Activity Report 2016

Section Application Domains

ALICE Project-Team

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 are tested and evaluated in the frame of our cooperation with the Gocad consortium, with applications in oil exploration and geomechanics, through co-advised Ph.D. thesis (Arnaud Botella, Julien Renaudeau). We think that the hex-dominant meshes that we generate have geometrical properties that make them suitable for some finite element analyses. We work on evaluating and measuring their impact with simple problems (heat equation, linear elasticity) and then practical applications (unfolding geological layer), with the Ph.D. thesis of Maxence Reberol.

In numerical simulation, developing discrete formulations that satisfy the conservation laws (conservation of mass, conservation of energy, conservation of momentum) is important to ensure that the numerical simulation faithfully reflects the behavior of the physics. There are interesting relations with optimal transport theory, as explained by Benamou and Brenier who developed a numerical algorithm for optimal transport that uses a fluid dynamics formulation [17]. Conversely, some dynamics can be approximated by a series of optimal transport problems, as in the Jordan-Kinderlehrer-Otto scheme [20] and in recent works by Mérigot. We started developing efficient geometric algorithms and optimisation methods that may serve as the basis for implementing these numerical methods in 3D. We started discussions / cooperation projects with Quentin Mérigot (MOKAPLAN project).

4.2. Fabrication

Our work around fabrication and additive manufacturing finds applications in different fields. Our algorithms for fast geometric computations on solids (boolean operations, morphological operations) are useful to model a variety of shapes, from mechanical engineering parts to prosthetics for medical applications.

Our by-example techniques allow for simpler modeling and processing of very intricate geometries and therefore also find applications in art and design, for unusual shapes that would be very difficult to obtain otherwise. Extensions of these techniques also find applications for reproducing naturally occurring micro-structures from a scanned sampled.

BIGS Project-Team

4. Application Domains

4.1. Tumor growth

Cancer is the result of inter-dependent multi-scale phenomena and this is mainly why the understanding of its spread is still an unsolved problem. In integrative biology, mathematical models play a central role; they help biologists and clinicians to answer complex questions through numerical simulations and statistical analyses. The main issue here is to better understand and describe the role of cell damage heterogeneity and associated mutant cell phenotypes in the therapeutic responses of cancer cell populations submitted to a radiotherapy sessions during *in vitro* experiments. The cell heterogeneity is often described as randomness in mathematical modeling and different representations, such as Markov chains, branching processes and even stochastic differential equations, have been recently used.

4.2. Photodynamic therapy

Since 1988, some control system scientists and biologists at the CRAN [0] have worked together to develop the photodynamic therapy (PDT in the sequel), an alternative treatment for cancer, by means of a model-based approach. The global aim in this direction is to use statistical as well as mechanistic models in order to improve the response reproducibility, help biologists and chemists in the design of new photosensitizing agents and provide insight into complex phenomena associated with oncogenesis, tumor angiogenesis and interactions with the treatment. This heavily relies on the production of accurate and simple enough models involving various type of stochastic processes, such as Markov chains, branching processes and stochastic differential equations. The main questions here concern generally identification or estimation properties, but simulation issues can be important too.

4.3. Genomic data and micro-organisms population study

Generation genomic technologies allow clinicians and biomedical researchers to drastically increase the amount of genomic data collected on large cohort of patients and populations. We want to contribute to a better understanding of the correlations between gene trough their expression data, of the structure of ARN and of the genetic bases of drug response and disease and to detect significant sequences characterizing a gene. For instance the biopharmaceutical company Transgene has recently contacted us to analyse their genomic and proteomic data particularly for the purpose to find markers of the success of therapies that they develop against cancer.

Network inference has also applications for the analysis of micro-organisms population, that we apply to micro-organism inside and around the truffle trough a collaboration with INRA Nancy. We want also study other specific complex microbial communities like that found at tree roots in order to characterize phenotype of the tree. There is also application in human health (for instance identification of network between bacteria inside colon).

4.4. Epidemiology and e-health

Trough J.-M. Monnez and his collaborator Pr E. Albuisson, BIGS is stakeholder of projects with University Hospital of Nancy that is FHU CARTAGE (Fédération Hospitalo Universitaire Cardial and ARTerial AGEing; leader: Pr Athanase BENETOS), RHU Fight HF (Fighting Heart Failure; leader: Pr Patrick ROSSIGNOL), and "Handle your heart", team responsible for the creation of a drug prescription support software for the treatment of heart failure. All these projects are in the context of personalized medicine and deal with biomarkers research; prognostic value of quantitative variables and events and scoring of heart failure. Other collaborations with clinicians concern foetopathology and cancer again.

