/or Ordinary Differential Equations (ODE), as is classical in fluid mechanics or in solid mechanics. This leads to the study of difficult nonlinear free boundary problems which have constituted a rich and active domain of research over the last decades.

(CWS) Complex wave systems are involved in a large number of applications in several areas of science and engineering: medicine (breast cancer detection, kidney stone destruction, osteoporosis diagnosis, etc.), telecommunications (in urban or submarine environments, optical fibers, etc.), aeronautics (target detection, aircraft noise reduction, etc.) and, in the longer term, quantum supercomputers. **For direct problems**, most theoretical issues are now widely understood. However, substantial efforts remain to be undertaken concerning the simulation of wave propagation in complex media. Such situations include heterogeneous media with strong local variations of the physical properties (high frequency scattering, multiple scattering media) or quantum fluids (Bose-Einstein condensates). In the first case for instance, the numerical simulation of such direct problems is a hard task, as it generally requires solving ill-conditioned possibly indefinite large size problems, following from space or space-time discretizations of linear or nonlinear evolution PDE set on unbounded domains. **For inverse problems**, many questions are open at both the theoretical (identifiability, stability and robustness, etc.) and practical (reconstruction methods, approximation and convergence analysis, numerical algorithms, etc.) levels.

3. Research Program

3.1. Control and stabilization of heterogeneous systems

Fluid-Structure Interaction Systems (FSIS) are present in many physical problems and applications. Their study involves solving several challenging mathematical problems:

- **Nonlinearity:** One has to deal with a system of nonlinear PDE such as the Navier-Stokes or the Euler systems;
- **Coupling:** The corresponding equations couple two systems of different types and the methods associated with each system need to be suitably combined to solve successfully the full problem;
- **Coordinates:** The equations for the structure are classically written with Lagrangian coordinates whereas the equations for the fluid are written with Eulerian coordinates;
- **Free boundary:** The fluid domain is moving and its motion depends on the motion of the structure. The fluid domain is thus an unknown of the problem and one has to solve a free boundary problem.

In order to control such FSIS systems, one has first to analyze the corresponding system of PDE. The oldest works on FSIS go back to the pioneering contributions of Thomson, Tait and Kirchhoff in the 19th century and Lamb in the 20th century, who considered simplified models (potential fluid or Stokes system). The first mathematical studies in the case of a viscous incompressible fluid modeled by the Navier-Stokes system and a rigid body whose dynamics is modeled by Newton's laws appeared much later [119], [114], [94], and almost all mathematical results on such FSIS have been obtained in the last twenty years.

The most studied FSIS is the problem modeling a **rigid body moving in a viscous incompressible fluid** ([77], [73], [112], [83], [88], [116], [118], [102], [86]). Many other FSIS have been studied as well. Let us mention [104], [91], [87], [76], [64], [82], [65], [84] for different fluids. The case of **deformable structures** has also been considered, either for a fluid inside a moving structure (e.g. blood motion in arteries) or for a moving deformable structure immersed in a fluid (e.g. fish locomotion). The obtained coupled FSIS is a complex system and its study raises several difficulties. The main one comes from the fact that we gather two systems of different nature. Some studies have been performed for approximations of this system: [69], [64], [97], [78], [67]). Without approximations, the only known results [74], [75] were obtained with very strong assumptions on the regularity of the initial data. Such assumptions are not satisfactory but seem inherent to this coupling between two systems of different natures. In order to study self-propelled motions of structures in a fluid, like fish locomotion, one can assume that the **deformation of the structure is prescribed and known**, whereas its displacement remains unknown ([110]). This permits to start the mathematical study of a challenging problem: understanding the locomotion mechanism of aquatic animals. This is related to control or stabilization problems for FSIS. Some first results in this direction were obtained in [92], [66], [106].

3.2. Inverse problems for heterogeneous systems

The area of inverse problems covers a large class of theoretical and practical issues which are important in many applications (see for instance the books of Isakov [93] or Kaltenbacher, Neubauer, and Scherzer [95]). Roughly speaking, an inverse problem is a problem where one attempts to recover an unknown property of a given system from its response to an external probing signal. For systems described by evolution PDE, one can be interested in the reconstruction from partial measurements of the state (initial, final or current), the inputs (a source term, for instance) or the parameters of the model (a physical coefficient for example). For stationary or periodic problems (i.e. problems where the time dependence is given), one can be interested in determining from boundary data a local heterogeneity (shape of an obstacle, value of a physical coefficient describing the medium, etc.). Such inverse problems are known to be generally ill-posed and their study leads to investigate the following questions:

- *Uniqueness.* The question here is to know whether the measurements uniquely determine the unknown quantity to be recovered. This theoretical issue is a preliminary step in the study of any inverse problem and can be a hard task.
- *Stability.* When uniqueness is ensured, the question of stability, which is closely related to sensitivity, deserves special attention. Stability estimates provide an upper bound for the parameter error given some uncertainty on data. This issue is closely related to the so-called observability inequality in systems theory.
- *Reconstruction.* Inverse problems being usually ill-posed, one needs to develop specific reconstruction algorithms which are robust to noise, disturbances and discretization. A wide class of methods is based on optimization techniques.

We can split our research in inverse problems into two classes which both appear in FSIS and CWS:

1. **Identification for evolution PDE.**

   Driven by applications, the identification problem for systems of infinite dimension described by evolution PDE has seen in the last three decades a fast and significant growth. The unknown to be recovered can be the (initial/final) state (e.g. state estimation problems [59], [85], [89], [115] for the design of feedback controllers), an input (for instance source inverse problems [56], [68], [79]) or a parameter of the system. These problems are generally ill-posed and many regularization approaches have been developed. Among the different methods used for identification, let us mention optimization techniques ([72]), specific one-dimensional techniques (like in [60]) or observer-based methods as in [100].

   In the last few years, we have developed observers to solve initial data inverse problems for a class of linear systems of infinite dimension. Let us recall that observers, or Luenberger observers [99], have been introduced in automatic control theory to estimate the state of a dynamical system of finite dimension from the knowledge of an output (for more references, see for instance [103] or [117]). Using observers, we have proposed in [105], [90] an iterative algorithm to reconstruct initial data from partial measurements for some evolution equations.We are deepening our activities in this direction by considering more general operators or more general sources and the reconstruction of coefficients for the wave equation. In connection with this problem, we study the stability in the determination of these coefficients. To achieve this, we use geometrical optics, which is a classical albeit powerful tool to obtain quantitative stability estimates on some inverse problems with a geometrical background, see for instance [62], [61].

2. **Geometric inverse problems.**

   We investigate some geometric inverse problems that appear naturally in many applications, like medical imaging and non destructive testing. A typical problem we have in mind is the following: given a domain Ω containing an (unknown) local heterogeneity ω, we consider the boundary value problem of the form

$$\begin{cases} Lu = 0, & (\Omega \setminus \omega) \\ u = f, & (\partial\Omega) \\ Bu = 0, & (\partial\omega) \end{cases}$$

   where L is a given partial differential operator describing the physical phenomenon under consideration (typically a second order differential operator), B the (possibly unknown) operator describing the boundary condition on the boundary of the heterogeneity and f the exterior source used to probe the medium. The question is then to recover the shape of ω and/or the boundary operator B from some measurement Mu on the outer boundary $\partial\Omega$. This setting includes in particular inverse scattering problems in acoustics and electromagnetics (in this case Ω is the whole space and the data are far field measurements) and the inverse problem of detecting solids moving in a fluid. It also includes, with slight modifications, more general situations of incomplete data (i.e. measurements on part of the outer boundary) or penetrable inhomogeneities. Our approach to tackle this type of problems is based on the derivation of a series expansion of the input-to-output map of the problem (typically the Dirichlet-to-Neumann map of the problem for the Calderón problem) in terms of the size of the obstacle.

3.3. Numerical analysis and simulation of heterogeneous systems

Within the team, we have developed in the last few years numerical codes for the simulation of FSIS and CWS. We plan to continue our efforts in this direction.

- In the case of FSIS, our main objective is to provide computational tools for the scientific community, essentially to solve academic problems.
- In the case of CWS, our main objective is to build tools general enough to handle industrial problems. Our strong collaboration with Christophe Geuzaine's team in Liège (Belgium) makes this objective credible, through the combination of DDM (Domain Decomposition Methods) and parallel computing.

Below, we explain in detail the corresponding scientific program.

- **Simulation of FSIS:** In order to simulate fluid-structure systems, one has to deal with the fact that the fluid domain is moving and that the two systems for the fluid and for the structure are strongly coupled. To overcome this free boundary problem, three main families of methods are usually applied to numerically compute in an efficient way the solutions of the fluid-structure interaction systems. The first method consists in suitably displacing the mesh of the fluid domain in order to follow the displacement and the deformation of the structure. A classical method based on this idea is the A.L.E. (Arbitrary Lagrangian Eulerian) method: with such a procedure, it is possible to keep a good precision at the interface between the fluid and the structure. However, such methods are difficult to apply for large displacements (typically the motion of rigid bodies). The second family of methods consists in using a *fixed mesh* for both the fluid and the structure and to simultaneously compute the velocity field of the fluid with the displacement velocity of the structure. The presence of the structure is taken into account through the numerical scheme. Finally, the third class of methods consists in transforming the set of PDEs governing the flow into a system of integral equations set on the boundary of the immersed structure. The members of SPHINX have already worked on these three families of numerical methods for FSIS systems with rigid bodies (see e.g. [109], [96], [111], [107], [108], [101]).
- **Simulation of CWS:** Solving acoustic or electromagnetic scattering problems can become a tremendously hard task in some specific situations. In the high frequency regime (i.e. for small wavelength), acoustic (Helmholtz's equation) or electromagnetic (Maxwell's equations) scattering problems are known to be difficult to solve while being crucial for industrial applications (e.g. in aeronautics and aerospace engineering). Our particularity is to develop new numerical methods based on the hybridization of standard numerical techniques (like algebraic preconditioners, etc.) with approaches borrowed from asymptotic microlocal analysis. Most particularly, we contribute to building hybrid algebraic/analytical preconditioners and quasi-optimal Domain Decomposition Methods (DDM) [63], [80], [81] for highly indefinite linear systems. Corresponding three-dimensional solvers (like for example GetDDM) will be developed and tested on realistic configurations (e.g. submarines, complete or parts of an aircraft, etc.) provided by industrial partners (Thales, Airbus). Another situation where scattering problems can be hard to solve is the one of dense multiple (acoustic, electromagnetic or elastic) scattering media. Computing waves in such media requires us to take into account not only the interactions between the incident wave and the scatterers, but also the effects of the interactions between the scatterers themselves. When the number of scatterers is very large (and possibly at high frequency [58], [57]), specific deterministic or stochastic numerical methods and algorithms are needed. We introduce new optimized numerical methods for solving such complex configurations. Many applications are related to this problem *e.g.* for osteoporosis diagnosis where quantitative ultrasound is a recent and promising technique to detect a risk of fracture. Therefore, numerical simulation of wave propagation in multiple scattering elastic media in the high frequency regime is a very useful tool for this purpose.

4. Application Domains

4.1. Robotic swimmers

Some companies aim at building biomimetic robots that can swim in an aquarium, as toys but also for medical purposes. An objective of Sphinx is to model and to analyze several models of these robotic swimmers. For the moment, we focus in the motion of a nanorobot. In that case, the size of the swimmers leads to neglect the inertia forces and to only consider the viscosity effects. Such nanorobots could be used for medical purposes to introduce some medicine or perform small surgical operations. In order to get a better understanding of such robotic swimmers, we have obtained control results via shape changes and we have developed simulation tools (see [71], [70], [101], [98]). Among all the important issues, we aim to consider the following ones:

1. Solve the control problem by limiting the set of admissible deformations.
2. Find the "best" location of the actuators, in the sense of being the closest to the exact optimal control.

The main tools for this investigation are the 3D codes that we have developed for simulation of fish in a viscous incompressible fluid (SUSHI3D) or in a inviscid incompressible fluid (SOLEIL).

4.2. Aeronautics

We will develop robust and efficient solvers for problems arising in aeronautics (or aerospace) like electromagnetic compatibility and acoustic problems related to noise reduction in an aircraft. Our interest for these issues is motivated by our close contacts with companies like Airbus or "Thales Systèmes Aéroportés". We will propose new applications needed by these partners and assist them in integrating these new scientific developments in their home-made solvers. In particular, in collaboration with C. Geuzaine (Université de Liège), we are building a freely available parallel solver based on Domain Decomposition Methods that can handle complex engineering simulations, in terms of geometry, discretization methods as well as physics problems, see http://onelab.info/wiki/GetDDM.

5. Highlights of the Year

5.1. Highlights of the Year

Four members of the team are involved in the scientific project ODISSE funded by the ANR (october 2019-october 2023). The goal of this project, which gathers researchers from communities of automatic control and applied mathematics, is to investigate inverse problems using observer techniques.

6. New Software and Platforms

6.1. GetDDM

KEYWORDS: Large scale - 3D - Domain decomposition - Numerical solver

FUNCTIONAL DESCRIPTION: GetDDM combines GetDP and Gmsh to solve large scale finite element problems using optimized Schwarz domain decomposition methods.

- Contact: Xavier Antoine
- URL: http://onelab.info/wiki/GetDDM

6.2. GPELab

Gross-Pitaevskii equations Matlab toolbox

KEYWORDS: 3D - Quantum chemistry - 2D

FUNCTIONAL DESCRIPTION: GPELab is a Matlab toolbox developed to help physicists for computing ground states or dynamics of quantum systems modeled by Gross-Pitaevskii equations. This toolbox allows the user to define a large range of physical problems (1d-2d-3d equations, general nonlinearities, rotation term, multi-components problems...) and proposes numerical methods that are robust and efficient.

- Contact: Xavier Antoine
- URL: http://gpelab.math.cnrs.fr/

7. New Results

7.1. Control, stabilization and optimization of heterogeneous systems

Participants: Rémi Buffe, Thomas Chambrion, Eloïse Comte, Arnab Roy, Takéo Takahashi, Jean-François Scheid, Julie Valein.

Control and optimization

The use of measures (instead of functions) as controls is usually referred to as "impulsive control". While the theory is now well understood for finite dimensional dynamics, many questions are still open for the control of PDEs. In [19], Thomas Chambrion and his co-authors discuss the notion of solution for the impulsive control (using measures instead of functions for the control) of the general bilinear Schrödinger equations. The results are adapted in [35] to the case of potentials with high regularity. These techniques have been used to extend the celebrated obstruction to controllability by Ball, Marsden and Slemrod to the case of abstract bilinear equations with bounded potentials [33] and the Klein-Gordon equation [20]. Other obstructions to controllability (preservation of regularity) have been investigated for the Gross-Pitaiewski equation with unbounded potentials [34].

In [15], an optimal control problem for groundwater pollution due to agricultural activities is considered, the objective being the optimization of the trade-off between the fertilizer use and the cleaning costs. The spread of the pollution is modeled by a convection-diffusion-reaction equation. We are interested in the buffer zone around the captation well and we determine its optimal size.

In [44], Eduardo Cerpa, Emmanuelle Crépeau and Julie Valein study the boundary controllability of the Korteweg-de Vries equation on a tree-shaped network, with less controls than equations.

In [27], Jérôme Lohéac and Takéo Takahashi study the locomotion of a ciliated microorganism in a viscous incompressible fluid. They use the Blake ciliated model: the swimmer is a rigid body with tangential displacements at its boundary that allow it to propel in a Stokes fluid. This can be seen as a control problem: using periodical displacements, is it possible to reach a given position and a given orientation? They are interested in the minimal dimension d of the space of controls that allows the microorganism to swim. Their main result states the exact controllability with $d = 3$ generically with respect to the shape of the swimmer and with respect to the vector fields generating the tangential displacements. The proof is based on analyticity results and on the study of the particular case of a spheroidal swimmer.

In [31], Arnab Roy and Takéo Takahashi study the controllability of a fluid-structure interaction system. They consider a viscous and incompressible fluid modeled by the Boussinesq system and the structure is a rigid body with arbitrary shape which satisfies Newton's laws of motion. They assume that the motion of this system is bidimensional in space. They prove the local null controllability for the velocity and temperature of the fluid and for the position and velocity of the rigid body for a control acting only on the temperature equation on a fixed subset of the fluid domain.

Rémi Buffe and Ludovick Gagnon consider N manifolds without boundary that intersect each other. They assume that the speed of propagation on each manifold is different, which implies that the Snell conditions applies at the interface. They give sufficient geometric conditions to ensure the controllability with distributed controls on $N - 1$ manifolds.

Stabilization

In [17], Lucie Baudouin, Emmanuelle Crépeau and Julie Valein study the exponential stability of the nonlinear Korteweg-de Vries equation with boundary time-delay feedback. Two different methods are employed: a Lyapunov functional approach (allowing to have an estimation on the decay rate, but with a restrictive assumption on the length of the spatial domain of the KdV equation) and an observability inequality approach, with a contradiction argument (for any non-critical lengths but without estimation on the decay rate).

In [55], Julie Valein shows the semi-global exponential stability of the nonlinear Korteweg-de Vries equation in the presence of a delayed internal feedback, for any lengths, in the case where the weight of the feedback with delay is smaller than the weight of the feedback without delay. In the case where the support of the feedback without delay is not included in the support of the feedback with delay, a local exponential stability result is proved if the weight of the delayed feedback is small enough.

Optimization

J.F. Scheid, V. Calesti (PhD Student) and I. Lucardesi study an optimal shape problem for an elastic structure immersed in a viscous incompressible fluid. They want to establish the existence of an optimal elastic domain associated with an energy-type functional for a Stokes-Elasticity system. We want to find an optimal reference domain (the domain before deformation) for the elasticity problem that minimizes an energy-type functional. This problem is concerned with 2D geometry and is an extension of the work of [113] for a 1D problem. The optimal domain is seeking in a class of admissible open sets defined with a diffeomorphism of a given domain. The main difficulty lies on the coupling between the Stokes problem written in a eulerian frame and the linear elasticity problem written in a lagrangian form. The shape derivative of the energy-type functional is also aimed to be determined in order to numerically obtain an optimal elastic domain. This work is in progress.

7.2. Direct and Inverse problems for heterogeneous systems

Participants: Rémi Buffe, Imene Djebour, David Dos Santos Ferreira, Ludovick Gagnon, Alexandre Munnier, Julien Lequeurre, Karim Ramdani, Takéo Takahashi, Jean-Claude Vivalda.

Direct problems

In [22], Imene Djebour and Takéo Takahashi consider a fluid–structure interaction system composed by a three-dimensional viscous incompressible fluid and an elastic plate located on the upper part of the fluid boundary. They use here Navier-slip boundary conditions instead of the standard no-slip boundary conditions. The main results are the local in time existence and uniqueness of strong solutions of the corresponding system and the global in time existence and uniqueness of strong solutions for small data and if one assumes the presence of frictions in the boundary conditions.

In [42], Mehdi Badra (University of Toulouse) and Takéo Takahashi analyze a bi-dimensional fluid-structure interaction system composed by a viscous incompressible fluid and a beam located at the boundary of the fluid domain. The main result is the existence and uniqueness of strong solutions for the corresponding coupled system. The proof is based on a the study of the linearized system and a fixed point procedure. In particular, they show that the linearized system can be written with a Gevrey class semigroup. The main novelty with respect to previous results is that they do not consider any approximation in the beam equation.

In [18], Muriel Boulakia (Sorbonne University), Sergio Guerrero (Sorbonne University) and Takéo Takahashi consider a system modeling the interaction between a viscous incompressible fluid and an elastic structure. The fluid motion is represented by the classical Navier–Stokes equations while the elastic displacement is described by the linearized elasticity equation. The elastic structure is immersed in the fluid and the whole system is confined into a general bounded smooth three-dimensional domain. The main result is the local in time existence and uniqueness of a strong solution of the corresponding system.

In [28], Debayan Maity (TIFR Bangalore), Jorge San Martin (University of Chile), Takéo Takahashi and Marius Tucsnak (University of Bordeaux) study the interaction of surface water waves with a floating solid constraint to move only in the vertical direction. They propose a new model for this interaction, taking into consideration the viscosity of the fluid. This is done supposing that the flow obeys a shallow water regime (modeled by the viscous Saint-Venant equations in one space dimension) and using a Hamiltonian formalism. Another contribution of this work is establishing the well-posedness of the obtained PDEs/ODEs system in function spaces similar to the standard ones for strong solutions of viscous shallow water equations. Their well-posedness results are local in time for any initial data and global in time if the initial data are close (in appropriate norms) to an equilibrium state. Moreover, they show that the linearization of the system around an equilibrium state can be described, at least for some initial data, by an integro-fractional differential equation related to the classical Cummins equation and which reduces to the Cummins equation when the viscosity vanishes and the fluid is supposed to fill the whole space. Finally, they describe some numerical tests, performed on the original nonlinear system, which illustrate the return to equilibrium and the influence of the viscosity coefficient.

In [30], Benjamin Obando and Takéo Takahashi consider the motion of a rigid body in a viscoplastic material. This material is modeled by the 3D Bingham equations, and the Newton laws govern the displacement of the rigid body. The main result is the existence of a weak solution for the corresponding system. The weak formulation is an inequality (due to the plasticity of the fluid), and it involves a free boundary (due to the motion of the rigid body). They approximate it by regularizing the convex terms in the Bingham fluid and by using a penalty method to take into account the presence of the rigid body.

In [23], Alexandre Munnier and his co-authors consider the dynamics of several rigid bodies immersed in a perfect incompressible fluid. We show that this dynamics can be modelized by a second order ODE whose coefficients depend on the vorticity and the circulation of the fluid around the bodies. This formulation permits to point out the geodesic nature of the solutions, the added mass effect, the gyroscopic effects and the Kutta-Joukowski-type lift forces.

In [24], Julien Lequeurre and his co-authors study an unsteady nonlinear fluid–structure interaction problem. We consider a Newtonian incompressible two-dimensional flow described by the Navier-Stokes equations set in an unknown domain depending on the displacement of a structure, which itself satisfies a linear wave equation or a linear beam equation. The fluid and the structure systems are coupled via interface conditions prescribing the continuity of the velocities at the fluid–structure interface and the action-reaction principle. We prove existence of a unique local in time strong solution. In the case of the wave equation or a beam equation with inertia of rotation, this is, to our knowledge the first result of existence of strong solutions for which no viscosity is added. One key point, is to use the fluid dissipation to control, in appropriate function spaces, the structure velocity.

J.F. Scheid and M. Bouguezzi (PhD student) in collaboration with D. Hilhorst and Y. Miyamoto work on the convergence of the solution of the one-phase Stefan problem in one-space dimension to a self-similar profile. The evolutional self-similar profile is viewed as a stationary solution of a Stefan problem written in a self-similar coordinates system. The proof of the convergence relies on the construction of sub and super-solutions for which it must be proved that they both tend to the same function. It remains to show that this limiting function actually corresponds to the self-similar solution of the original Stefan problem. This work is in progress.

Rémi Buffe, Ludovick Gagnon *et al.* obtain the exponential decay of the solutions of coupled wave equations with a transmission condition at the interface and with a viscoelastic damping term. They prove that the exponential decay is obtained if the support of the viscoelastic term satisfies the uniform escaping geometry condition. They also deal with the case where the damping term touches the interface.

Inverse problems

In [43], the authors are interested in the homogenization of time-harmonic Maxwell's equations in a composite medium with periodically distributed small inclusions of a negative material. Here a negative material is a material modelled by negative permittivity and permeability. Due to the sign-changing coefficients in the equations, it is not straightforward to obtain uniform energy estimates to apply the usual homogenization techniques. The analysis is based on a precise study of two associated scalar problems: one involving the sign-changing permittivity with Dirichlet boundary conditions, another involving the sign-changing permeability with Neumann boundary conditions. For both problems, we obtain a criterion on the physical parameters ensuring uniform invertibility of the corresponding operators as the size of the inclusions tends to zero. Then we use the results obtained for the scalar problems to derive uniform energy estimates for Maxwell's system.

In [37], Jean-Claude Vivalda and his co-authors prove that the class of continuous-time systems who are strongly differentially observable after time sampling is everywhere dense in the set of pairs (f, h) where f is a (parametrized) vector field given on a compact manifold and h is an observation function.

In [47], using a partial boundary measurement, Jean-Claude Vivalda and his co-authors design an observer for a system that models a desalination device; this observer being used to make an output tracking trajectory.

Rémi Buffe, David Dos Santos Ferreira and Ludovick Gagnon obtain an estimate on the magnetic Laplacian with sharp dependance on the power of the zeroth and first order potential and close to sharp norm of these potentials. This estimate is related to the observability inequality for the wave equation and to the cost of the control.

7.3. Numerical analysis and simulation of heterogeneous systems

Participant: Xavier Antoine.

Acoustics

Artificial boundary conditions: while high-order absorbing boundary conditions (HABCs) are accurate for smooth fictitious boundaries, the precision of the solution drops in the presence of corners if no specific treatment is applied. In [29], the authors present and analyze two strategies to preserve the accuracy of Padé-type HABCs at corners: first by using compatibility relations (derived for right angle corners) and second by regularizing the boundary at the corner. Exhaustive numerical results for two- and three-dimensional problems are reported in the paper. They show that using the compatibility relations is optimal for domains with right angles. For the other cases, the error still remains acceptable, but depends on the choice of the corner treatment according to the angle.

Domain decomposition : in [49], Xavier Antoine and his co-authors develop the first application of the optimized Schwarz domain decomposition method to aeroacoustics. Highly accurate three-dimensional simulations for turbofans are conducted through a collaboration with Siemens (ongoing CIFRE Ph.D. Thesis of Philippe Marchner). In [26], the authors propose a new high precision IGA B-Spline approximation of the high frequency scattering Helmholtz problem, which minimizes the numerical pollution effects that affect standard Galerkin finite element approaches.

Underwater acoustics

New adiabatic pseudo-differential models as well as their numerical approximation are introduced in [53] for the simulation of the propagation of wave fields in underwater acoustics. In particular, the calculation of gallery modes is shown to be accurately obtained. This work is related to a new collaboration with P. Petrov from the V.I. Il'ichev Pacific Oceanological Institute, Vladivostok, Russia.

Quantum theory

With E. Lorin, Xavier Antoine proposes in [13] an optimization technique of the convergence rate of relaxation Schwarz domain decomposition methods for the Schrödinger equation. This analysis is based on the use of microlocal analysis tools. Convergence proofs are given in [11] for the real-time Schrödinger equation with optimized transmission conditions. We extend these results to the case of multiple subdomains in [13].

In [52], the authors analyze the convergence and stability in of a discretization scheme for the linear Schrödinger equation with artificial boundary conditions.

In [39], Xavier Antoine and his co-authors develop an implementation of the PML technique in the framework of Fourier pseudo-spectral approximation schemes for the fast rotating Gross-Pitaevskii equation. This is the first work related to the international Inria team BEC2HPC, associated with China (https://team.inria.fr/bec2hpc/).

In [12], Antoine and his co-authors develop new Fourier pseudo-spectral schemes including a PML for the dynamics of the Dirac equation. The implementation of the method leads to the possibility of simulating complex quantum situations. In [38], the authors extend the approximation to the curved static Dirac equation. The goal is to be able to better understand quantum phenomena related to the charge carriers in strained graphene, with potential long term applications for designing quantum computers. This is a collaboration with E. Lorin (Carleton University), F. Fillion-Gourdeau and S. Mac Lean from the Institute for Quantum Computing, University of Waterloo.

Fractional PDE

In [32], with J. Zhang and D. Li, Xavier Antoine is interested in the development and analysis of fast second-order schemes to simulate the nonlinear time fractional Schrödinger equation in unbounded domains.

The authors propose in [14] the construction of PML operators for a large class of space fractional PDEs in one- and two-dimensions. The specific case of the fractional laplacian is carefully considered.

Xavier Antoine and Emmanuel Lorin are interested in [40] in the problem of building fast and robust linear algebra algorithms based on the discretization of the Cauchy integral formula used to represent the power matrix. Applications related to stationary PDEs are presented, with possibly randomly perturbed potentials. Differential doubly preconditioned iterative schemes are investigated in details in [41] to evaluate the power, and more generally functions, of matrices.

Error estimates of a semi-implicit ALE scheme for the one-phase Stefan problem. J.F. Scheid, M. Bouguezzi (PhD student) and D. Hilhorst study the convergence with error estimates of an Arbitrary-Lagrangian-Eulerian (ALE) scheme for the classical one-phase Stefan problem. Despite Stefan problems as well as ALE techniques are well-known in the mathematical litterature for many decades, surprisingly there is no global result on convergence (with error estimates) for fully space-time discretized scheme based on ALE formulations. The main difficulty lies on the unbounded behavior of the exact (and approximate) free boundary. Stability results have already been obtained for a time-discretized scheme (and continuous in space) for the one-space dimension case.

Chaotic advection in a viscous fluid under an electromagnetic field. J.F. Scheid, J.P. Brancher and J. Fontchastagner study the chaotic behavior of trajectories of a dynamical system arising from a coupling system beetwen Stokes flow and an electromagnetic field. They consider an electrically conductive viscous fluid crossed by a uniform electric current. The fluid is subjected to a magnetic field induced by the presence of a set of magnets. The resulting electromagnetic force acts on the conductive fluid and generates a flow in the fluid. According to a specific arrangement of the magnets surrounding the fluid, vortices can be generated and the trajectories of the dynamical system associated to the stationary velocity field in the fluid may have chaotic behavior. The aim of this study is to numerically show the chaotic behavior of the flow for the proposed disposition of the magnets along the container of the fluid. The flow in the fluid is governed by the Stokes equations with the Laplace force induced by the electric current and the magnetic field. An article is in preparation.

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

Since September 2019, X. Antoine has been the co-advisor (with C. Geuzaine from Liège university) of two PhD theses, which are funded respectively by Siemens and Thales (CIFRE contracts).The aim of the first thesis is the numerical simulation by domain decomposition methods of aeroacoustic problems; the aim of the second one is the HPC simulation by domain decomposition methods of electromagnetic problems.

Zhanhao Liu works on a PhD thesis funded by Saint Gobain Recherche about the use of statistical methods for the effective control of industrial plants.

9. Partnerships and Cooperations

9.1. National Initiatives

9.1.1. ANR

- **Project Acronym :** IFSMACS
  Project Title : Fluid-Structure Interaction: Modeling, Analysis, Control and Simulation
  Coordinator: Takéo Takahashi
  Participants: Julien Lequeurre, Alexandre Munnier, Jean-François Scheid, Takéo Takahashi
  Duration : 48 months (starting on October 1st, 2016)
  Other partners: Institut de Mathématiques de Bordeaux, Inria Paris, Institut de Mathématiques de Toulouse
  Abstract: The aim of this project is to analyze systems composed by structures immersed in a fluid. Studies of such systems can be motivated by many applications (motion of the blood in veins, fish locomotion, design of submarines, etc.) but also by the corresponding challenging mathematical problems. Among the important difficulties inherent to these systems, one can quote nonlinearity, coupling, free-boundaries. Our objectives include asymptotic analyses of FSIS, the study of controllability and stabilizability of FSIS, the understanding of locomotion of self-propelled structures and the analyze and development of numerical tools to simulate fluid-structure system.
  URL: http://ifsmacs.iecl.univ-lorraine.fr/
- **Project Acronym:** QUACO
  Project title: QUAntum COntrol: PDE systems and MRI
  Coordinator: Thomas Chambrion
  Duration: 48 months (starting January 1st 2018).
  URL: http://www.iecl.univ-lorraine.fr/~Thomas.Chambrion/QUACO/index.html
  Abstract The aim of the project is the use of geometrical tools for the study and the control of quantum system with application to MRI.
- **Project acronym:** ISDEEC
  Project title: Interaction entre Systèmes Dynamiques, Equations d'Evolution et Contrôle
  Coordinator: Romain Joly
  Participant: Julie Valein
  Other partners: Institut Fourier, Grenoble; Département de Mathématiques d'Orsay
  Duration: 36 months (2017-2020)
  URL: http://isdeec.math.cnrs.fr/
  Abstract The aim of the project is to study the qualitative dynamics of various classes of PDEs and classes of ODEs with special structure. This work program requires expertise in different mathematical domains such as dynamical systems theory, PDE techniques, control theory, geometry, functional analysis... while the current trend in mathematics is for high specialisation. The purpose of this project is to create and extend interactions between experts of these various domains, in order to deepen our understanding of the dynamics of evolution equations and to explore the new challenging questions, which will emerge.
- **Project Acronym:** ODISSE
  Project title: Observer Design for Infinite-dimensional Systems
  Coordinator: Vincent Andrieu
  Local coordinator: Karim Ramdani
  Duration: 48 months (starting on October 1st 2019)
  Participants: Ludovick Gagnon, Karim Ramdani, Julie Valein and Jean-Claude Vivalda.
  Other partners: Laas, Lagepp, Inria-Saclay
  Abstract: This ANR project includes 3 work-packages
  1. Theoretical aspects of observability and identifiability.

2. From finite dimensional systems to infinite dimensional systems : Infinite-dimensional Luenberger observers, Parametric identification and adaptive estimation algorithm, Infinite-dimensional observers for finite-dimensional systems.
3. From infinite dimensional systems to finite dimensional systems : discretization, hierarchical reduction.

9.2. International Initiatives

9.2.1. Inria International Labs

9.2.1.1. BEC2HPC

Title: Bose-Einstein Condensates : Computation and HPC simulation

Head: Xavier Antoine

International Partner: Sichuan University, Chengdu (China) - Department of mathematics - Qinglin TANG

Start year: 2019

See also: https://team.inria.fr/bec2hpc/

All members of the associate team are experts in the mathematical modeling and numerical simulation of PDEs related to engineering and physics applications. The first objective of the associate team is to develop efficient high-order numerical methods for computing the stationary states and dynamics of Bose-Einstein Condensates (BEC) modeled by Gross-Pitaevskii Equations (GPEs). A second objective is to implement and validate these new methods in a HPC environment to simulate large scale 2D and 3D problems in quantum physics. Finally, a third objective is to provide a flexible and efficient HPC software to the quantum physics community for simulating realistic problems.

9.2.2. Participation in Other International Programs

9.2.2.1. Réseau Franco-Brésilien de mathématiques

Ludovick Gagnon collaborates with the Universidade Federal da Paraiba and Universidade Federal do Rio de Janeiro funded by the Réseau Franco-Brésilien de mathématiques.

9.2.2.2. Indo-French Center of Applied Mathematics

Title : **Analysis, Control and Homogenization of Complex Systems**

International Partner: TIFR CAM, Bangalore

Heads: Takéo Takahashi (France) and Mythily Ramaswamy (India).

Duration: 2018 - 2021

Scientific Objectives

- Study the well-posedness of models arising from either structure in the fluid or structure on the boundary of the domain containing the fluid.
- Explore Controllability, Optimal Control and Stabilization of such fluid-structure interaction problems.
- Study systems describing fluid flows in a time dependent domain with a rapidly oscillating boundary using Homogenization Theory. The rapid oscillations of the boundary takes into account, the rough character of the boundary and its movements may take into account the displacement of a deformable body into a fluid flow.
- Carry out Finite Element Analysis for such models, including elastic structures as well as rigid ones.

9.3. International Research Visitors

9.3.1. Visits to International Teams

Jean-François Scheid was invited to the "École Supérieure des Sciences et Technologie d'Hammam-Sousse", Tunisia, 30 September–5 October 2019.

9.3.1.1. Research Stays Abroad

Xavier Antoine was invited to the Department of Mathematics, Sichuan University, Chengdu, January 2019 (2 weeks) + August 2019 (4.5 weeks) + November 2019 (3 weeks).

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events: Organisation

10.1.1.1. General Chair, Scientific Chair

- David Dos Santos Ferreira is the head of the Organization Committee of the next national conference of the SMF (French Mathematical Society) that will take place in Nancy from 25th-29th may 2020 (see: https://smf2020.math.cnrs.fr/).
- David Dos Santos Ferreira is, with Laurent Thomann, co-organizer of the national conference "Journées EDP". (see : http://jedp-2019.iecl.univ-lorraine.fr/).
- Julien Lequeurre and Alexandre Munnier are the heads of the national workshop "Journées EDP de l'Institut Elie Cartan de Lorraine" (see: http://journeesedp.iecl.univ-lorraine.fr/2019/).This an annual conference whose themes are those of the team PDE of the IECL (waves, fluid and fluid-structure interaction, form optimization,...).

10.1.1.2. Member of the Organizing Committees

- Karim Ramdani is a member of the Organizing Committee of the next national conference of the SMF (French Mathematical Society) (see: https://smf2020.math.cnrs.fr/).
- Thomas Chambrion was the organizer of the invited session "Analytic and Geometric Tools in Quantum Control", in the Conference on Decision and Control (CDC 2019, Nice, France).
- Ludovick Gagnon was an organizer of the CRAN/IECL day (November 22, 2019).
- Jean-François Scheid was a member of the organizing committee of the workshop "Journées Corrosion et Analyse Numérique", Laboratoire de Mathématiques d'Orsay, 4 – 5 July 2019.
- David Dos Santos Ferreira was a member of the scientific committee of the "Journées des Jeunes Edpistes Français", Rennes, 20-22 March 2019, https://jjedp19.sciencesconf.org/.

10.1.2. Scientific Events: Selection

10.1.2.1. Member of the Conference Program Committees

Xavier Antoine was a member of the scientific council of the international conference Waves 2019, Vienna, Austria, August, 2019.

10.1.3. Journal

10.1.3.1. Member of the Editorial Boards

- Xavier Antoine is an associate editor of "Multiscale in Science and Engineering" (Springer) and "International Journal of Computer Mathematics" (Taylor and Francis);
- David Dos Santos Ferreira is a member of the editorial board of "Mathematical Control and Related Fields";
- Jean-Claude Vivalda is a member of the editorial board of the "Journal of Dynamical and Control System".

10.1.3.2. Reviewer - Reviewing Activities

Jean-Claude Vivalda is a reviewer for the "Mathematical reviews".

10.1.4. Invited Talks

- Rémi Buffe was an invited speaker at the “International itinerant workshop in PDEs” (Roma (Italy), February 2019).
- Rémi Buffe was an invited speaker at the “Journées Jeunes Contrôleurs” (Paris, June 2019).
- Rémi Buffe was an invited speaker at the “Conférence THESPEGE - Spectral Theory and Geometry”, (Seillac (France), September 2019).
- Thomas Chambrion took part to the invited session “Control of nonlinear PDEs” in Conference on Nonlinear Control Systems (NOLCOS 2019, Vienna (Austria)).
- Ludovick Gagnon was an invited speaker at the first Joint Meeting Brazil-France in Mathematics (Rio de Janeiro, July 2019).
- Jean-François Scheid was invited at the “Journées Corrosion et Analyse Numérique”, (Orsay, 4–5 July 2019).
- Jean-François Scheid was invited at the workshop “New Trends in Probability and Analysis” (NTPA), (Hammamet, Tunisia, 23–26 September 2019).
- Takéo Takahashi was an invited speaker at the congress VII MACI 2019, Río Cuarto (Argentina), May 2019.
- Takéo Takahashi was an invited speaker at the workshop PDE 2019, Berlin (Germany), September 2019.
- Takéo Takahashi was an invited speaker at the workshop “Franco-Brazilian meeting in mathematical fluid mechanics”, Lyon (France), October 2019.
- Takéo Takahashi was an invited speaker at the workshop “Feedback Control”, Linz (Austria), November 2019.

10.1.5. Leadership within the Scientific Community

David Dos Santos Ferreira is one of the coordinators of the GDR “Analyse des EDP”.

10.1.6. Research Administration

- Xavier Antoine is the director of the maths laboratory IECL and an elected member of the scientific council of the “Université de Lorraine”.
- Xavier Antoine was the president of the HCERES evaluation panel of the laboratory Lamav, (Valenciennes, February 2019). He was also a member of the HCERES evaluation panel of the “Fédération de Recherche des Hauts de France”, (February 2019).
- Xavier Antoine is the local coordinator of the France-Chinese CNRS LIASFMA in applied mathematics.
- David Dos Santos Ferreira is the treasurer of the SMF (French Mathematical Society).
- Karim Ramdani is member of the board of the RNBM (Réseau National des Bibliothèques de Mathématiques) and is in charge of Open Access issues (with Benoît Kloeckner). Since October 2018, he is also a member of the Working Group “Publications” of the national “Comité pour la Science Ouverte” of the French ministry of Higher Education, Research and Innovation.
- Ludovick Gagnon is International in charge of international relations for the Inria Nancy Grand-Est.
- Julie Valein was a member of the selection committee of new "maître de conférences" at “Université de Besançon-ISIFC” in April-May 2019.
- Julie Valein is a co-organizer of the “Séminaire EDP de l’Institut Elie Cartan de Lorraine, site de Nancy”.
- Julien Lequeurre is the organizer of the “Séminaire EDP de l’Institut Elie Cartan de Lorraine, site de Metz”.

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Except L. Gagnon, K. Ramdani, T. Takahashi and J.-C. Vivalda, SPHINX members have teaching obligations at “Université de Lorraine” and are teaching at least 192 hours each year. They teach mathematics at different level (Licence, Master, Engineering school). Many of them have pedagogical responsibilities.

Moreover, Julie Valein is a member of the managing board and of the selection committee of the engineer school “Polytech Nancy”, she is also a member of the “personnel commission” of IECL.

10.2.2. Supervision

- PhD in progress
  - I. Badia, HPC simulation by domain decomposition methods of electromagnetic problems, (started in september 2019), X. Antoine and Ch. Geuzaine.
  - I. Djebour, Controlability and stabilization of fluid-structure interaction problems, (started in November 2017), T. Takahashi.
  - D. Gasperini, design of a new multi-frequency PDE-based approach for the numerical simulation of the Doppler effect arising in acoustic and electromagnetism, X. Antoine.
  - Z. Liu, Statistical methods for the automatic generation of efficient command laws without model, April 2018, Th. Chambrion.
  - Ph. Marchner, Numerical simulation by domain decomposition methods of aeroacoustic problems, Sept. 2019, X. Antoine and Ch. Geuzaine.
  - Julie Valein is a member of the monitoring committee of the theses of Imène Djebour (september 2018 and 2019, advisor Takéo Takahashi) and Ibtissem Zaafrani (september 2019, advisor Simon Labrunie)

10.2.3. Juries

- Takéo Takahashi reviewed the PhD thesis of Jiao He, Université de Lyon, 2019.
- Xavier Antoine reviewed the PhD theses of
  - M. Averseng, Université de Saclay, 2019.
  - P. Mennuni, Université de Lille, 2019.
  - P. Marchand, Université de Sorbonne Université, 2020 (defense).
- Xavier Antoine reviewed the HDR of S. Chaillat, ENSTA, 2019.
- Jean-Claude Vivalda was a member of the thesis jury of Missie María del Rocío Aguado Rojas defended at June 2019 at “Centrale-Supélec”.
- David Dos Santos Ferreira was the president of the HDR thesis jury of Matthieu Léautaud (University of Paris Diderot).
- David Dos Santos Ferreira was a member of the HDR thesis jury of Thierry Daudé (University of Cergy-Pontoise).
- David Dos Santos Ferreira reviewed the PhD thesis of Cristóbal Meroño Moreno (Universidad Autónoma de Madrid)

11. Bibliography

Major publications by the team in recent years

[1] X. ANTOINE, Q. TANG, J. ZHANG.*On the numerical solution and dynamical laws of nonlinear fractional Schrödinger/Gross-Pitaevskii equations*, in "Int. J. Comput. Math.", 2018, vol. 95, n^{o} 6-7, p. 1423–1443, https://doi.org/10.1080/00207160.2018.1437911

[2] N. BURQ, D. DOS SANTOS FERREIRA, K. KRUPCHYK.*From semiclassical Strichartz estimates to uniform L^p resolvent estimates on compact manifolds*, in "Int. Math. Res. Not. IMRN", 2018, n^{o} 16, p. 5178–5218, https://doi.org/10.1093/imrn/rnx042

[3] L. BĂLILESCU, J. SAN MARTÍN, T. TAKAHASHI.*Fluid-structure interaction system with Coulomb's law*, in "SIAM Journal on Mathematical Analysis", 2017, https://hal.archives-ouvertes.fr/hal-01386574

[4] L. GAGNON.*Lagrangian controllability of the 1-dimensional Korteweg–de Vries equation*, in "SIAM J. Control Optim.", 2016, vol. 54, n^{o} 6, p. 3152–3173, https://doi.org/10.1137/140964783

[5] O. GLASS, A. MUNNIER, F. SUEUR.*Point vortex dynamics as zero-radius limit of the motion of a rigid body in an irrotational fluid*, in "Inventiones Mathematicae", 2018, vol. 214, n^{o} 1, p. 171-287 [*DOI :* 10.1007/S00222-018-0802-4], https://hal.archives-ouvertes.fr/hal-00950544

[6] C. GRANDMONT, M. HILLAIRET, J. LEQUEURRE.*Existence of local strong solutions to fluid-beam and fluid-rod interaction systems*, in "Annales de l'Institut Henri Poincaré (C) Non Linear Analysis", July 2019, vol. 36, n^{o} 4, p. 1105-1149 [*DOI :* 10.1016/J.ANIHPC.2018.10.006], https://hal.inria.fr/hal-01567661

[7] A. MUNNIER, K. RAMDANI.*Calderón cavities inverse problem as a shape-from-moments problem*, in "Quarterly of Applied Mathematics", 2018, vol. 76, p. 407-435, forthcoming, https://hal.inria.fr/hal-01503425

[8] K. RAMDANI, J. VALEIN, J.-C. VIVALDA.*Adaptive observer for age-structured population with spatial diffusion*, in "North-Western European Journal of Mathematics", 2018, vol. 4, p. 39-58, forthcoming, https://hal.inria.fr/hal-01469488

[9] J.-F. SCHEID, J. SOKOLOWSKI.*Shape optimization for a fluid-elasticity system*, in "Pure Appl. Funct. Anal.", 2018, vol. 3, n^{o} 1, p. 193–217

Publications of the year

Articles in International Peer-Reviewed Journal

[10] X. ANTOINE, L. EMMANUEL.*Explicit computation of Robin parameters in optimized Schwarz waveform relaxation methods for Schrödinger equations based on pseudodifferential operators*, in "Communications in Computational Physics", 2019, forthcoming [*DOI :* 10.4208/CICP.OA-2018-0259], https://hal.archives-ouvertes.fr/hal-01929066

[11] X. ANTOINE, L. EMMANUEL.*On the rate of convergence of Schwarz waveform relaxation methods for the time-dependent Schrödinger equation*, in "Journal of Computational and Applied Mathematics", 2019, vol. 354, p. 15-30 [*DOI :* 10.1016/J.CAM.2018.12.006], https://hal.archives-ouvertes.fr/hal-01649736

[12] X. ANTOINE, E. LORIN.*A simple pseudospectral method for the computation of the time-dependent Dirac equation with Perfectly Matched Layers*, in "Journal of Computational Physics", 2019, vol. 395, p. 583-601 [*DOI :* 10.1016/J.JCP.2019.06.020], https://hal.archives-ouvertes.fr/hal-02340843

[13] X. ANTOINE, E. LORIN.*Asymptotic convergence rates of SWR methods for Schrödinger equations with an arbitrary number of subdomains*, in "Multiscale Science and Engineering", 2019, vol. 1, n^{o} 1, p. 34-46 [*DOI :* 10.1007/S42493-018-00012-Y], https://hal.archives-ouvertes.fr/hal-02340909

[14] X. ANTOINE, E. LORIN.*Towards perfectly matched layers for time-dependent space fractional PDEs*, in "Journal of Computational Physics", 2019, vol. 391, p. 59-90 [*DOI :* 10.1016/J.JCP.2019.04.025], https://hal.archives-ouvertes.fr/hal-01962622

[15] E. AUGERAUD-VÉRON, C. CHOQUET, E. COMTE.*Optimal buffer zone for the control of groundwater pollution from agricultural activities*, in "Applied Mathematics and Optimization", 2019, to appear, forthcoming [*DOI :* 10.1007/S00245-019-09638-2], https://hal.inria.fr/hal-02380678

[16] M. BADRA, T. TAKAHASHI.*Gevrey regularity for a system coupling the Navier-Stokes system with a beam equation*, in "SIAM Journal on Mathematical Analysis", 2019, forthcoming, https://hal.archives-ouvertes.fr/hal-02160011

[17] L. BAUDOUIN, E. CRÉPEAU, J. VALEIN.*Two approaches for the stabilization of nonlinear KdV equation with boundary time-delay feedback*, in "IEEE Transactions on Automatic Control", April 2019, vol. 64, n^o 4, p. 1403-1414, https://arxiv.org/abs/1711.09696 [*DOI :* 10.1109/TAC.2018.2849564], https://hal.laas.fr/hal-01643321

[18] M. BOULAKIA, S. GUERRERO, T. TAKAHASHI.*Well-posedness for the coupling between a viscous incompressible fluid and an elastic structure*, in "Nonlinearity", 2019, vol. 32, p. 3548-3592 [*DOI :* 10.1088/1361-6544/AB128C], https://hal.inria.fr/hal-01939464

[19] N. BOUSSAID, M. CAPONIGRO, T. CHAMBRION.*Regular propagators of bilinear quantum systems*, in "Journal of Functional Analysis", 2019, https://arxiv.org/abs/1406.7847 , forthcoming [*DOI :* 10.1016/J.JFA.2019.108412], https://hal.archives-ouvertes.fr/hal-01016299

[20] T. CHAMBRION, L. THOMANN.*A topological obstruction to the controllability of nonlinear wave equations with bilinear control term*, in "SIAM Journal on Control and Optimization", 2019, vol. 57, n^o 4, p. 2315-2327, https://arxiv.org/abs/1809.07107 [*DOI :* 10.1137/18M1215207], https://hal.archives-ouvertes.fr/hal-01876952

[21] T. CHAMBRION, L. THOMANN.*On the bilinear control of the Gross-Pitaevskii equation*, in "Annales de l'Institut Henri Poincaré (C) Non Linear Analysis", 2020, https://arxiv.org/abs/1810.09792 , forthcoming, https://hal.archives-ouvertes.fr/hal-01901819

[22] I. A. DJEBOUR, T. TAKAHASHI.*On the existence of strong solutions to a fluid structure interaction problem with Navier boundary conditions*, in "Journal of Mathematical Fluid Mechanics", 2019, forthcoming [*DOI :* 10.1007/S00021-019-0440-7], https://hal.archives-ouvertes.fr/hal-02061542

[23] O. GLASS, C. LACAVE, A. MUNNIER, F. SUEUR.*Dynamics of rigid bodies in a two dimensional incompressible perfect fluid*, in "Journal of Differential Equations", September 2019, vol. 267, n^o 6, p. 3561-3577, https://arxiv.org/abs/1902.07082 [*DOI :* 10.1016/J.JDE.2019.04.017], https://hal.archives-ouvertes.fr/hal-02024104

[24] C. GRANDMONT, M. HILLAIRET, J. LEQUEURRE.*Existence of local strong solutions to fluid-beam and fluid-rod interaction systems*, in "Annales de l'Institut Henri Poincaré (C) Non Linear Analysis", July 2019, vol. 36, n^o 4, p. 1105-1149 [*DOI :* 10.1016/J.ANIHPC.2018.10.006], https://hal.inria.fr/hal-01567661

[25] B. H. HAAK, D. MAITY, T. TAKAHASHI, M. TUCSNAK.*Mathematical analysis of the motion of a rigid body in a compressible Navier-Stokes-Fourier fluid*, in "Mathematical News / Mathematische Nachrichten", 2019, vol. 292, n^o 9, p. 1972-2017, https://arxiv.org/abs/1710.08245 [*DOI :* 10.1002/MANA.201700425], https://hal.archives-ouvertes.fr/hal-01619647

[26] T. KHAJAH, X. ANTOINE, S. P. BORDAS.*B-spline FEM for time-harmonic acoustic scattering and propagation*, in "Journal of Theoretical and Computational Acoustics", 2019, vol. 27, n^{o} 3, 1850059 [*DOI :* 10.1142/S2591728518500597], https://hal.archives-ouvertes.fr/hal-01377485

[27] J. LOHÉAC, T. TAKAHASHI.*Controllability of low Reynolds numbers swimmers of ciliate type*, in "ESAIM: Control, Optimisation and Calculus of Variations", 2020, Forthcoming article, forthcoming [*DOI :* 10.1051/COCV/2019010], https://hal.archives-ouvertes.fr/hal-01569856

[28] D. MAITY, J. SAN MARTÍN, T. TAKAHASHI, M. TUCSNAK.*Analysis of a simplified model of rigid structure floating in a viscous fluid*, in "Journal of Nonlinear Science", 2019, vol. 29, n^{o} 5, p. 1975–2020 [*DOI :* 10.1007/S00332-019-09536-5], https://hal.archives-ouvertes.fr/hal-01889892

[29] A. MODAVE, C. GEUZAINE, X. ANTOINE.*Corner treatments for high-order local absorbing boundary conditions in high-frequency acoustic scattering*, in "Journal of Computational Physics", 2020, vol. 401, 109029 [*DOI :* 10.1016/J.JCP.2019.109029], https://hal.archives-ouvertes.fr/hal-01925160

[30] B. OBANDO, T. TAKAHASHI.*Existence of weak solutions for a Bingham fluid-rigid body system*, in "Annales de l'Institut Henri Poincaré (C) Non Linear Analysis", 2019 [*DOI :* 10.1016/J.ANIHPC.2018.12.001], https://hal.archives-ouvertes.fr/hal-01942426

[31] A. ROY, T. TAKAHASHI.*Local null controllability of a rigid body moving into a Boussinesq flow*, in "Mathematical Control and Related Fields", 2019, vol. 9, n^{o} 4, p. 793-836 [*DOI :* 10.3934/MCRF.2019050], https://hal.archives-ouvertes.fr/hal-01572508

[32] J. ZHANG, D. LI, X. ANTOINE.*Efficient numerical computation of time-fractional nonlinear Schrödinger equations in unbounded domain*, in "Communications in Computational Physics", 2019, vol. 25, n^{o} 1, p. 218-243 [*DOI :* 10.4208/CICP.OA-2017-0195], https://hal.archives-ouvertes.fr/hal-01422725

International Conferences with Proceedings

[33] N. BOUSSAID, M. CAPONIGRO, T. CHAMBRION.*On the Ball-Marsden-Slemrod obstruction for bilinear control systems*, in "58 th IEEE Conference on Decision and Control", Nice, France, December 2019, https://arxiv.org/abs/1903.05846 , https://hal.archives-ouvertes.fr/hal-01537743

[34] T. CHAMBRION, L. THOMANN.*Obstruction to the bilinear control of the Gross-Pitaevskii equation: an example with an unbounded potential*, in "Joint 8th IFAC Symposium on Mechatronic Systems and 11th IFAC Symposium on Nonlinear Control Systems", Vienne, Austria, Proceedings of the joint 8th IFAC Symposium on Mechatronic Systems and 11th IFAC Symposium on Nonlinear Control Systems, 2019, vol. 52, n^{o} 16, p. 304 - 309, https://arxiv.org/abs/1903.04185 [*DOI :* 10.1016/J.IFACOL.2019.11.796], https://hal.archives-ouvertes.fr/hal-02063308

Conferences without Proceedings

[35] N. BOUSSAID, M. CAPONIGRO, T. CHAMBRION.*Impulsive control of the bilinear Schrödinger equation : propagators and attainable sets*, in "58th Conference on Decision and Control", Nice, France, 2019, https://hal.archives-ouvertes.fr/hal-02074801

[36] Z. LIU, M. PERRODIN, T. CHAMBRION, R. STOICA.*Modélisation statistique d'un procédé de centrifugation*, in "Journées de Statistique", Nancy, France, June 2019, https://hal.archives-ouvertes.fr/hal-02273932

Other Publications

[37] S. AMMAR, J.-C. VIVALDA, B. ZITOUNI.*Strong differential observability for sampled systems*, November 2019, working paper or preprint, https://hal.inria.fr/hal-02377400

[38] X. ANTOINE, F. FILLION-GOURDEAU, E. LORIN, S. MCLEAN.*Pseudospectral computational methods for the time-dependent Dirac equation in static curved spaces*, October 2019, https://arxiv.org/abs/1909.02894 - working paper or preprint, https://hal.archives-ouvertes.fr/hal-02340827

[39] X. ANTOINE, C. GEUZAINE, Q. TANG.*Perfectly Matched Layer for computing the dynamics of nonlinear Schrödinger equations by pseudospectral methods. Application to rotating Bose-Einstein condensates*, October 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-02340832

[40] X. ANTOINE, E. LORIN.*Double-preconditioning for Fractional Linear Systems. Application to Stationary Fractional Partial Differential Equations*, October 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-02340820

[41] X. ANTOINE, E. LORIN.*ODE-based Double-preconditioning for Solving Linear Systems $A^\alpha x = b$ and $f(A)x = b$*, October 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-02340590