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[0]Centre de Recherche en Automatique de Nancy, http://www.cran.uhp-nancy.fr/francais/themes_rech/sbs/beam/index.php

4.5. Dynamics of telomeres

A telomere is a region of repetitive and non coding nucleotide sequences at each end of a chromosome. The 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. Mathematical modeling of telomere dynamics is recent [36], [107], [91], [49]. Trough a collaboration with Pr A. Benetos, geriatrician at CHU Nancy, and some members of Inria team TOSCA, we want to work in three connected directions: (1) propose a dynamical model for the lengths of telomeres and study its mathematical properties (long term behavior of the distribution of lengths, quasi-stationarity, etc); (2) use these properties to develop new statistical methods for estimating the various parameters; and (3) find and use a suitable methodology for the analysis of the available data (Pr Benetos) for instance for the study of the length distribution for a subject and its evolution.

<div align="center">

CAMUS Team

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4. Application Domains

4.1. Application Domains

Performance being our main objective, our developments' 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.

<p style="text-align:center; color:red; font-weight:bold;">CAPSID Project-Team</p>

4. Application Domains

4.1. Biomedical Knowledge Discovery

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

This projects in this domain are carried out in collaboration with the Orpailleur Team.

Huge and ever increasing amounts of biomedical data ("Big Data") are bringing new challenges and novel opportunities for knowledge discovery in biomedicine. We are actively collaborating with biologists and clinicians to design and implement approaches for selecting, integrating, and mining biomedical data in various areas. In particular, we are focusing on leveraging bio-ontologies at all steps of this process (the main thesis topic of Gabin Personeni, co-supervised by Marie-Dominique Devignes and Adrien Coulet from the Orpailleur team). One specific application concerns exploiting Linked Open Data (LOD) to characterise the genes responsible for intellectual deficiency. This work is in collaboration with Pr. P. Jonveaux of the Laboratoire de Génétique Humaine at CHRU Nancy [56], [57]. This involves using inductive logic programming as a machine learning method and at least three different ontologies (Gene Ontology, Human Phenotype Ontology, and Disease Ontology).

Recently, a new application for biomedical knowledge discovery has emerged from the ANR "FIGHT-HF" (fight heart failure) project, which is in collaboration with several INSERM teams at CHRU Nancy. In this case, the molecular mechanisms that underly HF at the cellular and tissue levels will be considered against a background of all available data and ontologies, and represented in a single integrated complex network. A network platform is under construction with the help of a young start-up company called Edgeleap. Together with this company, we are developing query and analysis facilities to help biologists and clinicians to identify relevant biomarkers for patient phenotyping [25]. Docking of small molecules on candidate receptors, as well as protein-protein docking will also be used to clarify a certain number of relations in the complex HF network.

4.2. Prokaryotic Type IV Secretion Systems

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

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 [30]. 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 [41], [63]. However, the detailed nature of the interactions between the remaining components and those of the core channel remains to be resolved. Therefore, these secretion systems represent another family of complex biological systems (scales 2 and 3) that call for integrated modeling approaches to fully understand their machinery.

In the frame of the "MBI" platform (see Section 6.8), MD Devignes is pursuing her collaboration with Nathalie Leblond of the Genome Dynamics and Microbial Adaptation (DynAMic) laboratory (UMR 1128, Université de Lorraine, INRA) on the discovery of new 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 genome. As these elements encode all or a subset of the components of the Type IV secretion system, they constitute a valuable source of sequence data and constraints for modeling these systems in 3D. Another interesting aspect of this particular system is that unlike other secretion systems, the Type IV secretion systems are not restricted to a particular group of bacteria.

4.3. G-protein Coupled Receptors

Participants: Bernard Maigret [contact person], David Ritchie, Vincent Leroux.