[42] M. BADRA, T. TAKAHASHI.*Gevrey regularity for a system coupling the Navier-Stokes system with a beam: the non-flat case*, October 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-02303258

[43] R. BUNOIU, L. CHESNEL, K. RAMDANI, M. RIHANI.*Homogenization of Maxwell's equations and related scalar problems with sign-changing coefficients*, December 2019, working paper or preprint, https://hal.inria.fr/hal-02421312

[44] E. CERPA, E. CRÉPEAU, J. VALEIN.*Boundary controllability of the Korteweg-de Vries equation on a tree-shaped network*, May 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-02137907

[45] A. DUCA.*Bilinear quantum systems on compact graphs: well-posedness and global exact controllability*, June 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-01830297

[46] A. DUCA.*Simultaneous global exact controllability in projection of infinite 1D bilinear Schrödinger equations*, June 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-01481873

[47] M. GHATTASSI, T.-M. LALEG, J.-C. VIVALDA.*Analysis and Output Tracking Design for the Direct Contact Membrane distillation system*, November 2019, https://arxiv.org/abs/1902.00964 - 33 pages, 3 figures, https://hal.archives-ouvertes.fr/hal-02368695

[48] M. HILLAIRET, T. TAKAHASHI.*Existence of contacts for the motion of a rigid body into a viscous incompressible fluid with the Tresca boundary conditions*, December 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-02393058

[49] A. LIEU, P. MARCHNER, G. GABARD, H. BERIOT, X. ANTOINE, C. GEUZAINE.*A Non-Overlapping Schwarz Domain Decomposition Method with High-Order Finite Elements for Flow Acoustics*, November 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-02371050

[50] D. MAITY, T. TAKAHASHI.*Lp theory for the interaction between the incompressible Navier-Stokes system and a damped beam*, September 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-02294097

[51] A. MODAVE, A. ROYER, X. ANTOINE, C. GEUZAINE.*An optimized Schwarz domain decomposition method with cross-point treatment for time-harmonic acoustic scattering*, January 2020, working paper or preprint, https://hal.archives-ouvertes.fr/hal-02432422

[52] G. PANG, Y. YANG, X. ANTOINE, S. TANG.*Stability and convergence analysis of artificial boundary conditions for the Schrödinger equation on a rectangular domain*, October 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-02340837

[53] P. S. PETROV, X. ANTOINE.*Pseudodifferential adiabatic mode parabolic equations in curvilinear coordinates and their numerical solution*, November 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-02342637

[54] A. ROY, T. TAKAHASHI.*Stabilization of a rigid body moving in a compressible viscous fluid*, October 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-02314870

[55] J. VALEIN.*Stabilization of the Korteweg-de Vries equation with internal time-delay feedback*, February 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-02020757

References in notes

[56] C. ALVES, A. L. SILVESTRE, T. TAKAHASHI, M. TUCSNAK.*Solving inverse source problems using observability. Applications to the Euler-Bernoulli plate equation*, in "SIAM J. Control Optim.", 2009, vol. 48, n^{o} 3, p. 1632-1659

[57] X. ANTOINE, K. RAMDANI, B. THIERRY.*Wide Frequency Band Numerical Approaches for Multiple Scattering Problems by Disks*, in "Journal of Algorithms & Computational Technologies", 2012, vol. 6, n^{o} 2, p. 241–259

[58] X. ANTOINE, C. GEUZAINE, K. RAMDANI.*Computational Methods for Multiple Scattering at High Frequency with Applications to Periodic Structures Calculations*, in "Wave Propagation in Periodic Media", Progress in Computational Physics, Vol. 1, Bentham, 2010, p. 73-107

[59] D. AUROUX, J. BLUM.*A nudging-based data assimilation method : the Back and Forth Nudging (BFN) algorithm*, in "Nonlin. Proc. Geophys.", 2008, vol. 15, n^{o} 305-319

[60] M. I. BELISHEV, S. A. IVANOV.*Reconstruction of the parameters of a system of connected beams from dynamic boundary measurements*, in "Zap. Nauchn. Sem. S.-Peterburg. Otdel. Mat. Inst. Steklov. (POMI)", 2005, vol. 324, n^{o} Mat. Vopr. Teor. Rasprostr. Voln. 34, p. 20–42, 262

[61] M. BELLASSOUED, D. DOS SANTOS FERREIRA.*Stability estimates for the anisotropic wave equation from the Dirichlet-to-Neumann map*, in "Inverse Probl. Imaging", 2011, vol. 5, n^{o} 4, p. 745–773, http://dx.doi.org/10.3934/ipi.2011.5.745

[62] M. BELLASSOUED, D. D. S. FERREIRA.*Stable determination of coefficients in the dynamical anisotropic Schrödinger equation from the Dirichlet-to-Neumann map*, in "Inverse Problems", 2010, vol. 26, n^{o} 12, 125010, 30, http://dx.doi.org/10.1088/0266-5611/26/12/125010

[63] Y. BOUBENDIR, X. ANTOINE, C. GEUZAINE.*A Quasi-Optimal Non-Overlapping Domain Decomposition Algorithm for the Helmholtz Equation*, in "Journal of Computational Physics", 2012, vol. 2, n^{o} 231, p. 262-280

[64] M. BOULAKIA.*Existence of weak solutions for an interaction problem between an elastic structure and a compressible viscous fluid*, in "J. Math. Pures Appl. (9)", 2005, vol. 84, n^{o} 11, p. 1515–1554, http://dx.doi.org/10.1016/j.matpur.2005.08.004

[65] M. BOULAKIA, S. GUERRERO.*Regular solutions of a problem coupling a compressible fluid and an elastic structure*, in "J. Math. Pures Appl. (9)", 2010, vol. 94, n^{o} 4, p. 341–365, http://dx.doi.org/10.1016/j.matpur.2010.04.002

[66] M. BOULAKIA, A. OSSES.*Local null controllability of a two-dimensional fluid-structure interaction problem*, in "ESAIM Control Optim. Calc. Var.", 2008, vol. 14, n^{o} 1, p. 1–42, http://dx.doi.org/10.1051/cocv:2007031

[67] M. BOULAKIA, E. SCHWINDT, T. TAKAHASHI.*Existence of strong solutions for the motion of an elastic structure in an incompressible viscous fluid*, in "Interfaces Free Bound.", 2012, vol. 14, n^{o} 3, p. 273–306, http://dx.doi.org/10.4171/IFB/282

[68] G. BRUCKNER, M. YAMAMOTO.*Determination of point wave sources by pointwise observations: stability and reconstruction*, in "Inverse Problems", 2000, vol. 16, n^{o} 3, p. 723–748

[69] A. CHAMBOLLE, B. DESJARDINS, M. J. ESTEBAN, C. GRANDMONT.*Existence of weak solutions for the unsteady interaction of a viscous fluid with an elastic plate*, in "J. Math. Fluid Mech.", 2005, vol. 7, n^{o} 3, p. 368–404, http://dx.doi.org/10.1007/s00021-004-0121-y

[70] T. CHAMBRION, A. MUNNIER.*Locomotion and control of a self-propelled shape-changing body in a fluid*, in "J. Nonlinear Sci.", 2011, vol. 21, n^{o} 3, p. 325–385, http://dx.doi.org/10.1007/s00332-010-9084-8

[71] T. CHAMBRION, A. MUNNIER.*Generic controllability of 3D swimmers in a perfect fluid*, in "SIAM J. Control Optim.", 2012, vol. 50, n^{o} 5, p. 2814–2835, http://dx.doi.org/10.1137/110828654

[72] C. CHOI, G. NAKAMURA, K. SHIROTA.*Variational approach for identifying a coefficient of the wave equation*, in "Cubo", 2007, vol. 9, n^{o} 2, p. 81–101

[73] C. CONCA, J. SAN MARTÍN, M. TUCSNAK.*Existence of solutions for the equations modelling the motion of a rigid body in a viscous fluid*, in "Comm. Partial Differential Equations", 2000, vol. 25, n^{o} 5-6, p. 1019–1042, http://dx.doi.org/10.1080/03605300008821540

[74] D. COUTAND, S. SHKOLLER.*Motion of an elastic solid inside an incompressible viscous fluid*, in "Arch. Ration. Mech. Anal.", 2005, vol. 176, n^{o} 1, p. 25–102, http://dx.doi.org/10.1007/s00205-004-0340-7

[75] D. COUTAND, S. SHKOLLER.*The interaction between quasilinear elastodynamics and the Navier-Stokes equations*, in "Arch. Ration. Mech. Anal.", 2006, vol. 179, n^{o} 3, p. 303–352, http://dx.doi.org/10.1007/s00205-005-0385-2

[76] B. DESJARDINS, M. J. ESTEBAN.*On weak solutions for fluid-rigid structure interaction: compressible and incompressible models*, in "Comm. Partial Differential Equations", 2000, vol. 25, n^{o} 7-8, p. 1399–1413, http://dx.doi.org/10.1080/03605300008821553

[77] B. DESJARDINS, M. J. ESTEBAN.*Existence of weak solutions for the motion of rigid bodies in a viscous fluid*, in "Arch. Ration. Mech. Anal.", 1999, vol. 146, n^{o} 1, p. 59–71, http://dx.doi.org/10.1007/s002050050136

[78] B. DESJARDINS, M. J. ESTEBAN, C. GRANDMONT, P. LE TALLEC.*Weak solutions for a fluid-elastic structure interaction model*, in "Rev. Mat. Complut.", 2001, vol. 14, n^{o} 2, p. 523–538

[79] A. EL BADIA, T. HA-DUONG.*Determination of point wave sources by boundary measurements*, in "Inverse Problems", 2001, vol. 17, n^{o} 4, p. 1127–1139

[80] M. EL BOUAJAJI, X. ANTOINE, C. GEUZAINE.*Approximate Local Magnetic-to-Electric Surface Operators for Time-Harmonic Maxwell's Equations*, in "Journal of Computational Physics", 2015, vol. 15, n^{o} 279, p. 241-260

[81] M. EL BOUAJAJI, B. THIERRY, X. ANTOINE, C. GEUZAINE.*A quasi-optimal domain decomposition algorithm for the time-harmonic Maxwell's equations*, in "Journal of Computational Physics", 2015, vol. 294, n^{o} 1, p. 38-57 [*DOI :* 10.1016/J.JCP.2015.03.041], https://hal.archives-ouvertes.fr/hal-01095566

[82] E. FEIREISL.*On the motion of rigid bodies in a viscous compressible fluid*, in "Arch. Ration. Mech. Anal.", 2003, vol. 167, n^{o} 4, p. 281–308, http://dx.doi.org/10.1007/s00205-002-0242-5

[83] E. FEIREISL.*On the motion of rigid bodies in a viscous incompressible fluid*, in "J. Evol. Equ.", 2003, vol. 3, n^{o} 3, p. 419–441, Dedicated to Philippe Bénilan, http://dx.doi.org/10.1007/s00028-003-0110-1

[84] E. FEIREISL, M. HILLAIRET, Š. NEČASOVÁ.*On the motion of several rigid bodies in an incompressible non-Newtonian fluid*, in "Nonlinearity", 2008, vol. 21, n^{o} 6, p. 1349–1366, http://dx.doi.org/10.1088/0951-7715/21/6/012

[85] E. FRIDMAN.*Observers and initial state recovering for a class of hyperbolic systems via Lyapunov method*, in "Automatica", 2013, vol. 49, n^{o} 7, p. 2250 - 2260

[86] G. P. GALDI, A. L. SILVESTRE.*On the motion of a rigid body in a Navier-Stokes liquid under the action of a time-periodic force*, in "Indiana Univ. Math. J.", 2009, vol. 58, n^{o} 6, p. 2805–2842, http://dx.doi.org/10.1512/iumj.2009.58.3758

[87] O. GLASS, F. SUEUR.*The movement of a solid in an incompressible perfect fluid as a geodesic flow*, in "Proc. Amer. Math. Soc.", 2012, vol. 140, n^{o} 6, p. 2155–2168, http://dx.doi.org/10.1090/S0002-9939-2011-11219-X

[88] C. GRANDMONT, Y. MADAY.*Existence for an unsteady fluid-structure interaction problem*, in "M2AN Math. Model. Numer. Anal.", 2000, vol. 34, n^{o} 3, p. 609–636, http://dx.doi.org/10.1051/m2an:2000159

[89] G. HAINE.*Recovering the observable part of the initial data of an infinite-dimensional linear system with skew-adjoint generator*, in "Mathematics of Control, Signals, and Systems", 2014, vol. 26, n^{o} 3, p. 435-462

[90] G. HAINE, K. RAMDANI.*Reconstructing initial data using observers: error analysis of the semi-discrete and fully discrete approximations*, in "Numer. Math.", 2012, vol. 120, n^{o} 2, p. 307-343

[91] J. HOUOT, A. MUNNIER.*On the motion and collisions of rigid bodies in an ideal fluid*, in "Asymptot. Anal.", 2008, vol. 56, n^{o} 3-4, p. 125–158

[92] O. Y. IMANUVILOV, T. TAKAHASHI.*Exact controllability of a fluid-rigid body system*, in "J. Math. Pures Appl. (9)", 2007, vol. 87, n^{o} 4, p. 408–437, http://dx.doi.org/10.1016/j.matpur.2007.01.005

[93] V. ISAKOV.*Inverse problems for partial differential equations*, Applied Mathematical Sciences, Second, Springer, New York, 2006, vol. 127

[94] N. V. JUDAKOV.*The solvability of the problem of the motion of a rigid body in a viscous incompressible fluid*, in "Dinamika Splošn. Sredy", 1974, n^{o} Vyp. 18 Dinamika Zidkost. so Svobod. Granicami, p. 249–253, 255

[95] B. KALTENBACHER, A. NEUBAUER, O. SCHERZER.*Iterative regularization methods for nonlinear ill-posed problems*, Radon Series on Computational and Applied Mathematics, Walter de Gruyter GmbH & Co. KG, Berlin, 2008, vol. 6

[96] G. LEGENDRE, T. TAKAHASHI.*Convergence of a Lagrange-Galerkin method for a fluid-rigid body system in ALE formulation*, in "M2AN Math. Model. Numer. Anal.", 2008, vol. 42, n^{o} 4, p. 609–644, http://dx.doi.org/10.1051/m2an:2008020

[97] J. LEQUEURRE.*Existence of strong solutions to a fluid-structure system*, in "SIAM J. Math. Anal.", 2011, vol. 43, n^{o} 1, p. 389–410, http://dx.doi.org/10.1137/10078983X

[98] J. LOHÉAC, A. MUNNIER.*Controllability of 3D Low Reynolds Swimmers*, in "ESAIM:COCV", 2013

[99] D. LUENBERGER.*Observing the state of a linear system*, in "IEEE Trans. Mil. Electron.", 1964, vol. MIL-8, p. 74-80

[100] P. MOIREAU, D. CHAPELLE, P. LE TALLEC.*Joint state and parameter estimation for distributed mechanical systems*, in "Computer Methods in Applied Mechanics and Engineering", 2008, vol. 197, p. 659–677

[101] A. MUNNIER, B. PINÇON.*Locomotion of articulated bodies in an ideal fluid: 2D model with buoyancy, circulation and collisions*, in "Math. Models Methods Appl. Sci.", 2010, vol. 20, n^{o} 10, p. 1899–1940, http://dx.doi.org/10.1142/S0218202510004829

[102] A. MUNNIER, E. ZUAZUA.*Large time behavior for a simplified N-dimensional model of fluid-solid interaction*, in "Comm. Partial Differential Equations", 2005, vol. 30, n^{o} 1-3, p. 377–417, http://dx.doi.org/10.1081/PDE-200050080

[103] J. O'REILLY.*Observers for linear systems*, Mathematics in Science and Engineering, Academic Press Inc., Orlando, FL, 1983, vol. 170

[104] J. ORTEGA, L. ROSIER, T. TAKAHASHI.*On the motion of a rigid body immersed in a bidimensional incompressible perfect fluid*, in "Ann. Inst. H. Poincaré Anal. Non Linéaire", 2007, vol. 24, n^{o} 1, p. 139–165, http://dx.doi.org/10.1016/j.anihpc.2005.12.004

[105] K. RAMDANI, M. TUCSNAK, G. WEISS.*Recovering the initial state of an infinite-dimensional system using observers*, in "Automatica", 2010, vol. 46, n^o 10, p. 1616-1625

[106] J.-P. RAYMOND.*Feedback stabilization of a fluid-structure model*, in "SIAM J. Control Optim.", 2010, vol. 48, n^o 8, p. 5398–5443, http://dx.doi.org/10.1137/080744761

[107] J. SAN MARTÍN, J.-F. SCHEID, L. SMARANDA.*A modified Lagrange-Galerkin method for a fluid-rigid system with discontinuous density*, in "Numer. Math.", 2012, vol. 122, n^o 2, p. 341–382, http://dx.doi.org/10.1007/s00211-012-0460-1

[108] J. SAN MARTÍN, J.-F. SCHEID, L. SMARANDA.*The Lagrange-Galerkin method for fluid-structure interaction problems*, in "Boundary Value Problems.", 2013, p. 213–246

[109] J. SAN MARTÍN, J.-F. SCHEID, T. TAKAHASHI, M. TUCSNAK.*Convergence of the Lagrange-Galerkin method for the equations modelling the motion of a fluid-rigid system*, in "SIAM J. Numer. Anal.", 2005, vol. 43, n^o 4, p. 1536–1571 (electronic), http://dx.doi.org/10.1137/S0036142903438161

[110] J. SAN MARTÍN, J.-F. SCHEID, T. TAKAHASHI, M. TUCSNAK.*An initial and boundary value problem modeling of fish-like swimming*, in "Arch. Ration. Mech. Anal.", 2008, vol. 188, n^o 3, p. 429–455, http://dx.doi.org/10.1007/s00205-007-0092-2

[111] J. SAN MARTÍN, L. SMARANDA, T. TAKAHASHI.*Convergence of a finite element/ALE method for the Stokes equations in a domain depending on time*, in "J. Comput. Appl. Math.", 2009, vol. 230, n^o 2, p. 521–545, http://dx.doi.org/10.1016/j.cam.2008.12.021

[112] J. SAN MARTÍN, V. STAROVOITOV, M. TUCSNAK.*Global weak solutions for the two-dimensional motion of several rigid bodies in an incompressible viscous fluid*, in "Arch. Ration. Mech. Anal.", 2002, vol. 161, n^o 2, p. 113–147, http://dx.doi.org/10.1007/s002050100172

[113] J.-F. SCHEID, J. SOKOLOWSKI.*Shape optimization for a fluid-elasticity system*, in "Pure and Applied Functional Analysis", 2018, vol. 3, n^o 1, p. 193-217, https://hal.archives-ouvertes.fr/hal-01449478

[114] D. SERRE.*Chute libre d'un solide dans un fluide visqueux incompressible. Existence*, in "Japan J. Appl. Math.", 1987, vol. 4, n^o 1, p. 99–110, http://dx.doi.org/10.1007/BF03167757

[115] P. STEFANOV, G. UHLMANN.*Thermoacoustic tomography with variable sound speed*, in "Inverse Problems", 2009, vol. 25, n^o 7, 16, 075011

[116] T. TAKAHASHI.*Analysis of strong solutions for the equations modeling the motion of a rigid-fluid system in a bounded domain*, in "Adv. Differential Equations", 2003, vol. 8, n^o 12, p. 1499–1532

[117] H. TRINH, T. FERNANDO.*Functional observers for dynamical systems*, Lecture Notes in Control and Information Sciences, Springer, Berlin, 2012, vol. 420

[118] J. L. VÁZQUEZ, E. ZUAZUA.*Large time behavior for a simplified 1D model of fluid-solid interaction*, in "Comm. Partial Differential Equations", 2003, vol. 28, n^o 9-10, p. 1705–1738, http://dx.doi.org/10.1081/PDE-120024530

[119] H. F. WEINBERGER.*On the steady fall of a body in a Navier-Stokes fluid*, in "Partial differential equations (Proc. Sympos. Pure Math., Vol. XXIII, Univ. California, Berkeley, Calif., 1971)", Providence, R. I., Amer. Math. Soc., 1973, p. 421–439

Project-Team TONUS

TOkamaks and NUmerical Simulations

IN COLLABORATION WITH: Institut de recherche mathématique avancée (IRMA)

IN PARTNERSHIP WITH:
CNRS

Université de Strasbourg

RESEARCH CENTER
Nancy - Grand Est

THEME
Earth, Environmental and Energy Sciences

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Project-Team TONUS

Creation of the Team: 2012 January 01, updated into Project-Team: 2019 May 01

Keywords:

Computer Science and Digital Science:

A6.1.1. - Continuous Modeling (PDE, ODE)
A6.1.4. - Multiscale modeling
A6.1.5. - Multiphysics modeling
A6.2.1. - Numerical analysis of PDE and ODE
A6.2.7. - High performance computing
A6.5.2. - Fluid mechanics

Other Research Topics and Application Domains:

B4.2.2. - Fusion

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2. Overall Objectives

2.1. Overall Objectives

TONUS started in January 2014. It is a team of the Inria Nancy-Grand Est center. It is located in the mathematics institute (IRMA) of the University of Strasbourg.

The International Thermonuclear Experimental Reactor (ITER) is a large-scale scientific experiment that aims to demonstrate that it is possible to produce energy from fusion, by confining a very hot hydrogen plasma inside a toroidal chamber, called tokamak. In addition to physics and technology research, tokamak design also requires mathematical modelling and numerical simulations on supercomputers.

The objective of the TONUS project is to deal with such mathematical and computing issues. We are mainly interested in kinetic, gyrokinetic and fluid simulations of tokamak plasmas. In the TONUS project-team we are working on the development of new numerical methods devoted to such simulations. We investigate several classical plasma models, study new reduced models and new numerical schemes adapted to these models. We implement our methods in two software projects: Selalib [0] and SCHNAPS [0] adapted to new computer architectures.

We have strong relations with the CEA-IRFM team and participate in the development of their gyrokinetic simulation software GYSELA. We are involved in two Inria Project Labs, respectively devoted to tokamak mathematical modelling and high performance computing. The numerical tools developed from plasma physics can also be applied in other contexts. For instance, we collaborate with a small company in Strasbourg specialized in numerical software for applied electromagnetism. We also study kinetic acoustic models with the CEREMA and multiphase flows with EDF.

Finally, our topics of interest are at the interaction between mathematics, computer science, High Performance Computing, physics and practical applications.

3. Research Program

3.1. Kinetic models for plasmas

The fundamental model for plasma physics is the coupled Vlasov-Maxwell kinetic model: the Vlasov equation describes the distribution function of particles (ions and electrons), while the Maxwell equations describe the electromagnetic field. In some applications, it may be necessary to take relativistic particles into account, which leads to consider the relativistic Vlasov equation, even if in general, tokamak plasmas are supposed to be non-relativistic. The distribution function of particles depends on seven variables (three for space, three for the velocity and one for time), which yields a huge amount of computation. To these equations we must add several types of source terms and boundary conditions for representing the walls of the tokamak, the applied electromagnetic field that confines the plasma, fuel injection, collision effects, etc.

Tokamak plasmas possess particular features, which require developing specialized theoretical and numerical tools.

Because the magnetic field is strong, the particle trajectories have a very fast rotation around the magnetic field lines. A full resolution would require a prohibitive amount of computation. It is necessary to develop reduced models for large magnetic fields in order to obtain tractable calculations. The resulting model is called a gyrokinetic model. It allows us to reduce the dimensionality of the problem. Such models are implemented in GYSELA and Selalib.

On the boundary of the plasma, the collisions can no more be neglected. Fluid models, such as MagnetoHydroDynamics (MHD) become again relevant. For the good operation of the tokamak, it is necessary to control MHD instabilities that arise at the plasma boundary. Computing these instabilities requires special implicit numerical discretizations with excellent long time behavior.

In addition to theoretical modelling tools, it is necessary to develop numerical schemes adapted to kinetic, gyrokinetic and fluid models. Three kinds of methods are studied in TONUS: Particle-In-Cell (PIC) methods, semi-Lagrangian and fully Eulerian approaches.

[0] http://selalib.gforge.inria.fr/
[0] http://schnaps.gforge.inria.fr

3.1.1. Gyrokinetic models: theory and approximation

In most phenomena where oscillations are present, we can establish a three-model hierarchy: (i) the model parameterized by the oscillation period, (ii) the limit model and (iii) the two-scale model, possibly with its corrector. In a context where one wishes to simulate such a phenomenon where the oscillation period is small and the oscillation amplitude is not small, it is important to have numerical methods based on an approximation of the two-scale model. If the oscillation period varies significantly over the domain of simulation, it is important to have numerical methods that approximate properly and effectively the model parameterized by the oscillation period and the two-scale model. Implementing two-scale numerical methods (for instance by Frénod et al. [27]) is based on a numerical approximation of the Two-Scale model. These are called of order 0. A Two-Scale Numerical Method is called of order 1 if it incorporates information from the corrector and from the equation of which this corrector is a solution. If the oscillation period varies between very small values and values of order 1, it is necessary to have new types of numerical schemes (Two-Scale Asymptotic Preserving Schemes of order 1 or TSAPS) that preserve the asymptotics between the model parameterized by the oscillation period and the Two-Scale model with its corrector. A first work in this direction has been initiated by Crouseilles et al. [26].

3.1.2. Semi-Lagrangian schemes

The Strasbourg team has a long and recognized experience in numerical methods for Vlasov-type equations. We are specialized in both particle and phase space solvers for the Vlasov equation: Particle-in-Cell (PIC) methods and semi-Lagrangian methods. We also have a long-standing collaboration with CEA Cadarache for the development of the GYSELA software for gyrokinetic tokamak plasmas.

The Vlasov and the gyrokinetic models are partial differential equations that express the transport of the distribution function in the phase space. In the original Vlasov case, the phase space is the six-dimension position-velocity space. For the gyrokinetic model, the phase space is five-dimensional because we consider only the parallel velocity in the direction of the magnetic field and the gyrokinetic angular velocity instead of three velocity components.

A few years ago, Eric Sonnendrücker and his collaborators introduced a new family of methods for solving transport equations in the phase space. This family of methods are the semi-Lagrangian methods. The principle of these methods is to solve the equation on a grid of the phase space. The grid points are transported with the flow of the transport equation for a time step and interpolated back periodically onto the initial grid. The method is then a mix of particle Lagrangian methods and Eulerian methods. The characteristics can be solved forward or backward in time leading to the Forward Semi-Lagrangian (FSL) or Backward Semi-Lagrangian (BSL) schemes. Conservative schemes based on this idea can be developed and are called Conservative Semi-Lagrangian (CSL).

GYSELA is a 5D full gyrokinetic code based on a classical backward semi-Lagrangian scheme (BSL) [31] for the simulation of core turbulence that has been developed at CEA Cadarache in collaboration with our team [28].

More recently, we have started to apply the semi-Lagrangian methods to more general kinetic equations. Indeed, most of the conservation laws of physics can be represented by a kinetic model with a small set of velocities and relaxation source terms [4]. Compressible fluids or MHD equations have such representations. Semi-Lagrangian methods then become a very appealing and efficient approach for solving these equations.

3.1.3. PIC methods

Historically PIC methods have been very popular for solving the Vlasov equations. They allow solving the equations in the phase space at a relatively low cost. The main disadvantage of this approach is that, due to its random aspect, it produces an important numerical noise that has to be controlled in some way, for instance by regularizations of the particles, or by divergence correction techniques in the Maxwell solver. We have a long-standing experience in PIC methods and we started implementing them in Selalib. An important aspect is to adapt the method to new multicore computers. See the work by Crestetto and Helluy [25].

3.2. Fluid and reduced kinetic models for plasmas

As already said, kinetic plasmas computer simulations are very intensive, because of the gyrokinetic turbulence. In some situations, it is possible to make assumptions on the shape of the distribution function that simplify the model. We obtain in this way a family of fluid or reduced models.

Assuming that the distribution function has a Maxwellian shape, for instance, we obtain the MagnetoHydroDynamic (MHD) model. It is physically valid only in some parts of the tokamak (at the edges for instance). The fluid model is generally obtained from the hypothesis that the collisions between particles are strong.

But the reduction is not necessarily a consequence of collisional effects. Indeed, even without collisions, the plasma may still relax to an equilibrium state over sufficiently long time scales (Landau damping effect).

In the fluid or reduced-kinetic regions, the approximation of the distribution function could require fewer data while still achieving a good representation, even in the collisionless regime.

Therefore, a fluid or a reduced model is a model where the explicit dependency on the velocity variable is removed. In a more mathematical way, we consider that in some regions of the plasma, it is possible to exhibit a (preferably small) set of parameters α that allows us to describe the main properties of the plasma with a generalized "Maxwellian" M. Then

$$f(x,v,t) = M(\alpha(x,t),v).$$

In this case it is sufficient to solve for $\alpha(x,t)$. Generally, the vector α is the solution of a first order hyperbolic system.

Another way to reduce the model is to try to find an abstract kinetic representation with an as small as possible set of kinetic velocities. The kinetic approach has then only a mathematical meaning. It allows solving very efficiently many equations of physics.

3.2.1. Numerical schemes

As previously indicated, an efficient method for solving the reduced models is the Discontinuous Galerkin (DG) approach. It is possible to make it of arbitrary order. It requires limiters when it is applied to nonlinear PDEs occurring for instance in fluid mechanics. But the reduced models that we intend to write are essentially linear. The nonlinearity is concentrated in a few coupling source terms.

In addition, this method, when written in a special set of variables, called the entropy variables, has nice properties concerning the entropy dissipation of the model. It opens the door to constructing numerical schemes with good conservation properties and no entropy dissipation, as already used for other systems of PDEs [32], [24], [30], [29].

3.2.2. Matrix-free implicit schemes

In tokamaks, the reduced model generally involves many time scales. Among these time scales, many of them, associated to the fastest waves, are not relevant. In order to filter them out, it is necessary to adopt implicit solvers in time. When the reduced model is based on a kinetic interpretation, it is possible to construct implicit schemes that do not impose solving costly linear systems. In addition the resulting solver is stable even at a very high CFL (Courant Friedrichs Lax) number.

3.3. Electromagnetic solvers

Precise resolution of the electromagnetic fields is essential for proper plasma simulation. Thus it is important to use efficient solvers for the Maxwell systems and its asymptotics: Poisson equation and magnetostatics.

The proper coupling of the electromagnetic solver with the Vlasov solver is also crucial for ensuring conservation properties and stability of the simulation.

Finally, plasma physics implies very different time scales. It is thus very important to develop implicit Maxwell solvers and Asymptotic Preserving (AP) schemes in order to obtain good behavior on long time scales.

3.3.1. Coupling

The coupling of the Maxwell equations to the Vlasov solver requires some precautions. The most important one is to control the charge conservation errors, which are related to the divergence conditions on the electric and magnetic fields. We will generally use divergence correction tools for hyperbolic systems presented for instance in [23] (and the references therein).

3.3.2. Implicit solvers

As already pointed out, in a tokamak, the plasma presents several different space and time scales. It is not possible in practice to solve the initial Vlasov-Maxwell model. It is first necessary to establish asymptotic models by letting some parameters (such as the Larmor frequency or the speed of light) tend to infinity. This is the case for the electromagnetic solver and this requires implementing implicit time solvers in order to efficiently capture the stationary state, the solution of the magnetic induction equation or the Poisson equation.

4. Application Domains

4.1. Controlled fusion and ITER

The search for alternative energy sources is a major issue for the future. Among others, controlled thermonuclear fusion in a hot hydrogen plasma is a promising possibility. The principle is to confine the plasma in a toroidal chamber, called a tokamak, and to attain the necessary temperatures to sustain nuclear fusion reactions.The International Thermonuclear Experimental Reactor (ITER) is a tokamak being constructed in Cadarache, France. This was the result of a joint decision by an international consortium including the European Union, Canada, USA, Japan, Russia, South Korea, India and China. ITER is a huge project. As of today, the budget is estimated at 20 billion euros. The first plasma shot is planned for 2020 and the first deuterium-tritium operation for 2027. Many technical and conceptual difficulties have to be overcome before the actual exploitation of fusion energy. Consequently, much research has been carried out around magnetically confined fusion. Amongt hese studies, it is important to carry out computer simulations of the burning plasma. Thus, mathematicians and computer scientists are also needed in the design of ITER. The reliability and the precision of numerical simulations allow a better understanding of the physical phenomena and thus would lead to better designs. TONUS's main involvement is in such research. The required temperatures to attain fusion are very high, of the order of a hundred million degrees. Thus it is imperative to prevent the plasma from touching the tokamak inner walls. This confinement is obtained thanks to intense magnetic fields. The magnetic field is created by poloidal coils, which generate the toroidal component of the field. The toroidal plasma current also induces a poloidal component of the magnetic field that twists the magnetic field lines. The twisting is very important or the stability of the plasma. The idea goes back to research by Tamm and Sakharov, two Russian physicists, in the 50's. Other devices are essential for the proper operation of the tokamak: divertor for collecting the escaping particles, microwave heating for reaching higher temperatures, fuel injector for sustaining the fusionr eactions, toroidal coils for controlling instabilities, etc.

4.2. Other applications

The software and numerical methods that we develop can also be applied to other fields of physics or of engineering.

- For instance, we have a collaboration with the company AxesSim in Strasbourg for the development of efficient Discontinuous Galerkin (DG) solvers on hybrid computers (CPU/GPU). The applications are electro-magnetic simulations for the conception of antennas, electronic devices or aircraft electromagnetic compatibility.

- The acoustic conception of large rooms requires huge numerical simulations. It is not always possible to solve the full wave equation and many reduced acoustic models have been developed. A popular model consists in considering "acoustic" particles moving at the speed of sound. The resulting Partial Differential Equation (PDE) is very similar to the Vlasov equation. The same modelling is used in radiation theory. We have started to work on the reduction of the acoustic particles model and realized that our reduction approach perfectly applies to this situation. A PhD with CEREMA (Centre d'études et d'expertise sur les risques, l'environnement, la mobilité et l'aménagement) has started in October 2015 (PhD of Pierre Gerhard). The objective is to investigate the model reduction and to implement the resulting acoustic model in our DG solver.
- In September 2017, we started a collaboration with EDF Chatou (PhD of Lucie Quibel) on the modelling of multiphase fluids with complex equations of state. The goal is to simulate the high temperature liquid-vapor flow occurring in a nuclear plant. Among others, we will apply our recent kinetic method for designing efficient implicit schemes for this kind of flows.

5. Highlights of the Year

5.1. Highlights of the Year

Low Mach relaxation scheme

We designed a new relaxation scheme [16]-[18] for the Euler/shallow water equations in the low Mach regime. The scheme admits an uniform convergence and a close to uniform cost compare to the Mach number. Additionally the implicit part (the most complicated classically) is reduced at the maximum. This method is a good candidate for the MHD in Tokamak and the extension of the method for this problem is an ongoing work.

6. New Software and Platforms

6.1. CLAC

Conservation Laws Approximation on many Cores

SCIENTIFIC DESCRIPTION: It is clear now that future computers will be made of a collection of thousands of interconnected multicore processors. Globally it appears as a classical distributed memory MIMD machine. But at a lower level, each of the multicore processors is itself made of a shared memory MIMD unit (a few classical CPU cores) and a SIMD unit (a GPU). When designing new algorithms, it is important to adapt them to this kind of architecture. Our philosophy will be to program our algorithms in such a way that they can be run efficiently on this kind of computers. Practically, we will use the MPI library for managing the coarse grain parallelism, while the OpenCL library will efficiently operate the fine grain parallelism.

We have invested for several years until now into scientific computing on GPUs, using the open standard OpenCL (Open Computing Language). We were recently awarded a prize in the international AMD OpenCL innovation challenge thanks to an OpenCL two-dimensional Vlasov-Maxwell solver that fully runs on a GPU. OpenCL is a very interesting tool because it is an open standard now available on almost all brands of multicore processors and GPUs. The same parallel program can run on a GPU or a multicore processor without modification.

Because of the envisaged applications of CLAC, which may be either academic or commercial, it is necessary to conceive a modular framework. The heart of the library is made of generic parallel algorithms for solving conservation laws. The parallelism can be both fine-grained (oriented towards GPUs and multicore processors) and coarse-grained (oriented towards GPU clusters). The separate modules allow managing the meshes and some specific applications. In this way, it is possible to isolate parts that should be protected for trade secret reasons.

FUNCTIONAL DESCRIPTION: CLAC is a generic Discontinuous Galerkin solver, written in C/C++, based on the OpenCL and MPI frameworks.

- Partner: AxesSim
- Contact: Philippe Helluy
- URL: http://clac.gforge.inria.fr/

6.2. Selalib

SEmi-LAgrangian LIBrary

KEYWORDS: Plasma physics - Semilagrangian method - Parallel computing - Plasma turbulence

SCIENTIFIC DESCRIPTION: The objective of the Selalib project (SEmi-LAgrangian LIBrary) is to develop a well-designed, organized and documented library implementing several numerical methods for kinetic models of plasma physics. Its ultimate goal is to produce gyrokinetic simulations.

Another objective of the library is to provide to physicists easy-to-use gyrokinetic solvers, based on the semi-lagrangian techniques developed by Eric Sonnendrücker and his collaborators in the past CALVI project. The new models and schemes from TONUS are also intended to be incorporated into Selalib.

FUNCTIONAL DESCRIPTION: Selalib is a collection of modules conceived to aid in the development of plasma physics simulations, particularly in the study of turbulence in fusion plasmas. Selalib offers basic capabilities from general and mathematical utilities and modules to aid in parallelization, up to pre-packaged simulations.

- Partners: Max Planck Insitute - Garching - Université de Strasbourg
- Contact: Philippe Helluy
- URL: http://selalib.gforge.inria.fr/

6.3. SCHNAPS

Solver for Conservative Hyperbolic Nonlinear Applications for PlasmaS

KEYWORDS: Discontinuous Galerkin - StarPU - Kinetic scheme

FUNCTIONAL DESCRIPTION: Generic systems of conservation laws. Specific models: fluids, Maxwell, Vlasov, acoustics (with kinetic representation). Multitasking with StarPU. Explicit solvers (RK2, RK3, RK4): accelerated with OpenCL Implicit solvers: through kinetic representations and palindromic time integration.

- Participants: Philippe Helluy, Matthieu Boileau and Bérenger Bramas
- Contact: Philippe Helluy
- URL: http://schnaps.gforge.inria.fr/

6.4. Slappy

KEYWORDS: Python - Opencl

FUNCTIONAL DESCRIPTION: The code Slappy solves the advection equations on multi-patch and non-conform complex geometries with the Semi-Lagrangian method. Using this we can also treat some hyperbolic/parabolic PDE with the Approximate BGK method which, allows to write a PDE as a transport plus a local relaxation step. The code is written in PyOpcenCL and can be used on CPU/GPU.

- Contact: Emmanuel Franck

6.5. Patapon

Parallel Task in Python

KEYWORDS: Python - Parallel computing - High order time schemes

FUNCTIONAL DESCRIPTION: Patapon is a code in PyOpenCL which allows to solve PDE like MHD using the vectorial Lattice Boltzmann method on Cartesian grids.

- Participant: Philippe Helluy
- Contact: Philippe Helluy

6.6. tofu

Tomography for Fusion

KEYWORDS: 3D - Data visualization - Visualization - Magnetic fusion - Tomography - Diagnostics - Plasma physics - Ray-tracing - Python

FUNCTIONAL DESCRIPTION: tofu aims at providing the fusion and plasma community with an object-oriented, transparent and documented tool for designing tomography diagnostics, computing synthetic signal (direct problem) as well as tomographic inversions (inverse problem). It gives access to a full 3D description of the diagnostic geometry, thus reducing the impact of geometrical approximations on the direct and, most importantly, on the inverse problem.

RELEASE FUNCTIONAL DESCRIPTION: Python 2.7 is not supported anymore Python 3.6 and 3.7 are supported Several changes to try and make installation easier (on clusters, windows, mac....) and less verbose for users More explicit names for default saved configurations Major bug fix in one of the methods for computing synthetic signal Minor bug fixes in interactive figures Minor bug fixes in Plasma2D interpolation New configuration (ITER) available First version of a class handling 2D XRay bragg spectrometers First tools for magnetic field line tracing available on WEST Better documentation, more ressources More informative error messages extra tools for computing LOS length, closest point to magnetic axis... Better PEP8 compliance

- Partner: CEA
- Contact: Laura Mendoza
- URL: https://github.com/ToFuProject/tofu

7. New Results

7.1. Relaxation method for Guiding-Center equation

Participants: E. Franck, R. Helie, L. Navoret, P. Helluy.
In previous years, implicit kinetic relaxation methods have been developed to treat conservation laws without CFL and without a non-trivial matrix to reverse [6]-[4]. We have started to apply this method with a spectral discretization for transport equations such as the guiding-center equation (a non constant advection equation coupled with elliptic problem used in plasma physics). The scheme obtained has a very high order of convergence for an instability test case and is very simple to implement. We have also investigated the different kinetic relaxation representations. However, they suffer from inaccuracy at the boundaries. We have proposed a new approach in 1D [8] to analyse this behaviour and a new way to apply boundary conditions to ensure they are compatible both with the approximated system and its kinetic approximation. Extending this approach to higher dimensions is one of the objectives of the thesis of Romane Helie.

7.2. Relaxation method for transport in Tokamak

Participants: M. Boileau, P. Helluy, B. Bramas (Inria Camus).
To apply the relaxation method in a Tokamak context, we have developed a code called Chukrut (in Schnaps) that can handle kinetic relaxation models in Tokamak geometry [15]-[17]-[13]. In the poloidal direction the code uses an unstructured Discontinuous Galerkin solver which solves the transport equation (the main ingredient of the kinetic relaxation method) by using the scheduling graph linked to the upwind scheme. In the toroidal direction we use an exact solver on uniform grids (which will be replaced by a semi-Lagrangian solver). The algorithm is parallelised in the poloidal plane by a task-based OpenMP implementation and in the toroidal direction by MPI parallelism.

7.3. Relaxation method for Euler/MHD in low-Mach regime

Participants: E. Franck, L. Navoret, F. Bouchut (Marne la Vallée university).
Previously, we have proposed implicit relaxation methods for fluid models that allow us to reverse a simple system. However, previous methods [5] were not very effective in the multi-scale regimes of interest. We therefore proposed a semi-implicit scheme based on a dynamic splitting and a relaxation of fast waves only. The scheme was first applied to the Euler equations in low Mach regime. The scheme is stable and accurate regardless of the Mach number. We have successfully applied the method for the equilibria of the Shallow Water equations. Since last summer we have begun the extension for the 1D MHD with and without dispersive effects. The first results show that we obtain a similar method compared to the Euler case with acceptable stability conditions as for the Euler equations.

7.4. Reduced model for the Scrape-Off Layer

Participants: L. Navoret, M. Mehrenberger, P. Ghendrih (CEA Cadarache)
In this work, we consider a one-dimensional model for describing the two-species plasma dynamics in the scrape-off layer. This region is defined as the transition between the core of the plasma and the edge and is located around the first non-closed magnetic field line. The electron and ion distribution functions satisfy a Vlasov-Poisson system with source and absorption terms and a non-homogeneous equilibrium is expected to develop. A high-order semi-Lagrangian scheme has been implemented to correctly capture such a dynamics.

7.5. Recurrence phenomenon for finite element grid based Vlasov solver

Participants: L. Navoret, M. Mehrenberger, N. Pham
We have improved our previous (last year) result concerning the recurrence phenomenon by providing a complete proof of the asymptotic behaviour of the correlation function. Indeed, we prove that, in the fine grid limit, the correlation function of the density exactly concentrates at multiple times of the recurrence time. This thus fully confirms the fact the amplitude of the recurrence phenomenon is actually linked to the spectral accuracy of the velocity quadrature when computing the charge density at least for the linear transport equation.

7.6. Machine learning techniques for reduced model and stabilization

Participants: E. Franck, L. Navoret, V. Vigon (IRMA Strasbourg).
Just recently, we have begun to work on applications of machine learning techniques for the plasma simulation. This preliminary work is in the context of "Action exploratoire MALESI" and will really begin in 2020. The first point is the construction of a new closure for the fluid models using kinetic simulation as data. We have constructed 1D solvers for the Vlasov-Poisson equation with collisional operator and Compressible Navier-Stokes Poisson models. Comparing the models we observe that the classical Navier-Stokes closure is not sufficient when the Knudsen number is larger than 0.3-0.4. Currently we generate data using the Vlasov-Poisson code to train a neural-network for the closure. The second point is about the stabilization of the numerical method using CNN. We began a study to construct a Convulational Neural Network (CNN) to detect the Gibbs oscillations in the fluid simulations.

7.7. Asymptotic Preserving scheme for Vlasov-Maxwell to MHD

Participants: E. Franck, A. Crestetto (Nantes university), M. Badsi (Nantes university).
The MHD equation can be obtained by taking the limit of different small parameters of the bi-species Vlasov-Maxwell equations. Obtaining an "asymptotic preserving" scheme for the Vlasov equation (cost independent of the small parameters) is an important goal. Indeed, this type of scheme would allows us to construct coupling methods between MHD and Vlasov equations or to make simulations in various regimes to construct closures with data (see the previous point). During this year we have written a scheme able to treat the "quasi-neutral" and "mass-less" limits between the two-species Euler-Maxwell equations and the MHD model. The scheme is partially validated. We will finish the validation and add the collisional limit between Vlasov-Maxwell and Euler-Maxwell equations.

7.8. Optimal control for population dynamics

Participants: Y. Privat, L. Almeida (Sorbonne University), M. Duprez (Dauphine University) and N. Vauchelet (Paris 13 University).

Particular attention is being paid to the transmission of dengue fever, an arbovirus transmitted to humans by mosquitoes [3]-[2]. There is no vaccine to immunize a population. It has been observed that when a mosquito population was infected with the Wolbachia virus, they stopped transmitting the disease. In addition, the virus is transmitted from mother to child and is characterized by cytoplasmic incompatibility (no possible crosses between infected males and healthy females). On the other hand, infected mosquitoes have a reduced lifespan and fertility. Mathematically, this situation can be modelled (in a simplified way) using a controlled reaction-diffusion system. The control term represents the strategy of releasing (time-space) mosquitoes infected by Wolbachia. The practical questions that arise and that we wish to address are:

- how to carry out these releases to ensure the invasion?
- how to optimize the domain and form of releases?

Preliminary work has made it possible to determine a plausible temporal control strategy.

7.9. Observability for wave equation and high frequency behavior

Participants: Y. Privat, E. Humbert (Tours University) et E. Trélat (Sorbonne University).

We have determined the asymptotic in time of the observability constant in closed manifolds. In particular, we have proved that this limit can be represented as the minimum of two quantities: one purely spectral and another called the geometric quantity representing the limit of the average time spent by geodesics within the observation domain [19]-[19].

7.10. Developement of a Python library for tomography diagnostics

Participants: L. Mendoza

In the tofu code, a big component of both the direct and inverse solvers is the integration module. During the 2019 project it was developed and accelerated. Special attention was brought to memory optimization. Core functions for the inversions routines were developed and parallelized using OpenMP. The number of users and developers of the library has significantly increased in the last year (collaborators in CEA cadarache, ITER, CEA saclay, IPP Garching, etc.) so one of the main objectives was to better the continuous integration and documentation of the code: more unitary and simulation tests have been implemented, an online Web site with the documentation has been added, the library can be used on more platforms (windows, mac os x, and linux), and more fusion devices are now available (West, ITER, JET, etc.).

7.11. Finite volume methods for complex hyperbolic systems

Participants: P. Helluy, L. Quibel (EDF)

This year we have developed a Lattice Boltzmann scheme able to treat really complex and tabuled EOS (Equation Of State) for compressible multiphase flows (two and three phases). This new scheme have been implemented in the PyOpenCL Patapon. Additionally, in order to perform realistic simulations of such situations, we have also proposed a code based on a model that can handle both the thermodynamical disequilibrium between liquid and vapor and complex equations. This code is based on a relaxation scheme which is the best compromise between accuracy and stability.

7.12. The study of domain walls in micromagnetism

Participants: C. Courtès, R. Côte (IRMA)

A ferromagnetic material consists of a succession of isolated subdomains (known as the magnetic domains) in which the magnetic moments are aligned and point in the same direction. The interface separating two magnetic domains is called the domain wall and corresponds to a localized area where the direction of the magnetization suddenly changes. Mathematically, those domain walls correspond to the minimizers of the well-known micromagnatics energy. The magnetic behavior of ferromagnetic materials is due to the arrangement of the magnetic domains and to the dynamics of their domains walls. That dynamic is governed by the nonlinear Landau-Lifshitz-Gilbert equation. We study numerically and theoretically the stability and the interaction of two domain walls. Depending on the initial topological configuration, two domain walls may collide to give rise to a persistent profile or annihilate both, which results in aligning all magnetization vectors of the nanowire in the same direction.

7.13. Maxwell solvers

Participants: P. Helluy, M. Houillon
In collaboration with the AxesSim company, we continue the development of our CLAC software devoted to electromagnetic simulations in biological environment. We have implemented a new wire model. We have also run computations on the new CNRS supercomputer: Jean Zay. We now routinely launch simulations on 64 V100 GPUs in parallel for performing parameter studies of various antennas near to the human body (we can for instance vary the humidity level of the skin).

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

We collaborate with EDF Chatou in the context of L. Quibel PhD. The objective is to design new Equations Of States (EOS) for the simulation of multiphase flows. The EOScannot be chosen arbitrarily if one wants to ensure the stability of the fluid model. We are also interested to apply our palindromic method for computing low-Mach liquid-vapor flows.
We are involved in a common project with the company AxesSim in Strasbourg. The objective is to help to the development of a commercial software for the numerical simulation of electromagnetic phenomena. The applications are directed towards antenna design and electromagnetic compatibility. This project was partly supported by DGA through "RAPID" funds. A CIFRE PhD has started in AxesSim on the same kinds of subjects in March 2015 (Bruno Weber). The new project is devoted to the use of runtime system in order to optimize DG solvers applied to electromagnetism [33]. The resulting software will be applied to the numerical simulation of connected devices for clothes or medicine. The project is supported by the "Banque Publique d'Investissement" (BPI) and coordinated by the Thales company.

9. Partnerships and Cooperations

9.1. Regional Initiatives

The thesis of Pierre Gerhard devoted to numerical simulation of room acoustics is supported by the Alsace-region. It is a joint project with CEREMA (Centre d'études et d'expertise sur les risques, l'environnement, lamobilité et l'aménagement) in Strasbourg.

9.2. National Initiatives

9.2.1. National projects

PEPS "initiative Jeunes" CNRS. E. Franck with A. Crestetto (leader), M. Badsi, "Asymptotic scheme for multiscale problems in Plasma".

PEPS "initiative Jeunes" CNRS. C. Courtès with R. Côte (IRMA), P. A. Hervieux (IPCMS), R. Ignat (IMT), G. Manfredi (IPCMS), "Study of the influence of the temperature and the external magnetic field on the magnetization reversal".

9.2.2. HPC resources

Big Challenge GENCI: Simulation of electromagnetic interaction between connected objects and the human body. We solve the 3D Maxwell equations to compute the antena emission Bluetooth Low Energy (BLE) close to the body. The main goal is to scale the computation on the new supercomputer Jean Zay to treat a realistic test case.

9.3. European Initiatives

9.3.1. FP7 & H2020 Projects

Eurofusion project MAGYK, *Mathematics and Algorithms for GYrokinetic and Kinetic models* (2019-2021), led by E. Sonnendrucker.
Participants: L. Navoret

Eurofusion project *Strengthening the non-linear MHD code JOREK for application to key questions of the fusion roadmap* (2019-2021), led by M. Hoelzl.
Participants: E. Franck

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Member of the Organizing Committees

Philippe Helluy: Workshop on Compressible Multiphase Flows : Derivation, closure laws, thermodynamics, IRMA, May 2019.

Yannick Privat with Raphaël Côte and Thomas Duyckaerts: Workshop Control and dynamics of PDEs, Strasbourg, October 2019.

10.1.2. Journal

10.1.2.1. Member of the Editorial Boards

Yannick Privat is a member of the editorial boards of:

- AIMS Applied Mathematics,
- Evolution Equations and Control Theory.

Philippe Helluy is member of editorial board in:

- Computational and Applied Mathematics,
- International Journal of Finite Volume.

10.1.2.2. Reviewer - Reviewing Activities

- Emmanuel Franck was a reviewer for:
  - Numerical Methods for Partial Differential Equations.
- Yannick Privat was a reviewer for:

  - Applied Math. and Optimization,
  - Esaim Control Optimization and Calculust of Variations,
  - Discrete and Continuous Dynamical Systems,
  - Esaim Proceeding,
  - Journal de Mathématiques Pures et Appliquées,
  - Journal of Math. Biology,
  - Proceedings of the Royal Society A,
  - SIAM Journal on Control and Optimization,
  - Zeitschrift für angewandte Mathematik und Physik.
- Philippe Helluy was a reviewer for:
  - Journal of Computational Physics,
  - Computers and Fluids,
  - Numerical Methods for Partial Differential Equations,
  - European Journal of Mechanics / B Fluids.
- Matthieu Boileau was a reviewer for:
  - Proceedings of the Combustion Institutes.

10.1.3. Invited Talks and participations to conference as speaker

Yannick Privat:

- New Trends in PDE-Constrained Optimization, Linz, Austria. October 2019.
- Shape optimization and application days, Ecole Polytechnique, France. October 2019.
- "Groupement Euro-Maghrébin de Mathématiques et leurs Interactions". Madrid, Spain. November 2019.
- Dynamics, Equations and Applications (organizer of a mini-symposium), Cracovia, Poland. September 2019.

Emmanuel Franck:

- ICIAM 2019 (organizer mini-symposium), Valencia, Spain. July 2019.
- Workshop Multi-scale, Inria Nancy, June 2019.
- Jorek Meeting 2019, Munich, May 2019.

Laurent Navoret:

- ICIAM 2019 (organizer of a mini-symposium), Valencia, Spain. July 2019.

P. Helluy:

- ICNAAM 2019, Rhodes, September 2019
- NUMHYP, Malaga, June 2019.
- NUMKIN, Garching, Ocotober 2019.

Laura Mendoza:

- ICIAM 2019, Valencia, Spain. July 2019.
- Iter codeCamp, Cadarache, April 2019.
- EuroScipy 2019, Bilbao, September 2019.
- PyConFr, Bordeaux, November 2019.

Matthieu Boileau:

- Computation and learning days. April 2019. Lyon.
- Workshop Compressible multiphase flows, Strasbourg 2019.

10.1.4. Research Administration

Philippe Helluy:

- Director of the IRMA mathematics institute.

Mickael Gutnic:

- Director of the mathematics department (IRMA) in Strasbourg university.

Yannick Privat:

- Member of CNU section 26,
- Member of expert committee at IRMA Strasbourg

Matthieu Boileau:

- Manager of the "GDR calcul",
- Co-Manager of the network "metier calcul",
- Member of the "Commission de la Recherche du Conseil Académique de l'Université de Strasbourg"

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Licence: E. Franck, "Informatics S6", 35h, L3, Strasbourg University, France.

Master: Y. Privat, "Optimal control", 64h, M2, Strasbourg University, France.

Master: Y. Privat, "Optimization", 64h, M1, Strasbourg University, France.

Licence: Y. Privat, "Nonlinear Optimization", 52h, L3, Strasbourg University, France.

Agrégation: Y. Privat, "Text study", 30h. Strasbourg University, France

Licence: C. Courtès, "Scientific computing", 37h, L3, Strasbourg University, France.

Licence: C. Courtès, "Numerical analysis", 34h, L3, Strasbourg University, France.

Licence: C. Courtès, "Numerical analysis", 18h, L2, Strasbourg Unversity, France.

Licence: C. Courtès, "Multiple variables function", 10h, L2, Strasbourg Unversity, France.

Licence: L. Navoret, "Nonlinear Optimization", 18h, L3, Strasbourg University, France.

Licence: L. Navoret, "Statistics for biologists", 21.5h, L2, Strasbourg University, France.

Master: L. Navoret, "Scientific computing", 35h, M1, Strasbourg University, France.

Master: L. Navoret, "Numerical methods for PDEs", 30h, M1, Strasbourg University, France.

Master: L. Navoret, "Optimization", 12h, M1, Strasbourg University, France.

Master (physics): L. Navoret, "Numerical resolution techniques for engineering", 22h, M1, Strasbourg University, France.

Master (Agregation): L. Navoret, "Scientific computing", 50h, M2, Strasbourg University, France.

Master (cell physics): L. Navoret, "Basics in mathematics", 24h, M2, Strasbourg University, France.

Licence, P. Helluy, "Numerical analysis", 17h, L3, Strasbourg University, France.

Master, P. Helluy, "Scientific computing", 20h, Préparation agrégation, Strasbourg University, France.

Master, P. Helluy, "Scientific computing", 28h, M1, Strasbourg University, France.

Master, P. Helluy, "Hyperbolic systems", 35h, M2, Strasbourg University, France.