G-protein coupled receptors (GPCRs) are cell surface proteins which detect chemical signals outside a cell and which transform these signals into a cascade of cellular changes. Historically, the most well documented signaling cascade is the one driven by G-proteins trimers (guanine nucleotide binding proteins) [43] which ultimately regulate many cellular processes such as transcription, enzyme activity, and homeostatis, for example. But other pathways have recently been associated with the signals triggered by GPCRs, involving other proteins such as arrestins and kinases which drive other important cellular activities. For example, β-arrestin activation can block GPCR-mediated apoptosis (cell death). Malfunctions in such processes are related to diseases such as diabetes, neurological disorders, cardiovascular disease, and cancer. Thus, GPCRs are one of the main protein families targeted by therapeutic drugs [38] and the focus of much bio-medical research. Indeed, approximately 40–50% of current therapeutic molecules target GPCRs. However, despite enormous efforts, the main difficulty here is the lack of experimentally solved 3D structures for most GPCRs. Hence, computational modeling tools are widely recognized as necessary to help understand GPCR functioning and thus biomedical innovation and drug design.

In collaboration with the BIOS team (INRA Tours) and the AMIB team (Inria Saclay – Île de France) we used our Hex protein docking software to help model a multi-component G-protein coupled receptor (GPCR) complex [35]. The resulting 3D structure was shown to be consistent with the known experimental data for the protein components of this trans-membrane molecular signaling system. As part of an on-going collaboration with the Centre for Interdisciplinary Research (CIRB) at Collège de France, we modeled the interaction between the Apelin peptide and a GPCR called ApelinR [42]. This study provided mechanistic insights which could lead to the development of therapeutic agents for the treatment of heart failure.

CARAMBA Project-Team

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 [22] 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.

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[0]In [23], the minimal recommended RSA key size is 2048 bits for an usage up to 2030. See also Annex B, in particular Section B.1 "Records de calculs cryptographiques".

[0]The work [32] is one of the only two academic works cited by NIST in the initial version (2011) of the report [36].

We also develop more specialized software. Our flagship software package is Cado-NFS, 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.

<div align="center">**CARTE Team**</div>

4. Application Domains

4.1. Computer Virology

4.1.1. *The theoretical track*

It is rightful to wonder why there are only a few fundamental studies on computer viruses while it is one of the important flaws in software engineering. The lack of theoretical studies explains maybe the weakness in the anticipation of computer diseases and the difficulty to improve defenses. For these reasons, we do think that it is worth exploring fundamental aspects, and in particular self-reproducing behaviors.

4.1.2. *The virus detection track*

The crucial question is how to detect viruses or self-replicating malwares. Cohen demonstrated that this question is undecidable. The anti-virus heuristics are based on two methods. The first one consists in searching for virus signatures. A signature is a regular expression, which identifies a family of viruses. There are obvious defects. For example, an unknown virus will not be detected, like ones related to a 0-day exploit. We strongly suggest to have a look at the independent audit [47] in order to understand the limits of this method. The second one consists in analyzing the behavior of a program by monitoring it. Following [49], this kind of methods is not yet really implemented. Moreover, the large number of false-positive implies this is barely usable. To end this short survey, intrusion detection encompasses virus detection. However, unlike computer virology, which has a solid scientific foundation as we have seen, the IDS notion of "malwares" with respect to some security policy is not well defined. The interested reader may consult [67].

4.1.3. *The virus protection track*

The aim is to define security policies in order to prevent malware propagation. For this, we need (i) to define what is a computer in different programming languages and setting, (ii) to take into consideration resources like time and space. We think that formal methods like rewriting, type theory, logic, or formal languages, should help to define the notion of a formal immune system, which defines a certified protection.

4.1.4. *The experimentation track*

This study on computer virology leads us to propose and construct a "high security lab" in which experiments can be done in respect with the French law.

4.2. Computations and Dynamical Systems

4.2.1. *Continuous computation theories*

Understanding computation theories for continuous systems leads to studying hardness of verification and control of these systems. This has been used to discuss problems in fields as diverse as verification (see e.g., [31]), control theory (see e.g., [40]), neural networks (see e.g., [68]), and so on. We are interested in the formal decidability of properties of dynamical systems, such as reachability [59], the Skolem-Pisot problem [36], the computability of the ω-limit set [58]. Those problems are analogous to verification of safety properties.

Contrary to computability theory, complexity theory over continuous spaces is underdeveloped and not well understood. A central issue is the choice of the representation of objects by discrete data and its effects on the induced complexity notions. As for computability, it is well known that a representation is gauged by the topology it induces. However more structure is needed to capture the complexity notions: topologically equivalent representations may induce different classes of polynomial-time computable objects, e.g., developing a sound complexity theory over continuous structures would enable us to make abstract computability results more applicable by analyzing the corresponding complexity issues. We think that the preliminary step towards such a theory is the development of higher-order complexity, which we are currently carrying out.

In contrast with the discrete setting, it is of utmost importance to compare the various models of computation over the reals, as well as their associated complexity theories. In particular, we focus on the General Purpose Analog Computer of Claude Shannon [69], on recursive analysis [74], on the algebraic approach [65] and on Markov computability [61]. A crucial point for future investigations is to fill the gap between continuous and discrete computational models. This is one deep motivation of our work on computation theories for continuous systems.

4.2.2. *Analysis and verification of adversary systems*

The other research direction on dynamical systems we are interested in is the study of properties of adversary systems or programs, i.e., of systems whose behavior is unknown or indistinct, or which do not have classical expected properties. We would like to offer proof and verification tools, to guarantee the correctness of such systems. On one hand, we are interested in continuous and hybrid systems. In a mathematical sense, a hybrid system can be seen as a dynamical system, whose transition function does not satisfy the classical regularity hypotheses, like continuity, or continuity of its derivative. The properties to be verified are often expressed as reachability properties. For example, a safety property is often equivalent to (non-)reachability of a subset of unsure states from an initial configuration, or to stability (with its numerous variants like asymptotic stability, local stability, mortality, etc ...). Thus we will essentially focus on verification of these properties in various classes of dynamical systems.

We are also interested in rewriting techniques, used to describe dynamic systems, in particular in the adversary context. As they were initially developed in the context of automated deduction, the rewriting proof techniques, although now numerous, are not yet adapted to the complex framework of modelization and programming. An important stake in the domain is then to enrich them to provide realistic validation tools, both in providing finer rewriting formalisms and their associated proof techniques, and in developing new validation concepts in the adversary case, i.e., when usual properties of the systems like, for example, termination are not verified. For several years, we have been developing specific procedures for property proofs of rewriting, for the sake of programming, in particular with an inductive technique, already applied with success to termination under strategies [50], [51], [52], to weak termination [53], sufficient completeness [54] and probabilistic termination [56]. The last three results take place in the context of adversary computations, since they allow for proving that even a divergent program, in the sense where it does not terminate, can give the expected results. A common mechanism has been extracted from the above works, providing a generic inductive proof framework for properties of reduction relations, which can be parametrized by the property to be proved [55], [57]. Provided program code can be translated into rule-based specifications, this approach can be applied to correctness proof of software in a larger context. A crucial element of safety and security of software systems is the problem of resources. We are working in the field of Implicit Computational Complexity. Interpretation based methods like Quasi-interpretations (QI) or sup-interpretations, are the approach we have been developing these last years [62], [63], [64]. Implicit complexity is an approach to the analysis of the resources that are used by a program. Its tools come essentially from proof theory. The aim is to compile a program while certifying its complexity.

COAST Project-Team (section vide)

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 build 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 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.

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[0]See the Robotics 2020 Multi-Annual Roadmap [51], section 2.7.

[0]OHS (*Office d'Hygiène Sociale*) is an association managing several rehabilitation or retirement home structures.

[0]See the Robotics 2020 Multi-Annual Roadmap [51], section 2.5.

MADYNES Project-Team (section vide)

MAGRIT Project-Team

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 15 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 help therapeutic decisions and interventional gestures. Contributions of the team focus on the developments 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 specimen 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.

MIMESIS Team (section vide)

MULTISPEECH Project-Team

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 the 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 computer assisted learning, health and autonomy (more precisely aided communication and monitoring), annotation and processing of spoken documents, and multimodal computer interaction.

4.2. 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 a comparison of the learner's production to a reference, automatic diagnoses of the learner's production can be considered, as well as perceptual feedback relying on an automatic transformation of the learner's voice. The diagnosis step strongly relies on the studies on categorization of sounds and prosody in the mother tongue and in the second language. Furthermore, reliable diagnosis on each individual utterance is still a challenge, and elaboration of advanced automatic feedback requires a temporally accurate segmentation of speech utterances into phones and this explains why accurate segmentation of native and non-native speech is an important topic in the field of acoustic speech modeling.

4.3. Aided Communication and Monitoring

A foreseen application aims at improving the autonomy of elderly or disabled people, and fit with smartroom applications. In a first step, source separation techniques could be tuned and should help for locating and monitoring people through the detection of sound events inside apartments. 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) could also be envisaged.

4.4. 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 as for example, 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.