Licence, M. Boileau, "informatic", 10h, L3, Strasbourg university, France.

Master, M. Boileau, "data sciences", 20h , M2, Strasbourg University, France.

Master, M. Boileau, "Parallel computing", 20h, M1, Strasbourg University, France.

Master, M. Boileau, "Python for science", 36h, Strasbourg University, France.

Other, M. Boileau, "Basic for python", 14h, Urfist (Unité Régionale de Formation à l'Information Scientifique et Technique), France.

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10.2.2. Supervision

PhD in progress: G. Mestdagh, "Suivi de tumeur en temps réel par des méthodes d'optimisation", Strasbourg university. Beginning: September 2019. Y. Privat, S. Cotin.

PhD in progress: J. B. Arnau, "Stratégie de contrôle d'une population de moustiques pour la lutte contre les arbovirus". Beginning: September 2019. Y. Privat, Luis Almeida.

PhD in progress: A. Courtais, "Contrôle optimal de contacteurs à lit fixe par fabrication additive". Beginning: September 2017. Y. Privat, F. Lesage and A. Latifi.

PhD in progress: Idriss Mazari, "Répartition des ressources dans un enclos optimisant la survie des populations". Beginning: September 2017. Y. Privat, G. Nadin.

PhD in progress: Alexandre Delyon, "Étude de la géométrie des œufs de certains branchiopodes". Beginning: September 2016. Y. Privat, A. Henrot.

PhD in progress: Mustafa Gaja, "Compatible Finite Elements for Wave and Fluid Models: Application to Plasma Physics". Beginning: October 2015. E. Franck, E. Sonnendrücker (main supervisor).

PhD in progress: Pierre Gerhard, "Numerical methods for kinetic models. Application to building acoustic". Beginning: Ocotober 2015. P. Helluy (main supervisor), L. Navoret.

PhD in progress: Romane Helie, "Relaxation methods for kinetic models in plasma physics". Beginning: October 2019. P. Helluy (main supervisor), L. Navoret, E. Franck.

PhD in progress: Marie Houillon: "Modeling of thin wires in electromagnetic software", Advisors:Philippe Helluy and Laurent Navoret, from October 2017, Labex Irmia support.

PhD in progress: Lucie Quibel (CIFRE support): in collaboration with EDF Chatou, from October2017, Advisor: Philippe Helluy.

PhD: Maxime Schmitt: "Optimization of scientific software with arbitrary mesh refinement", Defense: September 2019, Advisors: Philippe Helluy and Cédric Bastoul (CAMUS team). Labex Irmia support.

10.2.3. Juries

Y. Privat was member of jury of the PhD committee of F. Feppon, Ecole Polytechnique.

Y. Privat was member of jury of the PhD committee of A. Rebei. Paris Sciences et Lettres university.

Y. Privat was reviewer of jury of the PhD committee of N. Lebbe. Grenoble university.

P. Helluy was reviewer of jury of the PhD committee of S. Fornet. Toulouse, ISAE.

P. Helluy was reviewer of jury of the PhD committee of M. Kadiri. Normandie university.

P. Helluy was member of jury of the PhD committee of S. Bulteau. Nantes university.

P.Helluy was member of jury of the PhD committee of P. A. Giorgi. Aix-Marseille university.

10.3. Popularization

L. Navoret were allowed to participate in the "fete de la science"

11. Bibliography

Publications of the year

Doctoral Dissertations and Habilitation Theses

[1] S. A. HIRSTOAGA.*Design and performant implementation of numerical methods for multiscale problems in plasma physics*, Université de Strasbourg, IRMA UMR 7501, April 2019, Habilitation à diriger des recherches, https://tel.archives-ouvertes.fr/tel-02081304

Articles in International Peer-Reviewed Journal

[2] L. ALMEIDA, M. DUPREZ, Y. PRIVAT, N. VAUCHELET.*Mosquito population control strategies for fighting against arboviruses*, in "Mathematical Biosciences and Engineering", 2019, vol. 16, n^o 6, p. 6274-6297, https://arxiv.org/abs/1901.05688 [*DOI :* 10.3934/MBE.2019313], https://hal.archives-ouvertes.fr/hal-01984426

[3] L. ALMEIDA, Y. PRIVAT, M. STRUGAREK, N. VAUCHELET.*Optimal releases for population replacement strategies, application to Wolbachia*, in "SIAM Journal on Mathematical Analysis", 2019, vol. 51, n° 4, p. 3170–3194, https://arxiv.org/abs/1909.02727 [*DOI :* 10.1137/18M1189841], https://hal.archives-ouvertes.fr/hal-01807624

[4] D. COULETTE, E. FRANCK, P. HELLUY, M. MEHRENBERGER, L. NAVORET.*High-order implicit palindromic discontinuous Galerkin method for kinetic-relaxation approximation*, in "Computers and Fluids", August 2019, https://arxiv.org/abs/1802.04590 [*DOI :* 10.1016/J.COMPFLUID.2019.06.007], https://hal.archives-ouvertes.fr/hal-01706614

[5] D. COULETTE, E. FRANCK, P. HELLUY, A. RATNANI, E. SONNENDRÜCKER.*Implicit time schemes for compressible fluid models based on relaxation methods*, in "Computers and Fluids", June 2019, vol. 188, p. 70-85 [*DOI :* 10.1016/J.COMPFLUID.2019.05.009], https://hal.archives-ouvertes.fr/hal-01514593

[6] C. COURTÈS, D. COULETTE, E. FRANCK, L. NAVORET.*Vectorial kinetic relaxation model with central velocity. Application to implicit relaxations schemes*, in "Communications in Computational Physics", 2019, forthcoming, https://hal.archives-ouvertes.fr/hal-01942317

[7] A. DELYON, A. HENROT, Y. PRIVAT.*Non-dispersal and density properties of infinite packings*, in "SIAM Journal on Control and Optimization", 2019, vol. 57, n° 2, p. 1467-1492 [*DOI :* 10.1137/18M1181183], https://hal.archives-ouvertes.fr/hal-01753911

[8] F. DRUI, E. FRANCK, P. HELLUY, L. NAVORET.*An analysis of over-relaxation in a kinetic approximation of systems of conservation laws*, in "Comptes Rendus Mécanique", January 2019, vol. 347, n° 3, p. 259-269, https://arxiv.org/abs/1807.05695 [*DOI :* 10.1016/J.CRME.2018.12.001], https://hal.archives-ouvertes.fr/hal-01839092

[9] E. HUMBERT, Y. PRIVAT, E. TRÉLAT.*Observability properties of the homogeneous wave equation on a closed manifold*, in "Communications in Partial Differential Equations", 2019, vol. 44, n° 9, p. 749–772, https://arxiv.org/abs/1607.01535 [*DOI :* 10.1080/03605302.2019.1581799], https://hal.archives-ouvertes.fr/hal-01338016

[10] I. MAZARI, G. NADIN, Y. PRIVAT.*Optimal location of resources maximizing the total population size in logistic models*, in "Journal de Mathématiques Pures et Appliquées", 2019, https://arxiv.org/abs/1907.05034 , forthcoming [*DOI :* 10.1016/J.MATPUR.2019.10.008], https://hal.archives-ouvertes.fr/hal-01607046

[11] Y. PRIVAT, E. TRÉLAT, E. ZUAZUA.*Spectral shape optimization for the Neumann traces of the Dirichlet-Laplacian eigenfunctions*, in "Calculus of Variations and Partial Differential Equations", 2019, vol. 58, n° 2, 64, https://arxiv.org/abs/1809.05316 [*DOI :* 10.1007/S00526-019-1522-3], https://hal.archives-ouvertes.fr/hal-01872896

[12] S. ZHANG, M. MEHRENBERGER, C. STEINER.*Computing the double-gyroaverage term incorporating short-scale perturbation and steep equilibrium profile by the interpolation algorithm*, in "plasma", April 2019, vol. 2, n^{o} 2, p. 91-126 [*DOI :* 10.3390/PLASMA2020009], https://hal.archives-ouvertes.fr/hal-02009446

Scientific Books (or Scientific Book chapters)

[13] *Linear stability of a vectorial kinetic relaxation scheme with a central velocity*, HYP2018 proceedings, 2019, forthcoming, https://hal.archives-ouvertes.fr/hal-01970499

Other Publications

[14] G. S. ALBERTI, Y. CAPDEBOSCQ, Y. PRIVAT.*On Randomisation In Computational Inverse Problems*, March 2019, https://arxiv.org/abs/1903.11273 - working paper or preprint, https://hal.archives-ouvertes.fr/hal-02077786

[15] M. BOILEAU, B. BRAMAS, E. FRANCK, P. HELLUY, L. NAVORET.*Parallel lattice-boltzmann transport solver in complex geometry*, December 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-02404082

[16] F. BOUCHUT, E. FRANCK, L. NAVORET.*A low cost semi-implicit low-Mach relaxation scheme for the full Euler equations*, December 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-02420859

[17] B. BRAMAS, P. HELLUY, L. MENDOZA, B. WEBER.*Optimization of a discontinuous finite element solver with OpenCL and StarPU*, July 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-01942863

[18] E. FRANCK, L. NAVORET.*Semi-implicit two-speed Well-Balanced relaxation scheme for Ripa model*, December 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-02407820

[19] E. HUMBERT, Y. PRIVAT, E. TRÉLAT.*Geometric and probabilistic results for the observability of the wave equation*, December 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-01652890

[20] R. HÉLIE, P. HELLUY, E. FRANCK, L. NAVORET.*Kinetic over-relaxation method for the convection equation with Fourier solver*, January 2020, working paper or preprint, https://hal.archives-ouvertes.fr/hal-02427044

[21] I. MAZARI, G. NADIN, Y. PRIVAT.*Shape optimization of a weighted two-phase Dirichlet eigenvalue*, January 2020, https://arxiv.org/abs/2001.02958 - working paper or preprint, https://hal.archives-ouvertes.fr/hal-02432387

[22] S. ZHANG.*Gyrokinetic Vlasov-Poisson model derived by hybrid-coordinate transform of the distribution function*, February 2019, working paper or preprint, https://hal.archives-ouvertes.fr/hal-01924706

References in notes

[23] C. ALTMANN, T. BELAT, M. GUTNIC, P. HELLUY, H. MATHIS, E. SONNENDRÜCKER, W. ANGULO, J.-M. HÉRARD.*A local time-stepping Discontinuous Galerkin algorithm for the MHD system*, in "Modélisation et Simulation de Fluides Complexes - CEMRACS 2008", Marseille, France, July 2009 [*DOI :* 10.1051/PROC/2009038], https://hal.inria.fr/inria-00594611

[24] T. BARTH.*On the role of involutions in the discontinous Galerkin discretization of Maxwell and magnetohydrodynamic systems*, in "IMA Vol. Math. Appl.", 2006, vol. 142, p. 69–88

[25] A. CRESTETTO, P. HELLUY.*Resolution of the Vlasov-Maxwell system by PIC Discontinuous Galerkin method on GPU with OpenCL*, in "CEMRACS'11", France, EDP Sciences, 2011, vol. 38, p. 257–274 [*DOI :* 10.1051/PROC/201238014], https://hal.archives-ouvertes.fr/hal-00731021

[26] N. CROUSEILLES, E. FRÉNOD, S. A. HIRSTOAGA, A. MOUTON.*Two-Scale Macro-Micro decomposition of the Vlasov equation with a strong magnetic field*, in "Mathematical Models and Methods in Applied Sciences", 2013, vol. 23, n^o 08, p. 1527–1559 [*DOI :* 10.1142/S0218202513500152.], https://hal.archives-ouvertes.fr/hal-00638617

[27] E. FRÉNOD, F. SALVARANI, E. SONNENDRÜCKER.*Long time simulation of a beam in a periodic focusing channel via a two-scale PIC-method*, in "Mathematical Models and Methods in Applied Sciences", 2009, vol. 19, n^o 2, p. 175-197, ACM 82D10 35B27 76X05, http://hal.archives-ouvertes.fr/hal-00180700/en/

[28] V. GRANDGIRARD, M. BRUNETTI, P. BERTRAND, N. BESSE, X. GARBET, P. GHENDRIH, G. MANFREDI, Y. SARAZIN, O. SAUTER, E. SONNENDRÜCKER, J. VACLAVIK, L. VILLARD.*A drift-kinetic Semi-Lagrangian 4D Vlasov code for ion turbulence simulation*, in "J. of Comput. Phys.", 2006, vol. 217, 395

[29] C. HAUCK, C.-D. LEVERMORE.*Convex Duality and Entropy-Based Moment Closures: Characterizing Degenerate Densities*, in "SIAM J. Control Optim.", 2008, vol. 47, p. 1977–2015

[30] C.-D. LEVERMORE.*Entropy-based moment closures for kinetic equations*, in "Transport Theory Statist. Phys.", 1997, vol. 26, n^o 4-5, p. 591–606

[31] E. SONNENDRÜCKER, J.-R. ROCHE, P. BERTRAND, A. GHIZZO.*The semi-Lagrangian method for the numerical resolution of the Vlasov equation*, in "J. Comput. Phys.", 1999, vol. 149, n^o 2, p. 201–220

[32] E. TADMOR.*Entropy conservative finite element schemes*, in "Numerical methods for Compressible Flows, Finite Difference Element and Volume Techniques", T. E. TEZDUYAR, T. J. R. HUGHES (editors), Proc. Winter Annual Meeting, Amer. Soc. Mech. Eng, AMD- Vol. 78, 1986, 149

[33] B. WEBER, P. HELLUY, T. STRUB.*Optimisation d'un algorithme Galerkin Discontinu en OpenCL appliqué à la simulation en électromagnétisme*, in "preprint", 2017

Project-Team VERIDIS

Modeling and Verification of Distributed Algorithms and Systems

IN COLLABORATION WITH: Laboratoire lorrain de recherche en informatique et ses applications (LORIA)

IN PARTNERSHIP WITH:
CNRS

Max-Planck-Institut für Informatik Saarbrücken

Université de Lorraine

RESEARCH CENTER
Nancy - Grand Est

THEME
Proofs and Verification

Table of contents

Project-Team VERIDIS

Creation of the Team: 2010 January 01, updated into Project-Team: 2012 July 01

VeriDis is a joint research group of CNRS, Inria, Max-Planck-Institut für Informatik, and Université de Lorraine. It consists of members of the Mosel research group at LORIA, Nancy, France, and members of the Automation of Logic group at Max-Planck Institute for Informatics in Saarbrücken, Germany.

Keywords:

Computer Science and Digital Science:

A2.1.7. - Distributed programming
A2.1.11. - Proof languages
A2.4. - Formal method for verification, reliability, certification
A2.4.1. - Analysis
A2.4.2. - Model-checking
A2.4.3. - Proofs
A2.5. - Software engineering
A7.2. - Logic in Computer Science
A8.4. - Computer Algebra

Other Research Topics and Application Domains:

B6.1. - Software industry
B6.1.1. - Software engineering
B6.3.2. - Network protocols
B6.6. - Embedded systems

1. Team, Visitors, External Collaborators

Research Scientists

Stephan Merz [Team leader, Inria, Senior Researcher, HDR]
Igor Konnov [Inria, Researcher, until September 2019]
Thomas Sturm [CNRS, Senior Researcher, HDR]
Uwe Waldmann [Max-Planck Institut für Informatik, Senior Researcher]
Christoph Weidenbach [Team leader, Max-Planck Institut für Informatik, Senior Researcher, HDR]

Faculty Members

Étienne André [Univ. de Lorraine, Professor, from September 2019, HDR]
Marie Duflot-Kremer [Univ. de Lorraine, Associate Professor]
Pascal Fontaine [Univ. de Lorraine, Associate Professor, until October 2019, HDR]
Dominique Méry [Univ de Lorraine, Professor]
Sorin Stratulat [Univ de Lorraine, Associate Professor]

External Collaborator

Jasmin Christian Blanchette [Vrije Universiteit Amsterdam]

PhD Students

Martin Bromberger [Max-Planck Institut für Informatik, until December 2019]
Antoine Defourné [Inria, from March 2019]
Margaux Duroeulx [Univ. de Lorraine]
Daniel El Ouraoui [Inria]
Alberto Fiori [Max-Planck Institut für Informatik]

Mathias Fleury [Max-Planck Institut für Informatik]
Alexis Grall [Univ. de Lorraine]
Pierre Lermusiaux [Univ. de Lorraine]
Nicolas Schnepf [Inria, joint with Resist team, until September 2019]
Hans-Jörg Schurr [Inria]
Marco Voigt [Max-Planck Institut für Informatik, until July 2019]

Post-Doctoral Fellows

Martin Bromberger [Max-Planck Institut für Informatik, from December 2019]
Yann Duplouy [Inria]
Hamid Rahkooy [CNRS, from June 2019]
Sophie Tourret [Max-Planck Institut für Informatik]
Marco Voigt [Max-Planck Institut für Informatik, from August 2019]

Administrative Assistants

Sophie Drouot [Inria]
Sylvie Hilbert [CNRS]
Jennifer Müller [Max-Planck Institut für Informatik]

2. Overall Objectives

2.1. Overall Objectives

The VeriDis project team includes members of the MOSEL group at LORIA, the computer science laboratory in Nancy, and members of the research group *Automation of Logic* at Max-Planck-Institut für Informatik in Saarbrücken. It is headed by Stephan Merz and Christoph Weidenbach. VeriDis was created in 2010 as a local research group of Inria Nancy – Grand Est and has been an Inria project team since July 2012.

The objectives of VeriDis are to contribute to advances in verification techniques, including automated and interactive theorem proving, and to make them available for the development and analysis of concurrent and distributed algorithms and systems, based on mathematically precise and practically applicable development methods. The techniques that we develop are intended to assist designers of algorithms and systems in carrying out formally proved developments, where proofs of relevant properties, as well as bugs, can be found with a high degree of automation.

Within this context, we work on techniques for *automated theorem proving* for expressive languages based on first-order logic, with support for theories (fragments of arithmetic, set theory etc.) that are relevant for specifying algorithms and systems. Ideally, systems and their properties would be specified in high-level, expressive languages, errors in specifications would be discovered automatically, and finally, full verification could also be performed completely automatically. Due to the fundamental undecidability of the problem, this cannot be achieved in general. Nevertheless, we have observed important advances in automated deduction in recent years, to which we have contributed. These advances suggest that a substantially higher degree of automation can be achieved over what is available in today's tools supporting deductive verification. Our techniques are developed within SMT (satisfiability modulo theories) solving and superposition reasoning, the two main frameworks of contemporary automated reasoning that have complementary strengths and weaknesses, and we are interested in making them converge when appropriate. Techniques developed within the symbolic computation domain, such as algorithms for quantifier elimination for appropriate theories, are also relevant, and we are working on integrating them into our portfolio of techniques. In order to handle expressive input languages, we are working on techniques that encompass tractable fragments of higher-order logic, for example for specifying inductive or co-inductive data types, for automating proofs by induction, or for handling collections defined through a characteristic predicate.

Since full automatic verification remains elusive, another line of our research targets *interactive proof platforms*. We intend these platforms to benefit from our work on automated deduction by incorporating powerful automated backends and thus raise the degree of automation beyond what current proof assistants can offer. Since most conjectures stated by users are initially wrong (due to type errors, omitted hypotheses or overlooked border cases), it is also important that proof assistants be able to detect and explain such errors rather than letting users waste considerable time in futile proof attempts. Moreover, increased automation must not come at the expense of trustworthiness: skeptical proof assistants expect to be given an explanation of the proof found by the backend prover that they can certify.

Our methodological and foundational research is accompanied by the development of *efficient software tools*, several of which go beyond pure research prototypes: they have been used by others, have been integrated in proof platforms developed by other groups, and participate in international competitions. We also validate our work on proof techniques by applying them to the *formal development of algorithms and systems*. We mainly target high-level descriptions of concurrent and distributed algorithms and systems. This class of algorithms is by now ubiquitous, ranging from multi- and many-core algorithms to large networks and cloud computing, and their formal verification is notoriously difficult. Targeting high levels of abstraction allows the designs of such systems to be verified before an actual implementation has been developed, contributing to reducing the costs of formal verification. The potential of distributed systems for increased resilience to component failures makes them attractive in many contexts, but also makes formal verification even more important and challenging. Our work in this area aims at identifying classes of algorithms and systems for which we can provide guidelines and identify patterns of formal development that makes verification less an art and more an engineering discipline. We mainly target components of operating systems, distributed and cloud services, and networks of computers or mobile devices.

Beyond formal verification, we pursue applications of some of the symbolic techniques that we are developing in other domains. We have observed encouraging success in using techniques of symbolic computation for the qualitative analysis of biological and chemical regulation networks described by systems of ordinary differential equations that were previously only accessible to large-scale simulation. This work is being pursued within a large-scale interdisciplinary collaboration. It aims for our work grounded in verification having an impact on the sciences, beyond engineering, which will feed back into our core formal methods community.

3. Research Program

3.1. Automated and Interactive Theorem Proving

The VeriDis team gathers experts in techniques and tools for automatic deduction and interactive theorem proving, and specialists in methods and formalisms designed for the development of trustworthy concurrent and distributed systems and algorithms. Our common objective is twofold: first, we wish to advance the state of the art in automated and interactive theorem proving, and their combinations. Second, we work on making the resulting technology available for the computer-aided verification of distributed systems and protocols. In particular, our techniques and tools are intended to support sound methods for the development of trustworthy distributed systems that scale to algorithms relevant for practical applications.

VeriDis members from Saarbrücken are developing the SPASS [10] workbench. It currently consists of one of the leading automated theorem provers for first-order logic based on the superposition calculus [56] and a theory solver for linear arithmetic.

In a complementary approach to automated deduction, VeriDis members from Nancy work on techniques for integrating reasoners for specific theories. They develop veriT [1], an SMT [0] solver that combines decision procedures for different fragments of first-order logic. The veriT solver is designed to produce detailed proofs; this makes it particularly suitable as a component of a robust cooperation of deduction tools.

[0] Satisfiability Modulo Theories [58]

Finally, VeriDis members design effective quantifier elimination methods and decision procedures for algebraic theories, supported by their efficient implementation in the Redlog system [4].

An important objective of this line of work is the integration of theories in automated deduction. Typical theories of interest, including fragments of arithmetic, are difficult or impossible to express in first-order logic. We therefore explore efficient, modular techniques for integrating semantic and syntactic reasoning methods, develop novel combination results and techniques for quantifier instantiation. These problems are addressed from both sides, i.e. by embedding decision procedures into the superposition framework or by allowing an SMT solver to accept axiomatizations for plug-in theories. We also develop specific decision procedures for theories such as non-linear real arithmetic that are important when reasoning about certain classes of (e.g., real-time) systems but that also have interesting applications beyond verification.

We rely on interactive theorem provers for reasoning about specifications at a high level of abstraction when fully automatic verification is not (yet) feasible. An interactive proof platform should help verification engineers lay out the proof structure at a sufficiently high level of abstraction; powerful automatic plug-ins should then discharge the resulting proof steps. Members of VeriDis have ample experience in the specification and subsequent machine-assisted, interactive verification of algorithms. In particular, we participate in a project at the joint Microsoft Research-Inria Centre on the development of methods and tools for the formal proof of TLA$^+$ [66] specifications. Our prover relies on a declarative proof language, and calls upon several automatic backends [3]. Trust in the correctness of the overall proof can be ensured when the backends provide justifications that can be checked by the trusted kernel of a proof assistant. During the development of a proof, most obligations that are passed to the prover actually fail – for example, because necessary information is not present in the context or because the invariant is too weak, and we are interested in explaining failed proof attempts to the user, in particular through the construction of counter-models.

3.2. Formal Methods for Developing and Analyzing Algorithms and Systems

Theorem provers are not used in isolation, but they support the application of sound methodologies for modeling and verifying systems. In this respect, members of VeriDis have gained expertise and recognition in making contributions to formal methods for concurrent and distributed algorithms and systems [2], [9], and in applying them to concrete use cases. In particular, the concept of *refinement* [55], [57], [70] in state-based modeling formalisms is central to our approach because it allows us to present a rational (re)construction of system development. An important goal in designing such methods is to establish precise proof obligations, many of which can be discharged by automatic tools. This requires taking into account specific characteristics of certain classes of systems and tailoring the model to concrete computational models. Our research in this area is supported by carrying out case studies for academic and industrial developments. This activity benefits from and influences the development of our proof tools.

In this line of work, we investigate specific development and verification patterns for particular classes of algorithms, in order to reduce the work associated with their verification. We are also interested in applications of formal methods and their associated tools to the development of systems that underlie specific certification requirements in the sense of, e.g., Common Criteria. Finally, we are interested in the adaptation of model checking techniques for verifying actual distributed programs, rather than high-level models.

Today, the formal verification of a new algorithm is typically the subject of a PhD thesis, if it is addressed at all. This situation is not sustainable given the move towards more and more parallelism in mainstream systems: algorithm developers and system designers must be able to productively use verification tools for validating their algorithms and implementations. On a high level, the goal of VeriDis is to make formal verification standard practice for the development of distributed algorithms and systems, just as symbolic model checking has become commonplace in the development of embedded systems and as security analysis for cryptographic protocols is becoming standard practice today. Although the fundamental problems in distributed programming are well-known, they pose new challenges in the context of modern system paradigms, including ad-hoc and overlay networks or peer-to-peer systems, and they must be integrated for concrete applications.

4. Application Domains

4.1. Application Domains

Distributed algorithms and protocols are found at all levels of computing infrastructure, from many-core processors and systems-on-chip to wide-area networks. We are particularly interested in the verification of algorithms that are developed for supporting novel computing paradigms, including ad-hoc networks that underly mobile and low-power computing or overlay networks, peer-to-peer networks that provide services for telecommunication, or cloud computing services. Computing infrastructure must be highly available and is ideally invisible to the end user, therefore correctness is crucial. One should note that standard problems of distributed computing such as consensus, group membership or leader election have to be reformulated for the dynamic context of these modern systems. We are not ourselves experts in the design of distributed algorithms, but we work together with domain experts on designing formal models of these protocols, and on verifying their properties. These cooperations help us focus on concrete algorithms and ensure that our work is relevant to the distributed algorithm community.

Our work on symbolic procedures for solving polynomial constraints finds applications beyond verification. In particular, we have been working in interdisciplinary projects with researchers from mathematics, computer science, system biology, and system medicine on the analysis of molecular interaction networks in order to infer the principal qualitative properties of models. Our techniques complement numerical analysis techniques and are validated against collections of models from computational biology.

5. Highlights of the Year

5.1. Highlights of the Year

5.1.1. Awards

Christoph Weidenbach received the Skolem test-of-time award of CADE, the international conference on automated deduction, for his paper *Towards an Automated Analysis of Security Protocols* [72].

Martin Bromberger, Mathias Fleury, Simon Schwarz and Christoph Weidenbach received the best student paper award at CADE 27 for their paper *SPASS-SATT: A CDCL(LA) Solver* .

BEST PAPERS AWARDS :

[31]
M. BROMBERGER, M. FLEURY, S. SCHWARZ, C. WEIDENBACH.*SPASS-SATT: A CDCL(LA) Solver*, in "27th International Conference on Automated Deduction (CADE-27)", Natal, Brazil, P. FONTAINE (editor), Lecture Notes in Computer Science, 2019, vol. 11716, p. 111-122 [*DOI :* 10.1007/978-3-030-29436-6_7], https://hal.inria.fr/hal-02405524

6. New Software and Platforms

6.1. Redlog

Reduce Logic System

KEYWORDS: Computer algebra system (CAS) - First-order logic - Constraint solving

SCIENTIFIC DESCRIPTION: Redlog is an integral part of the interactive computer algebra system Reduce. It supplements Reduce's comprehensive collection of powerful methods from symbolic computation by supplying more than 100 functions on first-order formulas.

Redlog generally works with interpreted first-order logic in contrast to free first-order logic. Each first-order formula in Redlog must exclusively contain atoms from one particular Redlog-supported theory, which corresponds to a choice of admissible functions and relations with fixed semantics. Redlog-supported theories include Nonlinear Real Arithmetic (Real Closed Fields), Presburger Arithmetic, Parametric QSAT, and many more.

NEWS OF THE YEAR: Parts of the Redlog code are 25 years old now. Version 1 of the underlying computer algebra system Reduce has been published even 50 years ago. In 2018 we therefore started to go for major revisions and improvements of Redlog's software architecture, which are still under way.

Redlog, as well as the underlying Reduce, depends on a quite minimalistic Lisp 1 dialect called Standard Lisp. Today, there are two independent implementations of Standard Lisp left, which are supported only on the basis of private commitment of essentially one individual per Lisp. With the large code base of Redlog plus the necessary algebraic algorithms from Reduce, a migration to a different language or computer algebra system is not feasible. We are therefore experimenting with the realization of a Standard Lisp on the basis of ANSI Common Lisp.