Large audio archives are important for some communities of users, e.g., linguists, ethnologists or researchers in digital humanities in general. In France, a notorious example is the "Archives du CNRS — Musée de l'homme", gathering about 50,000 recordings dating back to the early 1900s. When dealing with very old recordings, the practitioner is often faced with the problem of noise. This stems from the fact that a lot of interesting material from a scientific point of view is very old or has been recorded in very adverse noisy conditions, so that the resulting audio is poor. The work on source separation can lead to the design of semi-automatic denoising and enhancement features, that would allow these researchers to significantly enhance their investigation capabilities, even without expert knowledge in sound engineering.

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, prosody modification, and speaker conversion.

4.5. 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 audiobook, to facilitate the access to literature (for instance for blind people or illiterate people).

<p style="text-align:center">**NEUROSYS Project-Team**</p>

4. Application Domains

4.1. General remarks

The research directions of the team are motivated by general anaesthesia (GA) that has attracted our attention in the last years. The following paragraphs explain in some detail the motivation of our work on the four major phenomena of GA: loss of consciousness, immobility, amnesia and analgesia.

During general anaesthesia, the electroencephalogram (EEG) on the scalp changes characteristically: increasing the anaesthetic drug concentration the amplitudes of oscillations in the α-band ($\sim 8 - 12$Hz) and in the $\delta-$band ($2 - 8$Hz) increase amplitudes in frontal electrodes at low drug concentrations whereas the spectral power decreases in the $\gamma-$band ($\sim 20 - 60$Hz). This characteristic change in the power is the basis of today's EEG-monitors that assist the anaesthetist in the control of the anaesthesia depths of patients during surgery. However, the conventional monitors exhibit a large variability between the detected anaesthetic depth and the real depth of patients. Moreover, a certain number of patients re-gain consciousness during surgery (about $1 - 2$ out of 1000) and a large percentage of patients suffer from diverse after-effects, such as nausea or long-lasting cognitive impairments such as partial amnesia (from days to weeks). Since surgery under general anaesthesia is part of a hospital's everyday practice, a large number of patients suffer from these events every day. One reason for the lacking control of such disadvantageous effects is the dramatic lack of knowledge on what is going on in the brain during general anaesthesia and a weak EEG-online monitoring system during anaesthesia. Consequently, to improve the situation of patients during and after surgery and to develop improved anaesthetic procedures or even drugs, research is necessary to learn more about the neural processes in the brain and develop new monitoring machines.

4.2. Level of consciousness

The EEG originates from coherent neural activity of populations in the cortex. Hence to understand better the characteristic power changes in EEG during anaesthesia, it is necessary to study neural population dynamics subject to the concentration of anaesthetic drugs and their action on receptors on the single neuron level. We study mathematical models which will be constrained by the signal features extracted from experimental data, such as EEG (data provided by Jamie Sleigh, University of Auckland and Christoph Destrieux, University of Tours), Local Field Potentials (data provided by Flavio Fröhlich, University of North Carolina - Chapel Hill) and behavior. The combination of model and analysis of experimental data provides the optimal framework to reveal new knowledge on the neural origin of behavioral features, such as the loss of consciousness or the uncontrolled gain of consciousness during surgery. For instance, modelling studies show that the characteristic changes of spectral power (second-order statistics) are not sufficient to deduce all underlying neural mechanisms. Consequently, additional higher-order statistical measures may provide additional insight into underlying neural mechanisms and may provide a novel marker for the loss of consciousness.

Moreover, the constant supervision of anesthetized patients in intensive care is a demanding task for the personnel in hospital practice. It is almost not possible to take care of a patient constantly and hence the todays' medicine demands monitoring devices that control automatically the level of anaesthetic drugs based on the patients' neural activity (e.g., EEG). Brain-Computer-Interfaces (BCI) have already demonstrated their potential for the detection of consciousness in non-responsive patients. We will apply the data analysis techniques known in BCI to extract new markers for the depth of anaesthesia. More specifically, for deeper anaesthesia, auditory-evoked and Event-Related Desynchronization/Event-Related Synchronization (ERD/ERS) BCI could be used to better identify the state of consciousness in patients under anaesthesia. In this context, we have established a first contact to the University of Würzburg. Another research direction will link intracranial EEG and scalp EEG by characterising micro-awake episodes during sleep.