Scientifically we are currently improving on Parametric Gaussian Elimination in Reduce/Redlog, which has various applications in our bilateral interdisciplinary ANR/DFG project SYMBIONT (Symbolic Methods for Biological Networks), e.g., classification of real singularities of systems of implicit ordinary differential equations.

- Participant: Thomas Sturm
- Contact: Thomas Sturm
- URL: http://www.redlog.eu/

6.2. SPASS

KEYWORD: First-order logic

SCIENTIFIC DESCRIPTION: The classic SPASS is an automated theorem prover based on superposition that handles first-order logic with equality and several extensions for particular classes of theories. With version SPASS 3.9 we have stopped the development of the classic prover and have started the bottom-up development of SPASS 4.0 that will actually be a workbench of automated reasoning tools. Furthermore, we use SPASS 3.9 as a test bed for the development of new calculi.

SPASS 3.9 has been used as the basis for SPASS-AR, a new approximation refinement theorem proving approach.

FUNCTIONAL DESCRIPTION: SPASS is an automated theorem prover based on superposition that handles first-order logic with equality and several extensions for particular classes of theories.

- Contact: Christoph Weidenbach
- URL: http://www.spass-prover.org/

6.3. SPASS-SATT

KEYWORDS: Automated deduction - Decision

SCIENTIFIC DESCRIPTION: SPASS -SATT is an SMT solver for the theories of linear integer arithmetic, linear rational arithmetic and mixed linear arithmetic. It features new tests for the satisfiability of unbounded systems, as well as new algorithms for the detection of integer solutions.

We further investigated the use of redundancy elimination in SAT solving and underlying implementation techniques. Our aim is a new approach to SAT solving that needs fewer conflicts (on average) *and* is faster than the current state-of-the art solvers. Furthermore, we have developed a new calculus and first prototypical implementation of a SAT solver with mixed OR/XOR clauses.

FUNCTIONAL DESCRIPTION: SPASS-SATT is an SMT solver for linear integer arithmetic, mixed linear arithmetic and rational linear arithmetic.

NEWS OF THE YEAR: SPASS-SATT participated in the SMT competition 2019 in the quantifier free integer and rational linear arithmetic categories. It scored first on rational linear arithmetic and second on integer linear arithmetic. (The winner of the latter category was a portfolio solver that includes SPASS-SATT.) The main improvements are due to an advanced translation to clause normal form, a close interaction between the theory and the SAT solvers, and a new transformation turning unbounded integer problems into bounded integer problems.

- Participants: Martin Bromberger, Mathias Fleury and Christoph Weidenbach
- Contact: Martin Bromberger
- URL: https://www.mpi-inf.mpg.de/departments/automation-of-logic/software/spass-workbench/spass-satt/

6.4. veriT

KEYWORDS: Automated deduction - Formula solving - Verification

SCIENTIFIC DESCRIPTION: veriT comprises a SAT solver, a decision procedure for uninterpreted symbols based on congruence closure, a simplex-based decision procedure for linear arithmetic, and instantiation-based quantifier handling.

FUNCTIONAL DESCRIPTION: VeriT is an open, trustable and efficient SMT (Satisfiability Modulo Theories) solver, featuring efficient decision procedure for uninterpreted symbols and linear arithmetic, and quantifier reasoning.

NEWS OF THE YEAR: Efforts in 2019 have been focused on quantifier handling, higher logic, and proof production.

The veriT solver participated in the SMT competition SMT-COMP 2019 with good results. In particular, it took the bronze medal in the QF_UF division, solving as many problems as the two leading solvers but taking somewhat more time.

We target applications where validation of formulas is crucial, such as the validation of TLA$^+$ and B specifications, and work together with the developers of the respective verification platforms to make veriT even more useful in practice. The solver is available as a plugin for the *Rodin* platform, and it is integrated within *Atelier B*.

veriT is also a prototype platform for ideas developed within the Matryoshka project, aiming at greater availability of automated reasoning for proof assistants.

- Participants: Haniel Barbosa, Daniel El Ouraoui, Pascal Fontaine and Hans-JÖrg Schurr
- Partner: Université de Lorraine
- Contact: Pascal Fontaine
- URL: http://www.veriT-solver.org

6.5. SPIKE

KEYWORDS: Proof - Automated deduction - Automated theorem proving - Term Rewriting Systems - Formal methods

SCIENTIFIC DESCRIPTION: SPIKE, an automatic induction-based theorem prover built to reason on conditional theories with equality, is one of the few formal tools able to perform automatically mutual and lazy induction. Designed in the 1990s, it has been successfully used in many non-trivial applications and served as a prototype for different proof experiments and extensions.

FUNCTIONAL DESCRIPTION: Automated induction-based theorem prover

RELEASE FUNCTIONAL DESCRIPTION: Proof certification with Coq, cyclic induction, decision procedures

- Participant: Sorin Stratulat
- Contact: Sorin Stratulat
- URL: https://github.com/sorinica/spike-prover/wiki

6.6. TLAPS

TLA+ proof system

KEYWORD: Proof assistant

SCIENTIFIC DESCRIPTION: TLAPS is a platform for developing and mechanically verifying proofs about TLA+ specifications. The TLA+ proof language is hierarchical and explicit, allowing a user to decompose the overall proof into proof steps that can be checked independently. TLAPS consists of a proof manager that interprets the proof language and generates a collection of proof obligations that are sent to backend verifiers. The current backends include the tableau-based prover Zenon for first-order logic, Isabelle/TLA+, an encoding of TLA+ set theory as an object logic in the logical framework Isabelle, an SMT backend designed for use with any SMT-lib compatible solver, and an interface to a decision procedure for propositional temporal logic.

FUNCTIONAL DESCRIPTION: TLAPS is a proof assistant for the TLA+ specification language.

NEWS OF THE YEAR: Work in 2019 focused on providing support for reasoning about TLA+'s ENABLED and action composition constructs. We also prepared a minor release, fixing some issues and switching to Z3 as the default SMT back-end solver.

- Participants: Damien Doligez, Stephan Merz and Ioannis Filippidis
- Contact: Stephan Merz
- URL: https://tla.msr-inria.inria.fr/tlaps/content/Home.html

6.7. Apalache

Abstraction-based Parameterized TLA+ Checker

KEYWORD: Model Checker

SCIENTIFIC DESCRIPTION: Apalache is a symbolic model checker that works under the following assumptions:

(1) As in TLC, all specification parameters are fixed and finite, e.g., the system is initialized integers, finite sets, and functions of finite domains and co-domains. (2) As in TLC, all data structures evaluated during an execution are finite, e.g., a system specification cannot operate on the set of all integers. (3) Only finite executions up to a given bound are analysed.

Apalache translates bounded executions of a TLA+ specifications into a set of quantifier-free SMT constraints. By querying the SMT solver, the model checker either finds a counterexample to an invariant, or proves that there is no counterexample up to given computation length.

FUNCTIONAL DESCRIPTION: The first version implements a symbolic bounded model checker for TLA^+ that runs under the same assumptions as the explicit-state model checker TLC. It checks whether a TLA^+ specification satisfies an invariant candidate by checking satisfiability of an SMT formula that encodes: (1) an execution of bounded length, and (2) preservation of the invariant candidate in every state of the execution. Our tool is still in the experimental phase, due to a number of challenges posed by the semantics of TLA^+ to SMT solvers.

News Of The Year: In 2019, we have simplified the set of rewriting rules, which are used in the translation from TLA+ to SMT. We have shown that the rules are sound, that is, that the translator produces a set of SMT constraints that are equisatisfiable to the given TLA+ formula. We have conducted the experiments on 10 TLA+ specifications of distributed algorithms. When running bounded model checking, Apalache outperforms TLC in some cases. When checking inductive invariants, Apalache runs significantly faster than TLC. These results were reported at ACM OOPSLA 2019.

- Partner: Technische Universität Wien
- Contact: Igor Konnov
- Publications: hal-01899719v1 - hal-01871131v1 - hal-02280888v1
- URL: https://forsyte.at/research/apalache/

6.8. IMITATOR

Keywords: Verification - Parametric model - Parameter synthesis - Model Checking - Model Checker - Timed automata

Functional Description: IMITATOR is a software tool for parametric verification and robustness analysis of real-time systems with parameters. It relies on the formalism of networks of parametric timed automata, augmented with integer variables and stopwatches.

- Participants: Etienne Andre and Jaime Eduardo Arias Almeida
- Partner: Loria
- Contact: Etienne Andre
- Publications: The Inverse Method - Formalizing Time4sys using parametric timed automata - Minimal-Time Synthesis for Parametric Timed Automata - A benchmark library for parametric timed model checking
- URL: https://www.imitator.fr/

6.9. ByMC

Byzantine Model Checker

Keywords: Model Checker - Distributed computing - Verification

Scientific Description: In recent work, we have introduced a series of techniques for automatic verification of threshold-guarded distributed algorithms that have the following features: (1) up to t of n processes may exhibit crash or Byzantine failures, (2) the correct processes count messages and progress when they receive sufficiently many messages, e.g., at least $t+1$, (3) the number n of processes in the system is a parameter, as well as t, (4) and the parameters are restricted by a resilience condition, e.g., $n > 3t$.

ByMC supports a parallel mode, which allows one to run verification experiments in an MPI cluster such as Grid5000 and Vienna Scientific Cluster.

Functional Description: ByMC implements several techniques for the parameterized verification of threshold-guarded distributed algorithms such as reliable broadcast, one-step Byzantine consensus, non-blocking atomic commit, condition-based consensus, and randomized consensus. The tool accepts two kinds of inputs: (i) threshold automata (the framework of our verification techniques) and (ii) Parametric Promela (which is similar to the way in which the distributed algorithms are presented in the distributed computing literature). Internally, the tool analyzes representative executions by querying an SMT solver. Apart from verification, ByMC also implements a technique for the automatic synthesis of threshold guards.

The tool can run on a single computer as well as in an MPI cluster, e.g., Grid5000 or Vienna Scientific Cluster.

NEWS OF THE YEAR: In 2019, we have shown how to apply ByMC to randomized fault-tolerant consensus algorithms such as randomized consensus by Ben-Or and RS-BOSCO. This result was presented at CONCUR 2019.

- Partner: Technische Universität Wien
- Contact: Igor Konnov
- Publications: ByMC: Byzantine Model Checker - Reachability in Parameterized Systems: All Flavors of Threshold Automata - Model Checking of Fault-Tolerant Distributed Algorithms: from Classics towards Contemporary - Verification of Randomized Distributed Algorithms under Round-Rigid Adversaries
- URL: https://forsyte.at/software/bymc/

7. New Results

7.1. Automated and Interactive Theorem Proving

Participants: Jasmin Christian Blanchette, Martin Bromberger, Antoine Defourné, Daniel El Ouraoui, Alberto Fiori, Mathias Fleury, Pascal Fontaine, Stephan Merz, Hamid Rahkooy, Hans-Jörg Schurr, Sorin Stratulat, Thomas Sturm, Sophie Tourret, Marco Voigt, Uwe Waldmann, Christoph Weidenbach.

7.1.1. *Combination of Satisfiability Procedures*

Joint work with Christophe Ringeissen (Inria Nancy – Grand Est, Pesto) and Paula Chocron (Insikt Intelligence, Spain).

A satisfiability problem is often expressed in a combination of theories, and a natural approach consists in solving the problem by combining the satisfiability procedures available for the component theories. This is the purpose of the combination method introduced by Nelson and Oppen. However, in its initial presentation, the Nelson-Oppen combination method requires the theories to be signature-disjoint and stably infinite. The design of a generic combination method for non-disjoint unions of theories is difficult, but it is worth exploring simple non-disjoint combinations that appear frequently in verification. An example is the case of shared sets, where sets are represented by unary predicates. Another example is the case of bridging functions between data structures and a target theory (e.g., a fragment of arithmetic).

In 2015, we defined a sound and complete combination procedure *à la* Nelson-Oppen for the theory of absolutely free data structures (including lists and trees) connected to another theory via bridging functions [59]. This combination procedure has also been refined for standard interpretations. The resulting theory has a nice politeness property, enabling combinations with arbitrary decidable theories of elements. We also investigated other theories [60] amenable to similar combinations: this class includes the theory of equality, the theory of absolutely free data structures, and all the theories in between.

In 2018 and 2019, we have been improving the framework and unified both results. This was published in the Journal of Automated Reasoning in 2019 [19].

7.1.2. *Quantifier Handling in SMT*

Joint work with Cezary Kaliszyk (Univ. of Innsbruck).

SMT solvers generally rely on various instantiation techniques for handling quantifiers. We built a unifying framework encompassing quantified formulas with equality and uninterpreted functions, such that the major instantiation techniques in SMT solving can be cast in that framework. It is based on the problem of E-ground (dis)unification, a variation of the classic Rigid E-unification problem. We introduced a sound and complete calculus to solve this problem in practice: Congruence Closure with Free Variables (CCFV). Experimental evaluations of implementations of CCFV demonstrate notable improvements in the state-of-the-art solver CVC4 and make the solver veriT competitive with state-of-the-art solvers for several benchmark libraries, in particular those originating in verification problems.

In 2019, we investigated machine learning techniques for predicting the usefulness of an instance in order to decrease the number of instances passed to the SMT solver. For this, we proposed a meaningful way to characterize the state of an SMT solver, to collect instantiation learning data, and to integrate a predictor in the core of a state-of-the-art SMT solver. This ultimately leads to more efficient SMT solving for quantified problems.

7.1.3. Higher-Order SMT

Joint work with Haniel Barbosa, Andrew Reynolds, Cesare Tinelli (Univ. of Iowa), and Clark Barrett (Stanford)

SMT solvers have throughout the years been able to cope with increasingly expressive formulas, from ground logics to full first-order logic (FOL). In contrast, the extension of SMT solvers to higher-order logic (HOL) was mostly unexplored. We proposed a pragmatic extension for SMT solvers to support HOL reasoning natively without compromising performance on FOL reasoning, thus leveraging the extensive research and implementation efforts dedicated to efficient SMT solving. We showed how to generalize data structures and the ground decision procedure to support partial applications and extensionality, as well as how to reconcile quantifier instantiation techniques with higher-order variables. We also discussed a separate approach for redesigning an SMT solver for higher-order logic from the ground up via new data structures and algorithms. We applied our pragmatic extension to the CVC4 SMT solver and discussed a redesign of the veriT SMT solver. Our evaluation showed that they are competitive with state-of-the-art HOL provers and often outperform the traditional encoding into FOL.

This result was published at CADE 2019 [27]. We are also currently investigating extending the CCFV algorithm to higher-order logic.

7.1.4. Proofs for SMT

We have previously developed a framework for processing formulas in automatic theorem provers, with generation of detailed proofs that can be checked by external tools, including skeptical proof assistants. The main components are a generic contextual recursion algorithm and an extensible set of inference rules. Clausification, skolemization, theory-specific simplifications, and expansion of ‘let’ expressions are instances of this framework. With suitable data structures, proof generation adds only a linear-time overhead, and proofs can be checked in linear time. We implemented the approach in the SMT solver veriT. This allowed us to dramatically simplify the code base while increasing the number of problems for which detailed proofs can be produced. In 2019, the format of proof output was further improved, while also improving the reconstruction procedure in the proof assistant Isabelle/HOL. This allowed the tactic using SMT with proofs to be regularly suggested by Sledgehammer as the fastest method to automatically solve proof goals. This was the subject of a workshop publication [36].

7.1.5. Clause Learning from Simple Models

The goal of this research is to guide inferences in expressive logics via simple models. Intuitively, a model is simple if computations with respect to the model can be done in polynomial time. We have shown that for first-order logic, models built from ground literals are sufficient to guide resolution inferences between non-ground clauses [35]. We have also investigated the expressivity of model representation formalisms in general [41]. Model representation formalisms built on atoms with only linear variable occurrences have the finite model property. Hence, they cannot represent infinite models.

7.1.6. SPASS-SATT

We have further developed our CDCL(T) solver SPASS-SATT. It is the combination of our SAT solver SPASS-SAT with highly efficient theory solvers for linear arithmetic [31]. SPASS-SATT showed good performance at the SMT competition 2019 where it won the category on linear rational arithmetic and scored second on linear integer arithmetic. The winner of the linear integer arithmetic category was a portfolio solver including SPASS-SATT. Our main improvements are due to an advanced clause normal form translation, a close interaction between the theory solvers and the SAT solver SPASS-SAT, and and a new transformation turning unbounded integer problems into bounded integer problems.

7.1.7. Extension of a Highly Efficient Prover to λ-free Higher-Order Logic

Joint work with Simon Cruanes (Aesthetic Integration), Stephan Schulz (DHBW Stuttgart), and Petar Vukmirović (VU Amsterdam).

Superposition-based provers, such as E, SPASS, and Vampire, are among the most successful reasoning systems for first-order logic. They serve as backends in various frameworks, including software verifiers, automatic higher-order theorem provers, and one-click "hammers" in proof assistants. Decades of research have gone into refining calculi, devising efficient data structures and algorithms, and developing heuristics to guide proof search. This work has mostly focused on first-order logic with equality, with or without arithmetic.

To obtain better performance, we propose to start with a competitive first-order prover and extend it to full higher-order logic one feature at a time. Our goal is a *graceful* extension, in keeping with the zero-overhead principle: *What you don't use, you don't pay for.*

As a stepping stone towards full higher-order logic, we initially restricted our focus to a higher-order logic without λ-expressions. Compared with first-order logic, its distinguishing features are partial application and applied variables. Our vehicle is E, a prover developed primarily by Schulz. It is written in C and offers good performance. E regularly scores among the top systems at the CASC competition, and usually is the strongest open source prover in the relevant divisions. It also serves as a backend for competitive higher-order provers.

Our experiments show that the λ-free higher-order version of E is practically as fast as E on first-order problems and can also prove higher-order problems that do not require synthesizing λ-terms. As a next step, we plan to add support for λ-terms and higher-order unification. This work is described in a TACAS 2019 conference paper [42]; an extended version of this paper has been invited to a special issue of the *International Journal on Software Tools for Technology Transfer*.

7.1.8. Extension of the Superposition Calculus with λ-Abstractions

Joint work with Alexander Bentkamp (VU Amsterdam) and Petar Vukmirović (VU Amsterdam).

We designed a superposition calculus for a clausal fragment of extensional polymorphic higher-order logic that includes anonymous functions but excludes Booleans. The inference rules work on $\beta\eta$-equivalence classes of λ-terms and rely on higher-order unification to achieve refutational completeness.

We implemented the calculus in the Zipperposition prover. Our empirical evaluation includes benchmarks from the TPTP (Thousands of Problems for Theorem Provers) and interactive verification problems exported from Isabelle/HOL. The results appear promising and suggest that an optimized implementation inside a competitive prover such as E, SPASS, or Vampire would outperform existing higher-order automatic provers. This research was presented at the CADE 2019 conference [28].

7.1.9. Automated Reasoning over Biological Networks

[54] study toricity of steady state ideals of biological models. From a computational point of view, models identified as toric allow to employ tools from toric geometry for a complexity reduction step. From a scientific point of view, toric models are known to have scale invariant multistationarity in the space of linear conserved quantities. This can be interpreted as a dimension reduction of the multistationarity problem. We propose a generalization of the notion of toricity, compatible with our above remarks, in terms of the geometry of the variety instead of the syntactic shape of generators of the ideal. We consider 129 models from the BioModels repository [67], for which ODEbase [0] provides input data directly usable for symbolic computation. While the existing literature was mostly limited to the complex numbers, we use real quantifier elimination methods to treat also the real case, which is clearly the relevant domain from a scientific point of view. In practice, our real computations in Redlog [4] can compete with our complex ones. In theory we show that our real algorithms are in EXPTIME while Gröbner bases, which are typically used when working with ideal generators, are EXPSPACE-complete [68]. To our knowledge, this is the first time that such a comprehensive set of biomodels has been systematically processed using symbolic methods.

[0] http://odebase.cs.uni-bonn.de/

7.1.10. Towards an Improved Encoding of TLA+ Proof Obligations

We reconsider the encoding of proof obligations that arise in proofs about TLA^+ specifications in multi-sorted first-order logic, and specifically their translations to SMT solvers. Our previous work [69] relied on type inference for identifying expressions having atomic types such as integers but did not exploit more complex types, even if such types were constructed during type inference. A more pervasive use of types for translating set-theoretic expressions to the input language of SMT solvers appears promising in order to reduce the use of type injections and quantifiers and thus simplify the proof obligations passed to the solver, but it raises non-trivial soundness and completeness issues. Techniques of gradual typing designed for programming languages where type inference is not fully possible statically may be helpful in this context. A related problem is support for instantiation hints for quantified formulas given by the user. A first paper will be presented at JFLA 2020.

7.1.11. Formal Proofs of Tarjan's Algorithm

Joint work with Ran Chen (Chinese Academy of Sciences), Cyril Cohen and Laurent Théry (Inria Sophia Antipolis Méditerranée, Stamp), and Jean-Jacques Lévy (Inria Paris, Pi.r2).

We consider Tarjan's classical algorithm for computing strongly connected components in a graph as a case study of intermediate complexity for comparing interactive proof assistants. Representing the algorithm as a functional program (rather than its more conventional imperative representation), we proved its correctness in three different proof assistants (Coq, Isabelle/HOL, and Why3). The proofs are based on essentially the same formulation of the algorithm and of its invariants, allowing us to compare differences due to idiosyncracies of the proof assistants, such as their ability to handle mutually recursive function definitions, proving termination beyond syntactic criteria, and their degree of automation. Our results were presented at ITP 2019 [33].

7.1.12. Implementation of an Efficient Validation of FOLID Cyclic Induction Reasoning

Checking the soundness of cyclic induction reasoning for first-order logic with inductive definitions (FOL_{ID}) is decidable but the standard checking method is based on an exponential complement operation for Büchi automata. We devised a polynomial method "semi-deciding" this problem; its most expensive steps are reminiscent of the comparisons with multiset path orderings. In practice, it has been integrated in the CYCLIST prover and successfully checked all the proofs included in its distribution. The work was presented at the CiSS2019 conference (Circularity in Syntax and Semantics) and the software is available at https://members.loria.fr/SStratulat/files/e-cyclist.zip.

7.2. Formal Methods for Developing and Analyzing Algorithms and Systems

Participants: Étienne André, Marie Duflot-Kremer, Yann Duplouy, Margaux Duroeulx, Igor Konnov, Dominique Méry, Stephan Merz, Nicolas Schnepf, Christoph Weidenbach.

7.2.1. Synthesis of Security Chains for Software Defined Networks

Joint work with Rémi Badonnel and Abdelkader Lahmadi (Inria Nancy – Grand Est, Resist).

The PhD thesis of Nicolas Schnepf focuses on applying techniques based on formal methods in the area of network communications, and in particular for the construction, verification, and optimization of chains of security functions in the setting of software-defined networks (SDN). The main objective is to prevent applications from disrupting the functioning of the network or services, for example by launching denial of service attacks, port scanning or similar activities.

We designed techniques for formally verifying security chains using SMT solving and symbolic model checking. Furthermore, we developed and prototypically implemented an approach for (i) learning a Markov chain characterizing the network behavior of an Android application based on its observed communications, (ii) inferring appropriate security functions from the structure of that Markov chain and thresholds set by the network operator, using techniques of logic programming, (iii) combining security functions for individual applications into larger security chains, and (iv) optimizing the deployment of security chains for a given SDN infrastructure using techniques of (linear or non-linear) optimization or optimizing SMT solvers. Two papers were presented at IM 2019 [39], [38], the PhD thesis [12] was defended in September 2019, and a journal paper is in preparation.

7.2.2. Satisfiability Techniques for Reliability Assessment

Joint work with Nicolae Brînzei at Centre de Recherche en Automatique de Nancy.

In the context of the PhD thesis of Margaux Durœulx, funded by the Lorraine University of Excellence program, we explore the applicability of satisfiability techniques for assessing the reliability of complex systems. In particular, we consider component-based systems modeled using fault trees that can be seen as a visual representation of the structure function indicating which combinations of component failures lead to system failures. We rely on SAT solvers to compute minimal tie sets, i.e., minimal sets of components whose functioning ensures that the overall system works. These tie sets are instrumental for a probabilistic reliability assessment. In 2019, we have extended this idea to dynamic fault trees where the order of component failures needs to be taken into account in order to determine the failure status of the overall system [34].

7.2.3. Statistical Model Checking of Distributed Programs

Yann Duplouy joined the HAC SPECIS project (cf. section 9.2) in December 2018 as a post-doctoral researcher with the objective of designing and implementing a statistical model checker within the SimGrid framework. So far he added to SimGrid the possibility to use stochastic profiles, introducing probabilities in the model of the network. He also developed a prototype tool that can be interfaced with the SimGrid simulators to perform statistical model checking on the actual programs simulated using the SimGrid framework. He now validates this prototype on concrete case studies, including the Bit Torrent protocol with probabilistic failures of the nodes.

7.2.4. Parameterized Verification of Threshold-Guarded Fault-Tolerant Distributed Algorithms

Joint work with Nathalie Bertrand (Inria Rennes Bretagne – Atlantique, SUMO), Marijana Lazić (TU Munich) and Ilina Stoilkovska, Josef Widder, Florian Zuleger (TU Wien).

Many fault-tolerant distributed algorithms use threshold guards: processes broadcast messages and count the number of messages that they receive from their peers. Based on the total number n of processes and an upper bound on the number t of faulty processes, a correct process tolerates faults by receiving "sufficiently many" messages. For instance, when a correct process has received $t+1$ messages from distinct processes, at least one of these messages must originate from a non-faulty process. The main challenge is to verify such algorithms for all combinations of parameters n and t that satisfy a resilience condition, e.g., $n > 3t$.

In earlier work, we introduced threshold automata for representing processes in such algorithms and showed that systems of threshold automata have bounded diameters that do not depend on the parameters such as n and t, provided that a single-step acceleration is allowed [62], [63], [64].

Our previous results apply to asynchronous algorithms. It is well-known that distributed consensus cannot be solved in purely asynchronous systems [61]. However, when an algorithm is provided with a random coin, consensus becomes solvable (e.g., the algorithm by Ben-Or, 1993). In [29], we introduced an approach to parameterized verification of randomized threshold-guarded distributed algorithms, which proceed in an unbounded number of rounds and toss a coin to break symmetries. This approach integrates two levels of reasoning: (1) proving safety and liveness of a single round system with ByMC by replacing randomization with non-determinism, (2) showing almost-sure termination of an algorithm by using the verification results for the non-deterministic system. To show soundness, we proved several theorems that reduce reasoning about multiple rounds to reasoning about a single round. We verified five prominent algorithms, including Ben-Or's randomized consensus and randomized one-step consensus (RS-BOSCO [71]). The verification of the latter algorithm required us to run experiments in Grid5000. This paper was presented at CONCUR 2019.

Another way of making consensus solvable is to impose synchrony on the executions of a distributed system. In [40] we introduced synchronous threshold automata, which execute in lock-step and count the number of processes in given local states. In general, we showed that even reachability of a parameterized set of global states in such a distributed system is undecidable. However, we proved that systems of automata with monotonic guards have bounded diameters, which allows us to use SMT-based bounded model checking as a complete parameterized verification technique. We introduced a procedure for computing the diameter of a counter system of synchronous threshold automata, applied it to the counter systems of 8 distributed algorithms from the literature, and found that their diameters are tiny (from 1 to 4). This makes our approach practically feasible, despite undecidability in general. This paper was presented at TACAS 2019. The paper was invited to the special issue of TACAS 2019, to appear in the *International Journal on Software Tools for Technology Transfer* in 2020.

7.2.5. Symbolic Model Checking of TLA+ Specifications

Joint work with Jure Kukovec, Thanh Hai Tran, Josef Widder (TU Wien).

TLA$^+$ is a general language introduced by Leslie Lamport for specifying temporal behavior of computer systems [66]. The tool set for TLA$^+$ includes an explicit-state model checker TLC. As explicit state model checkers do not scale to large verification problems, we started the project APALACHE [0] on developing a symbolic model checker for TLA$^+$ in 2016.

Following our results in 2018 [65], we have extended the symbolic model checker for TLA$^+$. In [22], we have defined the translation process from TLA$^+$ to SMT as a series of rewriting rules. Furthermore, we have proven soundness of this translation. Our experiments show that APALACHE runs faster than TLC when proving inductive invariants. APALACHE also implements bounded model checking, which has to be improved, in order to make it competitive with TLC. The paper [22] was presented at ACM OOPSLA 2019.