4.3. Immobility

A research direction will be to take benefit of the relationship between the motor activity and anesthesia. Indeed, even if no movement is visually perceptible, a study by electroencephalographic recordings of brain activity in motor areas, quantifying the characteristics of amplitude and phase synchronization observed in the alpha and beta frequency bands, may reveal an intention of movement. This feature is important because it demonstrates that the patient is aware. Thus, we will develop an experimental protocol in collaboration with an anesthesiologist of the regional hospital on stimulating the median nerve at forearm level to track the evolution of the shape of the beta rebound in the motor cortex for various doses of the anesthetic agent.

4.4. Amnesia

Patients sometimes develop post-traumatic disorders associated with the surgery they underwent because they either woke up during the surgery or because the amnesiant effect of the general anaesthesia was only partial, declarative memory being maintained in some unexplained cases. It is still unknown how memory can be maintained under general anaesthesia and it needs to be investigated to improve the recovery from anaesthesia and to avoid as much as possible post-traumatic disorders. To learn more about memory under anaesthesia, we will focus our theoretical studies on the oscillation regimes observed in the hippocampus, mainly in the theta and gamma ranges, which are correlated with memory formation and retrieval.

4.5. Analgesia

One of the most important aspect in general anaesthesia is the loss of pain. During surgery, it is very difficult to find out whether the anesthetized patient feels pain and hence will develop cognitive impairment after surgery. Today, the anesthesiologist knows and detects physiological signs of pain, such as sweat, colour of skin or spontaneous involuntary movements. However, more objective criteria based on EEG may assist the pain detection and hence improves the patients' situation. To this end, we analyze large sets of patient EEG-data observed during surgery and aim to extract EEG signal features of pain.

ORPAILLEUR Project-Team

4. Application Domains

4.1. Life Sciences: Biology, Chemistry and Medicine

Participants: Adrien Coulet, Nicolas Jay, Joël Legrand, Jean Lieber, Pierre Monnin, Amedeo Napoli, Chedy Raïssi, Mohsen Sayed, Malika Smaïl-Tabbone, Yannick Toussaint, Mickaël Zehren.

> **Keywords:**   knowledge discovery in life sciences, bioinformatics, biology, chemistry, medicine, pharmacogenomics

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 environment, or between genetic and phenotypic data, especially for public health and pharmacogenomics domains. The latter case appears to be one main challenge in knowledge discovery in biology and involves knowledge discovery from complex data depending on domain knowledge.

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 among which 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 undirected labeled graphs. Graph mining methods may play an important role in this framework and Formal Concept Analysis can also be used in an efficient and well-founded way [86]. Graph mining in the framework of FCA is a very important task on which we are working, whose results can be transferred to text mining as well.

We are working on knowledge management in medicine and analysis of patient trajectories. The Kasimir research project is about decision support and knowledge management for the treatment of cancer. This is a multidisciplinary research project in which researchers in computer science (Orpailleur) and experts in oncology are participating. For a given cancer localization, a treatment is based on a protocol, which is applied in 70% of the cases and provides a treatment. The 30% remaining cases are "out of the protocol", e.g. contraindication, treatment impossibility, etc. and the protocol should be adapted, based on discussions among specialists. This adaptation process is modeled in Kasimir thanks to CBR, where semantic web technologies are used and adapted for several years.

The analysis of patient trajectories, i.e. the "path" of a patient during illness (chronic illnesses and cancer), can be considered as an analysis of sequences. It is important to understand such sequential data and sequence mining methods should be adapted for addressing the complex nature of medical events. We are interested in the analysis of trajectories at different levels of granularity and w.r.t. external domain ontologies. In addition, it is also important to be able to compare and classify trajectories according to their content. Then we are also interested in the definition of similarity measures able to take into account the complex nature of trajectories and that can be efficiently implemented for allowing quick and reliable classifications.

PractiKPharma (Practice-based evidences for actioning Knowledge in Pharmacogenomics) is a starting research project about the validation of state-of-the-art knowledge in pharmacogenomics by mining "Electronic Health Records" (EHRs) [55]. Pharmacogenomics is a field studying how genomic variations impact drug responses. Most of the state of the art in the field is only available in biomedical literature, with various levels of validation. Accordingly we propose firstly, to extract pharmacogenomic knowledge units from the literature and secondly, to confirm or moderate these units by mining EHRs. Comparing knowledge units extracted form the literature with facts extracted from EHRs is not a trivial task for several reasons, among which (i) the literature is in English, whereas EHRs are in French, (ii) EHRs represent observations at the patient level whereas the literature is generalizing sets of patients...