7.2.6. Incremental Development of Systems and Algorithms

Joint work with Rosemary Monahan (NUI Maynooth, Ireland) and Mohammed Mosbah (LaBRI, Bordeaux).

The development of distributed algorithms and, more generally, of distributed systems, is a complex, delicate, and challenging process. The approach based on refinement applies a design methodology that starts from the most abstract model and leads, in an incremental way, to a distributed solution. The use of a proof assistant gives a formal guarantee on the conformance of each refinement with the model preceding it. Our main result during 2019 is the development of a distributed pattern [26] handling the dynamicity of the topology of networks.

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

8.1.1. Logic4Business

The Max Planck Institute for Informatics (MPI-INF) and Logic 4 Business GmbH (L4B) have signed a cooperation contract. Its subject is the application of automated reasoning methods to product complexity management, in particular in the car industry. MPI-INF is providing software and know-how, L4B is providing real-world challenges.

9. Partnerships and Cooperations

9.1. Regional Initiatives

Antoine Defourné's PhD thesis and Yann Duplouy's post-doctoral research are co-funded by Région Grand Est.

[0] WWTF project APALACHE (ICT15-103): https://forsyte.at/research/apalache/

9.2. National Initiatives

9.2.1. PIA2 ISITE LUE

Project acronym: ISITE LUE - Digitrust

Project title: Lorraine Université d'Excellence, Citizen Trust in the Digital World

Duration: 2016 – 2020

Coordinator: Marine Minier

Participants: Margaux Durœulx, Stephan Merz

Abstract: Digitrust is one of the "impact" projects within the excellence funding acquired by University of Lorraine and supports research into different aspects related to the trustworthiness and security of digital systems. It funds the PhD thesis of Margaux Durœulx on the use of SAT techniques for assessing system reliability.

9.2.2. ANR International Project ProMiS

Project acronym: ProMiS.

Project title: Provable Mitigation of Side Channel through Parametric Verification

Duration: November 2019 – April 2022.

Coordinators: Étienne André and Jun Sun (Singapore Management University, Singapore).

Other partners: École Centrale Nantes, Singapore University of Technology and Design.

Participants: Étienne André.

Abstract: ProMiS is an international project, funded by ANR in France and by NRF in Singapore under the PRCI program.

The Spectre vulnerability has recently been reported, which affects most modern processors. The idea is that attackers can extract information about the private data using a timing attack. It is an example of side channel attacks, where secure information flows through side channels unintentionally. How to systematically mitigate such attacks is an important and yet challenging research problem.

We propose to automatically synthesize mitigation of side channel attacks (e.g., timing or cache) using well-developed verification techniques. The idea is to reduce this problem to the parameter synthesis problem of a given formalism (for instance, parametric timed automata). Given a program or system with design parameters which can be tuned to mitigate side channel attacks, our approach will automatically generate provably secure valuations of the parameters. We plan to deliver a toolkit which can be automatically applied to real-world systems.

9.2.3. ANR International Project SYMBIONT

Project acronym: SYMBIONT.

Project title: Symbolic Methods for Biological Networks.

Duration: July 2018 – June 2021.

Coordinators: Thomas Sturm and Andreas Weber (Univ. of Bonn, Germany).

Other partners: Univ. of Lille 1, Univ. of Montpellier, Inria Saclay Île de France (Lifeware), RWTH Aachen (Department of Mathematics and Joint Research Center for Computational Biomedecine), Univ. of Kassel.

Participants: Thomas Sturm, Hamid Rahkooy.

Abstract: SYMBIONT is an international interdisciplinary project, funded by ANR in France and by DFG in Germany under the PRCI program. It includes researchers from mathematics, computer science, systems biology, and systems medicine. Computational models in systems biology are built from molecular interaction networks and rate laws, involving parameters, resulting in large systems of differential equations. The statistical estimation of model parameters is computationally expensive and many parameters are not identifiable from experimental data. The project aims at developing novel symbolic methods, aiming at the formal deduction of principal qualitative properties of models, for complementing the currently prevailing numerical approaches. Concrete techniques include tropical geometry, real algebraic geometry, theories of singular perturbations, invariant manifolds, and symmetries of differential systems. The methods are implemented in software and validated against models from computational biology databases.

More information: https://www.symbiont-project.org/.

9.2.4. ANR Project Formedicis

Project acronym: Formedicis.

Project title: Formal methods for the development and the engineering of critical interactive systems.

Duration: January 2017 – December 2020.

Coordinator: Bruno d'Augsbourg (Onera).

Other partners: ENSEEIHT/IRIT Toulouse, ENAC, Université de Lorraine (Veridis).

Participants: Dominique Méry, Horatiu Cirstea.

Abstract: During the last 30 years, the aerospace domain has successfully devised rigorous methods and tools for the development of safe functionally-correct software. During this process, interactive software has received a relatively lower amount of attention. However, Human-System Interactions (HSI) are important for critical systems and especially in aeronautics: for example, the investigation into the crash of the Rio-Paris flight AF 447 in 2009 pointed out a design issue in the Flight Director interface as one of the original causes of the crash. Formedicis aims at designing a formal hub language, in which designers can express their requirements concerning the interactive behavior that must be embedded inside applications, and at developing a framework for validating, verifying, and implementing critical interactive applications expressed in that language.

More information: http://www.agence-nationale-recherche.fr/Project-ANR-16-CE25-0007.

9.2.5. ANR Project DISCONT

Project acronym: DISCONT.

Project title: Correct integration of discrete and continuous models.

Duration: March 2018 – February 2022.

Coordinator: Paul Gibson (Telecom Sud Paris), until February 2019; Dominique Méry, since March 2019.

Other partners: ENSEEIHT/IRIT Toulouse, LACL, ClearSy, Université de Lorraine (Veridis).

Participants: Dominique Méry, Zheng Cheng.

Abstract: Cyber-Physical Systems (CPSs) connect the real world to software systems through a network of sensors and actuators that interact in complex ways, depending on context and involving different spatial and temporal scales. Typically, a discrete software controller interacts with its physical environment in a closed-loop schema where input from sensors is processed and output is generated and communicated to actuators. We are concerned with the verification of the correctness of such discrete controllers, which requires correct integration of discrete and continuous models. Correctness should arise from a design process based on sound abstractions and models of the relevant physical laws. The systems are generally characterized by differential equations with solutions in continuous domains; discretization steps are therefore of particular importance for assessing the correctness of CPSs. DISCONT aims at bridging the gap between the discrete and continuous worlds of formal methods and control theory. We will lift the level of abstraction above that found in current bridging techniques and provide associated methodologies and tools. Our concrete objectives are to develop a formal hybrid model, elaborate refinement steps for control requirements, propose a rational step-wise design method and support tools, and validate them based on use cases from a range of application domains.

More information: https://fusionforge.int-evry.fr/www/discont/.

9.2.6. ANR Project PARDI

Project acronym: PARDI.

Project title: Verification of parameterized distributed systems.

Duration: January 2017 – December 2021.

Coordinator: Philippe Quéinnec (ENSEEIHT/IRIT Toulouse).

Other partners: Université Paris Sud/LRI, Université Nanterre/LIP6, Inria Nancy – Grand Est (Veridis).

Participants: Igor Konnov, Stephan Merz.

Abstract: Distributed systems and algorithms are parameterized by the number of participating processes, the communication model, the fault model, and more generally the properties of interaction among the processes. The project aims at providing methodological and tool support for verifying parameterized systems, using combinations of model checking and theorem proving. VeriDis contributes its expertise on TLA$^+$ and its verification tools, and the integration with the Cubicle model checker is a specific goal of the project.

More information: http://pardi.enseeiht.fr/.

9.2.7. Inria IPL HAC SPECIS

Project acronym: HAC SPECIS.

Project title: High-performance application and computers: studying performance and correctness in simulation.

Duration: June 2016 – June 2020.

Coordinator: Arnaud Legrand (CNRS & Inria Grenoble Rhône Alpes, Polaris).

Other partners: Inria Grenoble Rhône Alpes (Avalon), Inria Rennes Bretagne Atlantique (Myriads), Inria Bordeaux Sud Ouest (Hiepacs, Storm), Inria Saclay Île de France (Mexico), Inria Nancy Grand Est (Veridis).

Participants: Marie Duflot-Kremer, Stephan Merz.

Abstract: The goal of HAC SPECIS is to allow the study of real HPC systems with respect to both correctness and performance. To this end, this Inria Project Lab assembles experts from the HPC, formal verification, and performance evaluation communities. VeriDis contributes its expertise in formal verification techniques. In particular, our goal is to extend the functionalities of exhaustive and statistical model checking within the SimGrid platform. Yann Duplouy joined the project in December 2018 as a post-doctoral researcher with the objective of designing and implementing a statistical model checker for SimGrid.

More information: http://hacspecis.gforge.inria.fr.

9.2.8. DFG Transregional Research Center 248 CPEC

Project acronym: CPEC.

Project title: Foundations of Perspicuous Software Systems.

Duration: January 2019 – December 2022.

Coordinators: Holger Hermanns (Saarland University, Germany) and Raimund Dachselt (University of Dresden, Germany).

Other partners: Max Planck Institute for Software Systems, Saarbrücken.

Participants: Alberto Fiori, Sophie Tourret, Christoph Weidenbach.

Abstract: With cyber-physical technology increasingly impacting our lives, it is very important to ensure that humans can understand them. Systems lack support for making their behaviour plausible to their users. And even for technology experts it is nowadays virtually impossible to provide scientifically well-founded answers to questions about the exact reasons that lead to a particular decision, or about the responsibility for a malfunctioning. The root cause of the problem is that contemporary systems do not have any built-in concepts to explicate their behaviour. They calculate and propagate outcomes of computations, but are not designed to provide explanations. They are not perspicuous. The key to enable comprehension in a cyber-physical world is a science of perspicuous computing.

More information: https://www.perspicuous-computing.science/.

9.3. European Initiatives

9.3.1. FP7 & H2020 Projects

9.3.1.1. ERC Matryoshka

Program: ERC.

Project acronym: Matryoshka.

Duration: April 2017 – March 2022.

Coordinator: Jasmin Blanchette (VU Amsterdam).

Participants: Antoine Defourné, Daniel El Oraoui, Mathias Fleury, Pascal Fontaine, Stephan Merz, Hans-Jörg Schurr, Sophie Tourret, Uwe Waldmann.

Abstract: Proof assistants are increasingly used to verify hardware and software and to formalize mathematics. However, despite some success stories, they remain very laborious to use. The situation has improved with the integration of first-order automatic theorem provers – superposition provers and SMT (satisfiability modulo theories) solvers – but only so much can be done when viewing automatic provers as black boxes. The purpose of Matryoshka is to deliver much higher levels of automation to users of proof assistants by fusing and extending two lines of research: automatic and interactive theorem proving. Our approach is to enrich superposition and SMT with higher-order (HO) reasoning in a careful manner, in order to preserve their desirable properties. With higher-order superposition and higher-order SMT in place, we will develop highly automatic provers building on modern superposition provers and SMT solvers, following a novel stratified architecture, and integrate them in proof assistants. Users stand to experience substantial productivity gains: From 2010 to 2016, the success rate of automatic provers on interactive proof obligations from a representative benchmark suite called Judgment Day has risen from 47% to 77%; with this project, we aim at 90%–95% proof automation.

More information: http://matryoshka.gforge.inria.fr/.

9.3.2. Collaborations in European Programs, Except FP7 & H2020

Program: Erasmus+.

Project acronym: PIAF.

Project title: Pensée Informatique et Algorithmique au Fondamental / Computational and Algorithmic Thinking in Primary Education.

Coordinator: Université de Liège.

Other partners: Université du Luxembourg, Saarland University, ESPE Nancy.

Participant: Marie Duflot-Kremer.

Abstract: The goal of the PIAF project is threefold: creating a repository of skills related to computational and algorithmic thinking, designing activities aiming at the acquisition of these skills, and evaluating the impact of these activities on primary school children and their computational thinking capacities.

Program: ERASMUS+.

Project acronym: ARC.

Project title: Automated reasoning in the class.

Coordinator: West University of Timisoara (Romania).

Other partners: Johaness Kepler University Linz (Austria), RWTH Aachen University (Germany), Eszterhazy Karoly University (Hungary), Université de Lorraine.

Participant: Sorin Stratulat.

Abstract: The main objective of the project is to improve the education of computer science students in fields related to computational logic, by creating innovative and advanced learning material that uses automated reasoning and by training a large number of academic staff in using this in a modern way. Thus indirectly the project objectives include the effects of increased software reliability: virus elimination, online safety, better detection of negative online phenomena (fake news, cyberbullying, etc.), and other.

9.4. International Research Visitors

9.4.1. Visits of International Scientists

Maria Paola Bonacina.

Date: 11 February 2019 – 16 February 2019.

Institution: Università degli Studi di Verona, Italy.

Host: Pascal Fontaine.

Maria Paola Bonacina is a professor at the Università degli Studi di Verona, Italy. She is well known in the community for her numerous works in the field of automated reasoning, notably in SMT, combination of theories, and procedures for first-order logic. During her one-week stay in Nancy, we particularly discussed SGGS (semantically-guided goal-sensitive theorem proving) as a means of inspiration for instantiation in SMT. We also worked on a review paper on combination of theories, published in 2019 [49].

Armin Biere.

Date: 27 May 2019 – 29 May 2019.

Institution: Johannes Keppler Universität, Linz, Austria.

Host: Christoph Weidenbach.

Armin Biere is professor at the University of Linz. He is a leading researcher in the SAT community. During his stay we discussed recent developments in SAT solving. In particular, resolution based inference and reduction mechanisms beyond subsumption resolution.

9.4.1.1. Internships

Manon Blanc

Date: 1 June 2019 – 31 July 2019

Institution: ENS Cachan

Host: Pascal Fontaine

In her bachelor thesis, Manon Blanc studied and experimentally evaluated two different subtropical methods for handling polynomial constraints within SMT.

Mehran Aghabozorgi

Date: 5 August 2019 – 7 October 2019

Institution: Isfahan University of Technology, Iran

Host: Christoph Weidenbach

Mehran worked on algorithms enhancing SAT pre- and inprocessing. He implemented blocked clause elimination as well as a variable elimination algorithm aiming at smaller clause sets.

9.4.2. Visits to International Teams

9.4.2.1. Research Stays Abroad

Thomas Sturm visited the University of Bonn (Institute of Computer Science II) for 4 weeks during 2019, and the University of Kassel (Mathematical Institute). Topics included perspectives for SMT Solving in symbolic reaction network analysis, toricity of steady state varieties, scaling methods for systems of ordinary differential equations (ODE), and logic approaches for the classification of real singularities of ODE.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Organization of Scientific Events

10.1.1.1. Membership in Organizing Committees

Jasmin Blanchette co-organized the *2nd Deduction Mentoring Workshop* (DeMent 2019). He also coorganized the *VeriDis Group Retreat + Second European Workshop on Higher-Order Automated Reasoning* (Matryoshka 2019).

Pascal Fontaine co-organized the Third Workshop on Mathematical Logic and its Applications, in Nancy.

Igor Konnov and Stephan Merz were organizers of the sixth *Workshop on Formal Reasoning in Distributed Algorithms* (FRIDA 2019), colocated with DISC 2019 in Budapest, Hungary.

The International Summer School on Verification Techniques, Systems, and Applications (VTSA) has been organized since 2008 in the Greater Region (Nancy, Saarbrücken, Luxembourg, Liège, and Koblenz), and Stephan Merz and Christoph Weidenbach are co-organizers of VTSA. In 2019, VTSA took place in August in Esch sur Alzette, Luxembourg.

10.1.2. Program Committees

10.1.2.1. Chair of Conference Program Committees

Jasmin Blanchette co-chaired the program committee of the *9th ACM SIGPLAN International Conference on Certified Programs and Proofs* (CPP 2020).

Pascal Fontaine served as the chair of the *Conference on Automated Deduction* (CADE-27).

Dominique Méry co-chaired the program committee of the *13th International Symposium on Theoretical Aspects of Software Engineering* (TASE 2019).

Stephan Merz was Tool Exhibition Chair at the *3rd World Congress for Formal Methods* (FM Week 2019).

10.1.2.2. Membership in Conference Program Committees

Jasmin Blanchette served on the program committees of the *27th International Conference on Automated Deduction* (CADE-27), *19th Conference on Formal Methods in Computer-Aided Design* (FM-CAD 2019), *21st International Symposium on Principles and Practice of Declarative Programming* (PPDP 2019), *12th International Symposium on Frontiers of Combining Systems* (FroCoS 2019), *26th International Conference on Tools and Algorithms for the Construction and Analysis of Systems* (TACAS 2020), and *4th Conference on Artificial Intelligence and Theorem Proving* (AITP 2019). He also served on the following workshop committees: *Second Workshop on Automated Reasoning: Challenges, Applications, Directions, Exemplary Achievements* (ARCADE 2019) and *Deduktionstreffen 2019*.

Pascal Fontaine served on the program committees of the *International Symposium on Frontiers of Combining Systems* (FroCoS 2019), the *International Conference on Automated Reasoning with Analytic Tableaux and Related Methods* (TABLEAUX 2019), and the *International Conference on Theory and Applications of Satisfiability Testing* (SAT 2019). He also served on the committee of *Automated Reasoning: Challenges, Applications, Directions, Exemplary Achievements* (ARCADE 2019).

Dominique Méry served on the program committees of the *16th International Colloquium on Theoretical Aspects of Computing* (ICTAC 2019), the *8th Workshop on Formal Methods for Interactive Systems* (FMIS 2019), the *Workshop on Practical Formal Verification for Software Dependability* (AFFORD'19), the *24th International Conference on Engineering of Complex Computer Systems* (ICECCS 2019), the *Workshop on Formal Methods for Autonomous Systems* (FMAS 2019), the *23rd International Symposium on Formal Methods* (FM 2019), the *Workshop on Models and Data Engineering for Cyber-Physical Systems* (CPS@MEDI 2019), the *Workshop on Formal Models for Mastering Heterogeneous Multifaceted Systems* (REMEDY 2019), the *3rd Workshop on Formal Approaches for Advanced Computing Systems* (FAACS 2019), the *21st International Conference on Formal Engineering Methods* (ICFEM 2019), and the *9th International Conference on Model and Data Engineering* (MEDI 2019).

Stephan Merz served on the program committees of the *19th International Workshop on Automated Verification of Critical Systems* (AVoCS 2019), the *Doctoral Symposium, Formal Methods* (DS-FM 2019), the *5th International Workshop on Formal Integrated Development Environment* (F-IDE 2019), and the *21st International Conference on Formal Engineering Methods* (ICFEM 2019).

Sorin Stratulat served on the program committees of the *International Symposium on Symbolic and Numeric Algorithms for Scientific Computing* (SYNASC 2019), the *International Conference on Information Assurance and Security* (IAS 2019), and the *International Conference on Computational Intelligence in Security for Information Systems* (CISIS 2019).

Thomas Sturm served on the program committees of the *21st International Workshop on Computer Algebra in Scientific Computing* (CASC 2019) and the *4th International Workshop on Satisfiability Checking and Symbolic Computation* (SC-SQUARE 2019).

Uwe Waldmann served on the program committees of the *27th International Conference on Automated Deduction* (CADE-27) and the *International Conference on Automated Reasoning with Analytic Tableaux and Related Methods* (TABLEAUX 2019).

Christoph Weidenbach served on the program committees of the *International Conference on Automated Deduction* (CADE 27), and the *International Symposium on Frontiers of Combining Systems* (FroCoS 2019). He also served on the committee of *Automated Reasoning: Challenges, Applications, Directions, Exemplary Achievements* (ARCADE 2019).

10.1.3. Journals

10.1.3.1. Member of Editorial Boards

Jasmin Blanchette and Stephan Merz served as guest editors for the special issue on *Interactive Theorem Proving* (ITP 2016) of the *Journal of Automated Reasoning* [16].

Dominique Méry is the Book Reviews Editor for *Formal Aspects of Computing*.

Thomas Sturm has been an editor of the *Journal of Symbolic Computation* (Elsevier) since 2003 and an editor of *Mathematics in Computer Science* (Springer) since 2013. He edited a special issue of the Journal of Symbolic Computation on *Symbolic Computation and Satisfiability Checking*.

Christoph Weidenbach is a member of the editorial board of the *Journal of Automated Reasoning* (JAR) (Springer). He also served as an editor on the special issue on *Automated Reasoning Systems* of JAR.

10.1.4. Invited Talks

Jasmin Blanchette gave a keynote talk at the *8th ACM SIGPLAN International Conference on Certified Programs and Proofs* (CPP 2019).

Dominique Méry was an invited speaker at the *16th International Colloquium on Theoretical Aspects of Computing* (ICTAC 2019).

Stephan Merz was invited to the meeting of IFIP Working Group 2.3 in October 2019 in Los Altos, California. He was an invited speaker at the meeting of the AFSEC group of GDR GPL in December 2019 in Toulouse.

Sorin Stratulat was an invited speaker at FROM 2019 (Working Formal Methods Symposium) in Timisoara, Romania, where he presented an efficient way to validate cyclic pre-proofs for first-order logic with inductive definitions.

Christoph Weidenbach was invited to give a lecture at the SAT/SMT/AR summer school 2019 in Lisbon, Portugal. He was invited to present at the computer science lecture series at the University of Bonn, Germany.

10.1.5. Leadership within the Scientific Community

Jasmin Blanchette served as a regular member of the CADE (*Conference on Automated Deduction*) Inc. Board of Trustees. He is also a regular member of the steering committees for the ITP (*Interactive Theorem Proving*) and TAP (*Tests and Proofs*) conference series.

Pascal Fontaine is an SMT-LIB manager, together with Clark Barrett (Stanford University) and Cesare Tinelli (University of Iowa). He was a regular member of the steering committee for the FroCoS (*Frontiers of Combining Systems*) conference series until September 2019, and he is a member of the steering committee for the SC-Square (*Satisfiability Checking and Symbolic Computation* workshop series. He was ex-officio member of the CADE (*Conference on Automated Deduction*) Inc. Board of Trustees until July 2019. He is an elected member of the steering committee for the SMT (*Satisfiability Modulo Theories*) workshop series.

Stephan Merz is a member of the IFIP Working Group 2.2 on *Formal Description of Programming Concepts* and a member of the steering committee of the workshop on Automated Verification of Critical Systems (AVoCS).

Thomas Sturm has been elected the chair of the steering committee of the ACM conference series *International Symposium on Symbolic and Algebraic Computation (ISSAC)*.

Christoph Weidenbach is the president of CADE and a member of the steering committee of IJCAR.

10.1.6. Scientific Expertise

Dominique Méry was a member of the committee for the thesis award of GDR GPL (*Génie de la Programmation et du Logiciel*) 2019.

Stephan Merz contributed an assessment of candidates for a professorship at TU Vienna, Austria.

Thomas Sturm served as an external expert on the appointment committee for a professorship in Computer Algebra at the University of Kassel, Germany. He is taking an advisory role as a "project partner" in the UK EPSRC Project EP/R019622/1 *Embedding Machine Learning within Quantifier Elimination Procedures*.

Christoph Weidenbach is a member of the selection committee of the Saarbrücken Graduate School in Computer Science.

10.1.7. Research Administration

Dominique Méry participated in the evaluation committees of HCERES for the LIASD (*Laboratoire d'informatique avancée de Saint-Denis*) and the doctoral school of École Polytechnique.

Stephan Merz is the delegate for scientific affairs at the Inria Nancy – Grand Est research center and a member of Inria's Evaluation Committee. In 2019, he was a member of the hiring committees of senior researchers at Inria and of junior researchers at Inria Rennes Bretagne Atlantique. He is also a member of the *bureau* of the computer science committee of the doctoral school IAEM Lorraine and of the executive committee of the project on citizens' trust in the digital world (DigiTrust) funded by *Lorraine Université d'Excellence*.

Uwe Waldmann is a member of the admissions committee for scholarships of the International Max Planck Research School for students aiming at a master's degree.

Christoph Weidenbach coordinates the scientific affairs at MPI-INF.

10.2. Teaching, Supervision, Thesis Committees

10.2.1. Teaching

Licence : Marie Duflot-Kremer, Algorithmique et Programmation 1, 60 HETD, L1, Université de Lorraine, France

Licence : Marie Duflot-Kremer, Algorithmique et Programmation 2, 10 HETD, L1, Université de Lorraine, France

Diplôme inter universitaire : Marie Duflot-Kremer, formation d'enseignants du secondaire à la spécialité NSI, 43 HETD, Université de Lorraine, France

Licence : Marie Duflot-Kremer, Introduction au Web, 20 HETD, L1, Université de Lorraine, France

Licence : Marie Duflot-Kremer, Accompagnement Algorithmique 1, 26 HETD, L1, Université de Lorraine, France

Licence : Marie Duflot-Kremer, Programmation Web, 5 HETD, L3, Université de Lorraine, France

Master: Marie Duflot-Kremer and Stephan Merz, Elements of model checking, 40 HETD, M2 Informatique and Master Erasmus Mundus DESEM, Université de Lorraine, France.

Master: Marie Duflot-Kremer and Stephan Merz, Algorithmes distribués, 24 HETD M1 informatique, Université de Lorraine, France.

Master: Pascal Fontaine, Réseaux, 50 HETD, M1 MIAGE, Université de Lorraine, France.

Master: Pascal Fontaine is the head of the MIAGE degree at Université de Lorraine.

Licence : Sorin Stratulat, Algorithmique des structures de contrôle, 45 HETD, L1 Informatique, ISFATES, Université de Lorraine, France.

Licence : Sorin Stratulat, Algorithmique des structures de données, 45 HETD, L1 Informatique, ISFATES, Université de Lorraine, France.

Master: Sorin Stratulat, Analyse et conception de logiciels, 105.5 HETD, M1 Informatique, Université de Lorraine, France.

Master: Sorin Stratulat, Génie Logiciel, 20 HETD, M2 Informatique, Université de Lorraine, France.

Master: Sophie Tourret, Concrete Semantics with Isabelle/HOL, 6 ECTS, Saarland University, Germany.

Master: Uwe Waldmann, Automated Reasoning, 9 ECTS, Saarland University, Germany.

Master: Christoph Weidenbach, Decision Procedures, 6 ECTS, Saarland University, Germany.

10.2.2. Supervision

PhD: Martin Bromberger, Decision Procedures for Linear Arithmetic. Saarland University, 10 December 2019. Supervised by Thomas Sturm and Christoph Weidenbach.

PhD: Nicolas Schnepf, Orchestration et vérification de fonctions de sécurité pour des environnements intelligents. Université de Lorraine, 30 September 2019. Supervised by Rémi Badonnel, Abdelkader Lahmadi, and Stephan Merz.

PhD: Marco Voigt, Decidable Fragments of First-Order Logic and of First-Order Linear Arithmetic with Uninterpreted Predicates. Saarland University, 31 July 2019. Supervised by Thomas Sturm and Christoph Weidenbach.

PhD in progress: Antoine Defourné, SMT for TLAPS, Université de Lorraine. Supervised by Jasmin Blanchette, Pascal Fontaine, and Stephan Merz, since March 2019.

PhD in progress: Margaux Duroeulx, SAT Techniques for Reliability Assessment, Université de Lorraine. Supervised by Nicolae Brînzei, Marie Duflot-Kremer, and Stephan Merz, since October 2016.

PhD in progress: Alberto Fiori, Clause Learning from Simple Models, Saarland University. Supervised by Christoph Weidenbach, since August 2018.

PhD in progress: Mathias Fleury, Formalization of Logical Calculi, Saarland University. Supervised by Christoph Weidenbach and Jasmin Blanchette, since September 2015.

PhD in progress: Alexis Grall, Integration of a modeling language and a language for programming distributed systems, Université de Lorraine. Supervised by Horatiu Cirstea and Dominique Méry, since October 2018.

PhD in progress: Daniel El Ouraoui, Higher-Order SMT, Université de Lorraine. Supervised by Jasmin Blanchette, Pascal Fontaine, and Stephan Merz, since November 2017.

PhD in progress: Pierre Lermusiaux, Analysis of properties of interactive critical systems, Université de Lorraine. Supervised by Horatiu Cirstea and Pierre-Etienne Moreau, since October 2017.

PhD in progress: Hans-Jörg Schurr, Higher-Order SMT, Université de Lorraine. Supervised by Jasmin Blanchette, Pascal Fontaine, and Stephan Merz, since November 2017.

10.2.3. Thesis Committees

Pascal Fontaine served as a reviewer in the thesis committees for Martin Bromberger (Universität des Saarlandes, Germany), Albin Coquereau (Université Paris-Saclay, France), Hakan Metin (Sorbonne Université, France), Simon Robillard (Chalmers University of Technology, Sweden) and Stefano Varotti (University of Trento, Italy).

Stephan Merz served as an examiner in the PhD committee of The Anh Pham (ENS Rennes) and as the president in the PhD committee of Renaud Vilmart (Univ. of Lorraine). He was a member of the PhD committee of Nicolas Schnepf as the thesis advisor.

Thomas Sturm served as a reviewer in the thesis committees for Martin Bromberger and Marco Voigt (Saarland University, Germany).

Christoph Weidenbach served as a reviewer in the thesis committees for Martin Bromberger and Marco Voigt (Saarland University, Germany).

10.3. Popularization

10.3.1. Responsibilities at Inria or Beyond

- Marie Duflot-Kremer is the deputy vice-president for outreach activities in the supervisory council of SIF (*Société Informatique de France*) and a member of the scientific committee of *Fondation Blaise Pascal*.

- Christoph Weidenbach is a member of the advisory committee for the German computer science competitions for pupils. Together with his colleagues at Saarland university he organizes the “Computer Science Research Days” for the most talented high-school students out of the competition every year. In addition, he organizes the final training for the German Informatics Olympiad team and coaches the Saarland University student teams for the ICPC.

10.3.2. Articles and Contents

Marie Duflot-Kremer is a member of the ERASMUS+ project PIAF (cf. section 9.3) with collleagues from Liège, Luxembourg and Saarbrücken. This projects aims at studying how computational thinking can be introduced in primary education (with kids rangng from 5 to 12 years old). The goal is first to agree on a shared reference document on computational thinking competences, and then to produce and test educational scenarios and didactical resources. So far this year the reference document has been designed (and a paper has been submitted recently to a conference). The work on the scenarios and the resources is ongoing.

10.3.3. Education

Marie Duflot-Kremer intervenes in the training of teachers:

- for primary school, half a day for training teachers on how to add a bit of computer science in their teaching;
- for secondary school, she took part (43 hours in 2019) in the advanced training of high school teachers who deliver a newly introduced computer science course (Numérique et Sciences Informatiques), and one day training for math teachers about unplugged activities;
- half a day of training for members of INSPE (Institut National Supérieur du Professorat et de l’Education), the people in charge of training teachers.

10.3.4. Interventions

Marie Duflot-Kremer takes part every year in several events, including local ones such as *Fête de la Science* (for which she trains 3rd year students to handle the workshops and gave this year a talk/show on “informagics”), Pint of Science, a talk for the local phase of the *Tournoi Français des Jeunes Mathématiciennes et Mathématiciens* and the local NSI (*Numérique et Sciences Informatiques*) day for secondary school teachers.

She is also invited for workshops and talks in events outside of the Nancy region, like national or regional days of APMEP (*Association des Professeurs de Mathématiques de l’Enseignement Public*) in Dijon and Grenoble, the SETT conference in Namur or the video game creation competition for kids in Manosque.

10.3.5. Creation of Media or Tools for Science Outreach

As a member of the national group *Informatique Sans Ordinateur* (ISO), Marie Duflot-Kremer takes part in creating new popularization activities and publishing online documentation to help people reproduce unplugged computer science activities. She also proposed and supervised a project of master students in cognitive sciences who created an escape game presenting various computer science concepts to kids from 13 years old. The documentation is available on her webpage. [0]

11. Bibliography

Major publications by the team in recent years

[1] T. Bouton, D. C. B. de Oliveira, D. Déharbe, P. Fontaine.*veriT: an open, trustable and efficient SMT-solver*, in "Proc. Conference on Automated Deduction (CADE)", Montreal, Canada, R. Schmidt (editor), Lecture Notes in Computer Science, Springer, 2009, vol. 5663, p. 151-156

[0] https://members.loria.fr/MDuflot/.

[2] D. CANSELL, D. MÉRY.*The Event-B Modelling Method: Concepts and Case Studies*, in "Logics of Specification Languages", Berlin-Heidelberg, D. BJØRNER, M. C. HENSON (editors), Monographs in Theoretical Computer Science, Springer, 2008, p. 47-152

[3] D. COUSINEAU, D. DOLIGEZ, L. LAMPORT, S. MERZ, D. RICKETTS, H. VANZETTO.*TLA+ Proofs*, in "18th International Symposium On Formal Methods - FM 2012", Paris, France, D. GIANNAKOPOULOU, D. MÉRY (editors), Lecture Notes in Computer Science, Springer, 2012, vol. 7436, p. 147-154

[4] A. DOLZMANN, T. STURM.*Redlog: Computer algebra meets computer logic*, in "ACM SIGSAM Bull.", 1997, vol. 31, n^{o} 2, p. 2-9

[5] D. DÉHARBE, P. FONTAINE, S. MERZ, B. WOLTZENLOGEL PALEO.*Exploiting Symmetry in SMT Problems*, in "23rd Intl. Conf. Automated Deduction (CADE 2011)", Wroclaw, Poland, N. BJØRNER, V. SOFRONIE-STOKKERMANS (editors), LNCS, Springer, 2011, vol. 6803, p. 222-236

[6] A. FIETZKE, C. WEIDENBACH.*Superposition as a Decision Procedure for Timed Automata*, in "Mathematics in Computer Science", 2012, vol. 6, n^{o} 4, p. 409-425

[7] E. KRUGLOV, C. WEIDENBACH.*Superposition Decides the First-Order Logic Fragment Over Ground Theories*, in "Mathematics in Computer Science", 2012, vol. 6, n^{o} 4, p. 427-456

[8] F. KRÖGER, S. MERZ.*Temporal Logic and State Systems*, Texts in Theoretical Computer Science, Springer, 2008, 436, http://hal.inria.fr/inria-00274806/en/

[9] S. MERZ.*The Specification Language TLA^{+}*, in "Logics of Specification Languages", Berlin-Heidelberg, D. BJØRNER, M. C. HENSON (editors), Monographs in Theoretical Computer Science, Springer, 2008, p. 401-451

[10] C. WEIDENBACH, D. DIMOVA, A. FIETZKE, M. SUDA, P. WISCHNEWSKI.*SPASS Version 3.5*, in "22nd International Conference on Automated Deduction (CADE-22)", Montreal, Canada, R. SCHMIDT (editor), LNAI, Springer, 2009, vol. 5663, p. 140-145

Publications of the year

Doctoral Dissertations and Habilitation Theses

[11] M. BROMBERGER.*Decision Procedures for Linear Arithmetic*, Saarland University, December 2019, https://hal.inria.fr/tel-02427371

[12] N. SCHNEPF.*Orchestration and verification of security functions for smart devices*, Université de Lorraine, September 2019, https://hal.univ-lorraine.fr/tel-02351769

[13] M. VOIGT.*Decidable Fragments of First-Order Logic and of First-Order Linear Arithmetic with Uninterpreted Predicates*, Universität des Saarlandes, July 2019, https://hal.inria.fr/tel-02406821

Articles in International Peer-Reviewed Journal

[14] A. Bentkamp, J. C. Blanchette, D. Klakow. *A Formal Proof of the Expressiveness of Deep Learning*, in "Journal of Automated Reasoning", August 2019, vol. 63, n^{o} 2, p. 347-368 [*DOI :* 10.1007/s10817-018-9481-5], https://hal.inria.fr/hal-02296014

[15] J. C. Blanchette, L. Gheri, A. Popescu, D. Traytel. *Bindings as Bounded Natural Functors*, in "Proceedings of the ACM on Programming Languages", January 2019, vol. 3, n^{o} POPL, p. 1-34 [*DOI :* 10.1145/3290335], https://hal.archives-ouvertes.fr/hal-01989726

[16] J. C. Blanchette, S. Merz. *Selected Extended Papers of ITP 2016: Preface*, in "Journal of Automated Reasoning", February 2019, vol. 62, n^{o} 2, p. 169-170 [*DOI :* 10.1007/s10817-018-9470-8], https://hal.inria.fr/hal-02395177

[17] R. Bradford, J. H. Davenport, M. England, H. Errami, V. Gerdt, D. Grigoriev, C. Hoyt, M. Košta, O. Radulescu, T. Sturm, A. Weber. *Identifying the parametric occurrence of multiple steady states for some biological networks*, in "Journal of Symbolic Computation", May 2020, vol. 98, p. 84-119 [*DOI :* 10.1016/j.jsc.2019.07.008], https://hal.inria.fr/hal-02397154

[18] M. Bromberger, T. Sturm, C. Weidenbach. *A complete and terminating approach to linear integer solving*, in "Journal of Symbolic Computation", July 2019, forthcoming [*DOI :* 10.1016/j.jsc.2019.07.021], https://hal.inria.fr/hal-02397168

[19] P. Chocron, P. Fontaine, C. Ringeissen. *Politeness and Combination Methods for Theories with Bridging Functions*, in "Journal of Automated Reasoning", 2019, forthcoming [*DOI :* 10.1007/s10817-019-09512-4], https://hal.inria.fr/hal-01988452

[20] I. Dramnesc, T. Jebelean, S. Stratulat. *Mechanical Synthesis of Sorting Algorithms for Binary Trees by Logic and Combinatorial Techniques*, in "Journal of Symbolic Computation", 2019, vol. 90, p. 3-41 [*DOI :* 10.1016/j.jsc.2018.04.002], https://hal.archives-ouvertes.fr/hal-01590654

[21] I. Konnov. *Handbook of Model Checking by Edmund M. Clarke, Thomas A. Henzinger, Helmut Veith, and Roderick Bloem (eds), published by Springer International Publishing AG, Cham, Switzerland, 2018*, in "Formal Aspects of Computing", 2019, p. 455-456 [*DOI :* 10.1007/s00165-019-00486-z], https://hal.inria.fr/hal-02398334

[22] I. Konnov, J. Kukovec, T.-H. Tran. *TLA+ Model Checking Made Symbolic*, in "Proceedings of the ACM on Programming Languages", 2019, vol. 3, n^{o} OOPSLA, p. 123:1–123:30 [*DOI :* 10.1145/3360549], https://hal.archives-ouvertes.fr/hal-02280888

[23] M. Romero, M. Duflot, T. Viéville. *The robot game : analysis of a computational thinking unplugged activity under the perspective of embodied cognition*, in "Review of science, mathematics and ICT education", June 2019, vol. 13, n^{o} 1 [*DOI :* 10.26220/rev.3089], https://hal.inria.fr/hal-02144467

[24] N. Schnepf, R. Badonnel, A. Lahmadi, S. Merz. *Rule-Based Synthesis of Chains of Security Functions for Software-Defined Networks*, in "Electronic Communications of the EASST", 2019, vol. 076, https://hal.inria.fr/hal-02397981

Articles in Non Peer-Reviewed Journal

[25] J. H. DAVENPORT, M. ENGLAND, A. GRIGGIO, T. STURM, C. TINELLI.*Symbolic computation and satisfiability checking*, in "Journal of Symbolic Computation", July 2019, Invited Editorial, forthcoming [*DOI :* 10.1016/J.JSC.2019.07.017], https://hal.inria.fr/hal-02397190

Invited Conferences

[26] D. MÉRY.*Verification by Construction of Distributed Algorithms*, in "Theoretical Aspects of Computing - ICTAC 2019 - 16th International Colloquium", Mammamet, Tunisia, R. M. HIERONS, M. MOSBAH (editors), Theoretical Aspects of Computing - ICTAC 2019 - 16th International Colloquium, Hammamet, Tunisia, October 31 - November 4, 2019, Proceedings, Springer, October 2019, n^{o} 11884, p. 22-38 [*DOI :* 10.1007/978-3-030-32505-3_2], https://hal.inria.fr/hal-02400379

International Conferences with Proceedings

[27] H. BARBOSA, A. REYNOLDS, D. EL OURAOUI, C. TINELLI, C. BARRETT.*Extending SMT Solvers to Higher-Order Logic*, in "CADE-27", Natal, Brazil, Lecture Notes in Computer Science, Springer, August 2019, vol. 11716, p. 35-54 [*DOI :* 10.1007/978-3-030-29436-6_3], https://hal.archives-ouvertes.fr/hal-02300986

[28] A. BENTKAMP, J. C. BLANCHETTE, S. TOURRET, P. VUKMIROVIĆ, U. WALDMANN.*Superposition with Lambdas*, in "CADE-27", Natal, Brazil, August 2019, p. 55-73 [*DOI :* 10.1007/978-3-030-29436-6_4], https://hal.inria.fr/hal-02296038

[29] N. BERTRAND, I. KONNOV, M. LAZIC, J. WIDDER.*Verification of Randomized Consensus Algorithms under Round-Rigid Adversaries*, in "CONCUR 2019 - 30th International Conference on Concurrency Theory", Amsterdam, Netherlands, August 2019, p. 1-16 [*DOI :* 10.4230/LIPICS.CONCUR.2019.33], https://hal.inria.fr/hal-02191348

[30] J. C. BLANCHETTE.*Formalizing the Metatheory of Logical Calculi and Automatic Provers in Isabelle/HOL (Invited Talk)*, in "CPP 2019 - The 8th ACM SIGPLAN International Conference on Certified Programs and Proofs", Cascais, Portugal, CPP 2019 - The 8th ACM SIGPLAN International Conference on Certified Programs and Proofs, 2019 [*DOI :* 10.1145/3293880.3294087], https://hal.archives-ouvertes.fr/hal-01937136

[31] *Best Paper*
M. BROMBERGER, M. FLEURY, S. SCHWARZ, C. WEIDENBACH.*SPASS-SATT: A CDCL(LA) Solver*, in "27th International Conference on Automated Deduction (CADE-27)", Natal, Brazil, P. FONTAINE (editor), Lecture Notes in Computer Science, 2019, vol. 11716, p. 111-122 [*DOI :* 10.1007/978-3-030-29436-6_7], https://hal.inria.fr/hal-02405524.

[32] G. BUSANA, B. DENIS, M. DUFLOT, S. HIGUET, L. KATAJA, Y. KREIS, C. LADURON, C. MEYERS, Y. PARMENTIER, R. REUTER, A. WEINBERGER.*PIAF : développer la Pensée Informatique et Algorithmique dans l'enseignement Fondamental*, in "Didapro 8 - DIDASTIC - L'informatique, objets d'enseignements – enjeux épistémologiques, didactiques et de formation", Lille, France, Actes du 8e colloque international francophone sur la didactique de l'informatique (Didapro 8 - DIDASTIC), 2020, Session poster, https://hal.archives-ouvertes.fr/hal-02424418

[33] R. CHEN, C. COHEN, J.-J. LEVY, S. MERZ, L. THÉRY.*Formal Proofs of Tarjan's Strongly Connected Components Algorithm in Why3, Coq and Isabelle*, in "ITP 2019 - 10th International Conference on Interactive Theorem Proving", Portland, United States, J. HARRISON, J. O'LEARY, A. TOL-

MACH (editors), Schloss Dagstuhl–Leibniz-Zentrum für Informatik, 2019, vol. 141, p. 13:1 - 13:19 [*DOI :* 10.4230/LIPIcs.ITP.2019.13], https://hal.inria.fr/hal-02303987

[34] M. DUROEULX, N. BRINZEI, M. DUFLOT, S. MERZ.*Integrating satisfiability solving in the assessment of system reliability modeled by dynamic fault trees*, in "29th European Safety and Reliability Conference, ESREL 2019", Hannover, Germany, Research Publishing Services, September 2019 [*DOI :* 10.3850/981-973-0000-00-0], https://hal.inria.fr/hal-02262205

[35] A. FIORI, C. WEIDENBACH.*SCL: Clause Learning from Simple Models*, in "27th International Conference on Automated Deduction", Natal, Brazil, P. FONTAINE (editor), Lecture Notes in Computer Science, 2019, vol. 11716, p. 233-249 [*DOI :* 10.1007/978-3-030-29436-6_14], https://hal.inria.fr/hal-02405550

[36] M. FLEURY, H.-J. SCHURR.*Reconstructing veriT Proofs in Isabelle/HOL*, in "PxTP 2019 - Sixth Workshop on Proof eXchange for Theorem Proving", Natal, Brazil, August 2019, vol. 301, p. 36-50, https://arxiv.org/abs/1908.09480 [*DOI :* 10.4204/EPTCS.301.6], https://hal.inria.fr/hal-02276530

[37] A. SCHLICHTKRULL, J. C. BLANCHETTE, D. TRAYTEL.*A Verified Prover Based on Ordered Resolution*, in "CPP 2019 - The 8th ACM SIGPLAN International Conference on Certified Programs and Proofs", Cascais, Portugal, CPP 2019 - The 8th ACM SIGPLAN International Conference on Certified Programs and Proofs, January 2019 [*DOI :* 10.1145/3293880.3294100], https://hal.archives-ouvertes.fr/hal-01937141

[38] N. SCHNEPF, R. BADONNEL, A. LAHMADI, S. MERZ.*A Tool Suite for the Automated Synthesis of Security Function Chains*, in "IFIP/IEEE IM 2019 - IFIP/IEEE International Symposium on Integrated Network Management", Washington, United States, April 2019, https://hal.inria.fr/hal-02111658

[39] N. SCHNEPF, R. BADONNEL, A. LAHMADI, S. MERZ.*Automated Factorization of Security Chains in Software-Defined Networks*, in "IFIP/IEEE IM 2019 - IFIP/IEEE International Symposium on Integrated Network Management", Washington, United States, April 2019, https://hal.inria.fr/hal-02111656

[40] I. STOILKOVSKA, I. KONNOV, J. WIDDER, F. ZULEGER.*Verifying Safety of Synchronous Fault-Tolerant Algorithms by Bounded Model Checking*, in "TACAS 2019 - International Conference on Tools and Algorithms for the Construction and Analysis of Systems", Prague, Czech Republic, April 2019 [*DOI :* 10.1007/978-3-030-17465-1_20], https://hal.inria.fr/hal-01925653

[41] A. TEUCKE, M. VOIGT, C. WEIDENBACH.*On the Expressivity and Applicability of Model Representation Formalisms*, in "12th International Symposium on Frontiers of Combining Systems (FroCoS 2019)", London, United Kingdom, A. HERZIG, A. POPESCU (editors), Lecture Notes in Computer Science, Springer, 2019, vol. 11715, p. 22-39 [*DOI :* 10.1007/978-3-030-29007-8_2], https://hal.inria.fr/hal-02406605

[42] P. VUKMIROVIĆ, J. C. BLANCHETTE, S. CRUANES, S. SCHULZ.*Extending a Brainiac Prover to Lambda-Free Higher-Order Logic*, in "TACAS 2019 - 25th International Conference on Tools and Algorithms for the Construction and Analysis of Systems", Prague, Czech Republic, April 2019, p. 192-210, https://hal.inria.fr/hal-02178274

[43] P. VUKMIROVIĆ, J. C. BLANCHETTE, S. CRUANES, S. SCHULZ.*Faster, Higher, Stronger: E 2.3*, in "TACAS 2019", Prague, Czech Republic, LNAI, August 2019, vol. 11716, p. 495-507 [*DOI :* 10.1007/978-3-030-29436-6_29], https://hal.inria.fr/hal-02296188

[44] C. WEIDENBACH.*The Challenge of Unifying Semantic and Syntactic Inference Restrictions*, in "2nd International Workshop on Automated Reasoning: Challenges, Applications, Directions, Exemplary Achievements (ARCADE 2019)", Natal, Brazil, Electronic Proceedings in Theoretical Computer Science, 2019, https://hal.inria.fr/hal-02406673

National Conferences with Proceeding

[45] P. LERMUSIAUX, H. CIRSTEA, P.-E. MOREAU.*Pattern eliminating transformations*, in "CIEL 2019 - 8ème Conférence en IngénierieE du Logiciel", Toulouse, France, June 2019, https://hal.inria.fr/hal-02186325

Conferences without Proceedings

[46] H. BARBOSA, J. C. BLANCHETTE, M. FLEURY, P. FONTAINE, H.-J. SCHURR.*Better SMT Proofs for Easier Reconstruction*, in "Conference on Artificial Intelligence and Theorem Proving (AITP 2019)", Obergurgl, Austria, April 2019, https://hal.archives-ouvertes.fr/hal-02381819

[47] J. C. BLANCHETTE, D. E. OURAOUI, P. FONTAINE, C. KALISZYK.*Machine Learning for Instance Selection in SMT Solving*, in "Conference on Artificial Intelligence and Theorem Proving (AITP 2019)", Obergurgl, Austria, April 2019, https://hal.archives-ouvertes.fr/hal-02381430

Scientific Books (or Scientific Book chapters)

[48] P. BAUMGARTNER, U. WALDMANN.*Hierarchic Superposition Revisited*, in "Description Logic, Theory Combination, and All That - Essays Dedicated to Franz Baader on the Occasion of His 60th Birthday", C. LUTZ, U. SATTLER, C. TINELLI, A.-Y. TURHAN, F. WOLTER (editors), Lecture Notes in Computer Science, Springer, 2019, vol. 11560, p. 15-56 [*DOI :* 10.1007/978-3-030-22102-7_2], https://hal.inria.fr/hal-02402941

[49] M. P. BONACINA, P. FONTAINE, C. RINGEISSEN, C. TINELLI.*Theory Combination: Beyond Equality Sharing*, in "Description Logic, Theory Combination, and All That - Essays Dedicated to Franz Baader on the Occasion of His 60th Birthday", C. LUTZ, U. SATTLER, C. TINELLI, A.-Y. TURHAN, F. WOLTER (editors), Theoretical Computer Science and General Issues, Springer, June 2019, vol. 11560, p. 57-89, https://hal.inria.fr/hal-02194001

[50] S. MERZ.*Formal specification and verification*, in "Concurrency: the Works of Leslie Lamport", D. MALKHI (editor), ACM Books, Association for Computing Machinery, 2019, vol. 29, p. 103-129 [*DOI :* 10.1145/3335772.3335780], https://hal.inria.fr/hal-02387780

Books or Proceedings Editing

[51] P. FONTAINE (editor). *Automated Deduction – CADE-27 : 27th International Conference on Automated Deduction, Natal, Brazil, August 27–30, 2019, Proceedings*, Lecture Notes in Artificial Intelligence, Springer, Natal, Brazil, 2019, vol. 11716, forthcoming, https://hal.inria.fr/hal-02194007

[52] D. MÉRY, S. QIN (editors). *2019 International Symposium on Theoretical Aspects of Software Engineering (TASE)*, IEEE, Guillin, China, November 2019, https://hal.inria.fr/hal-02400510

Other Publications

[53] N. BERTRAND, I. KONNOV, M. LAZIC, J. WIDDER.*Verification of Randomized Distributed Algorithms under Round-Rigid Adversaries*, April 2019, Experiments presented in this paper were carried out using the Grid5000

testbed, supported by a scientific interest group hosted by Inria and including CNRS, RENATER and several Universities as well as other organizations, see grid5000.fr, https://hal.inria.fr/hal-01925533

[54] D. GRIGORIEV, A. IOSIF, H. RAHKOOY, T. STURM, A. WEBER.*Efficiently and Effectively Recognizing Toricity of Steady State Varieties*, December 2019, https://arxiv.org/abs/1910.04100 - working paper or preprint [*DOI :* 10.04100], https://hal.inria.fr/hal-02397107

References in notes

[55] J.-R. ABRIAL.*Modeling in Event-B: System and Software Engineering*, Cambridge University Press, 2010

[56] L. BACHMAIR, H. GANZINGER.*Rewrite-Based Equational Theorem Proving with Selection and Simplification*, in "Journal of Logic and Computation", 1994, vol. 4, n^{o} 3, p. 217–247

[57] R. BACK, J. VON WRIGHT.*Refinement calculus—A systematic introduction*, Springer Verlag, 1998

[58] C. BARRETT, R. SEBASTIANI, S. A. SESHIA, C. TINELLI.*Satisfiability Modulo Theories*, in "Handbook of Satisfiability", A. BIERE, MARIJN J. H. HEULE, H. VAN MAAREN, T. WALSH (editors), Frontiers in Artificial Intelligence and Applications, IOS Press, February 2009, vol. 185, chap. 26, p. 825-885

[59] P. CHOCRON, P. FONTAINE, C. RINGEISSEN.*A Polite Non-Disjoint Combination Method: Theories with Bridging Functions Revisited*, in "25th International Conference on Automated Deduction, CADE-25", Berlin, Germany, A. P. FELTY, A. MIDDELDORP (editors), Lecture Notes in Computer Science, Springer, August 2015, vol. 9195, p. 419-433 [*DOI :* 10.1007/978-3-319-21401-6_29], https://hal.inria.fr/hal-01157898

[60] P. CHOCRON, P. FONTAINE, C. RINGEISSEN.*A Rewriting Approach to the Combination of Data Structures with Bridging Theories*, in "Frontiers of Combining Systems - 10th International Symposium, FroCoS 2015", Wroclaw, Poland, C. LUTZ, S. RANISE (editors), Lecture Notes in Computer Science, Springer, September 2015, vol. 9322, p. 275–290 [*DOI :* 10.1007/978-3-319-24246-0_17], https://hal.inria.fr/hal-01206187

[61] M. J. FISCHER, N. A. LYNCH, M. S. PATERSON.*Impossibility of Distributed Consensus with one Faulty Process*, in "J. ACM", 1985, vol. 32, n^{o} 2, p. 374–382

[62] I. KONNOV, H. VEITH, J. WIDDER.*On the completeness of bounded model checking for threshold-based distributed algorithms: Reachability*, in "Inf. Comput.", 2017, vol. 252, p. 95–109

[63] I. KONNOV, J. WIDDER.*ByMC: Byzantine Model Checker*, in "ISoLA 2018 - 8th International Symposium On Leveraging Applications of Formal Methods, Verification and Validation", Limassol, Cyprus, Lecture Notes in Computer Science, October 2018, vol. 11246, p. 327-342 [*DOI :* 10.1007/978-3-030-03424-5_22], https://hal.inria.fr/hal-01909653

[64] J. KUKOVEC, I. KONNOV, J. WIDDER.*Reachability in Parameterized Systems: All Flavors of Threshold Automata*, in "CONCUR 2018 - 29th International Conference on Concurrency Theory", Beijing, China, September 2018 [*DOI :* 10.4230/LIPICS.CONCUR.2018.19], https://hal.inria.fr/hal-01871142

[65] J. KUKOVEC, T.-H. TRAN, I. KONNOV.*Extracting Symbolic Transitions from $TLA+$ Specifications*, in "Abstract State Machines, Alloy, B, TLA, VDM, and Z. ABZ 2018", Southampton, United Kingdom, M. BUTLER, A. RASCHKE, T. S. HOANG, K. REICHL (editors), Lecture Notes in Computer Science, June 2018, vol. 10817, p. 89-104 [*DOI :* 10.1007/978-3-319-91271-4_7], https://hal.inria.fr/hal-01871131

[66] L. LAMPORT.*Specifying Systems*, Addison-Wesley, Boston, Mass., 2002

[67] N. LE NOVERE, B. BORNSTEIN, A. BROICHER, M. COURTOT, M. DONIZELLI, H. DHARURI, L. LI, H. SAURO, M. SCHILSTRA, B. SHAPIRO, J. L. SNOEP, M. HUCKA.*BioModels Database: a free, centralized database of curated, published, quantitative kinetic models of biochemical and cellular systems*, in "Nucleic Acids Research", 2006, vol. 34, n^{o} suppl 1, p. D689-D691, https://doi.org/10.1093/nar/gkj092

[68] E. W. MAYR, A. R. MEYER.*The complexity of the word problems for commutative semigroups and polynomial ideals*, in "Advances in Mathematics", 1982, vol. 46, n^{o} 3, p. 305-329, https://doi.org/10.1016/0001-8708(82)90048-2

[69] S. MERZ, H. VANZETTO.*Encoding TLA+ into unsorted and many-sorted first-order logic*, in "Science of Computer Programming", June 2018, vol. 158, p. 3-20 [*DOI :* 10.1016/J.SCICO.2017.09.004], https://hal.inria.fr/hal-01768750

[70] C. MORGAN.*Programming from Specifications*, Prentice Hall, 1998, 2nd edition

[71] Y. J. SONG, R. VAN RENESSE.*Bosco: One-Step Byzantine Asynchronous Consensus*, in "DISC", LNCS, 2008, vol. 5218, p. 438–450

[72] C. WEIDENBACH.*Towards an Automatic Analysis of Security Protocols in First-Order Logic*, in "16th International Conference on Automated Deduction (CADE-16)", Trento, Italy, H. GANZINGER (editor), Lecture Notes in Computer Science, Springer, 1999, vol. 1632, p. 314-328