4.2. Cooking

Participants: Emmanuelle Gaillard, Jean Lieber, Emmanuel Nauer.

    Keywords: cooking, knowledge engineering, case-based reasoning, semantic web

123 The origin of the Taaable project is the Computer Cooking Contest (CCC). A contestant to CCC is a system that answers queries about recipes, using a recipe base; if no recipe exactly matches the query, then the system adapts another recipe. Taaable is a case-based reasoning system based on various technologies from semantic web, knowledge discovery, knowledge representation and reasoning. From a research viewpoint the system enables to test scientific results and to study the complementarity of various research trends in an application domain which is simple to understand and which raises complex issues at the same time.

4.3. Agronomy

Participants: Sébastien Da Silva, Florence Le Ber, Jean-François Mari.

    Keywords: simulation in agronomy, graph model in agronomy

Research in agronomy was conducted in the framework of an Inria-INRA collaboration, taking place in the INRA research network PAYOTE about landscape modeling. In this framework, Sébastien da Silva prepared and defended a PhD thesis [74] in September 2014, supervised by Claire Lavigne (DR in ecology, INRA Avignon) and Florence Le Ber. The research work was related to the characterization and the simulation of hedgerow structures in agricultural landscapes, based on Hilbert-Peano curves and Markov models [48].

Moreover, an on-going research work about the representation of peasant knowledge is involved within a collaboration with IRD in Madagascar [81]. Sketches drawn by peasants were transformed into graphs and compared thanks to Formal Concept Analysis.

4.4. Digital Humanities

Participant: Jean Lieber.

    Keywords: digital humanities, semantic web, SPARQL, approximate search, case-based reasoning

Recent contacts with the digital humanity community occurred with a group of researchers working in history and philosophy of science and technologies (located in Brest, Montpellier and Nancy). They want to benefit from semantic Web technologies in order to provide better accesses to their text corpora. A paper based on this starting collaboration was published [69], about exact and approximate search in RDFS-annotated text corpora based on the SPARQL technology and on case-based reasoning principles.

PESTO Project-Team

4. Application Domains

4.1. Formal methods for Cryptographic protocols

Security protocols, such as TLS, Kerberos or ssh, are the main tool for securing our communications. The aim of our work is to 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 design 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

Treatment of information released by users on social networks can violate a user's privacy. The goal of our work is to allow one a controlled information release while guaranteeing a user's privacy.

<p style="text-align:center; color:red;">**SEMAGRAMME Project-Team**</p>

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.

It seems clear, nowadays, that the need for semantics is ubiquitous. Nevertheless, according to the present state of the art, there are only a few applications for which a deep semantic analysis results in a real improvement over non semantic-based techniques. This is due to the fact that most current application chains are such that their weakest links are not located at the semantic level.

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. The ANR project Polymnie (see section 7.2.1.1) is especially dedicated to this aim.

<p style="text-align:center;color:red;font-weight:bold;font-size:larger;">SPHINX Project-Team</p>

4. Application Domains

4.1. Robotic swimmers

Some companies aim at building biomimetic robots that can swim in an aquarium, as toys (Robotswim) [0] but also for medical objectives. During the last three years, some members of the Inria Project-Team CORIDA [0] (Munnier, Scheid and Takahashi) together with members of the automatics laboratory of Nancy CRAN (Daafouz, Jungers) have initiated an active collaboration (CPER AOC) to construct a swimming ball in a very viscous fluid. This ball has a macroscopic size but since the fluid is highly viscous, its motion is similar to the motion of a nanorobot. Such nanorobots could be used for medical purposes to bring 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 [85], [84], [83]). However, in practice the admissible deformations of the ball are limited since they are realized using piezo-electric actuators. In the next four years, we will take into account these constraints by developing two approaches :

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 into a viscous incompressible fluid (SUSHI3D) or into a inviscid incompressible fluid (SOLEIL).

4.2. Aeronautics

We will develop robust and efficient solvers for problems arising in aeronautics (or aerospace) like electro-magnetic 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. Part of this development is done through the grant ANR BECASIM.

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[0]The website http://www.robotic-fish.net/ presents a list of several robotic fish that have been built in the last years.
[0]Most members of SPHINX were members of the former Inria project-team CORIDA

TONUS Team

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 made of 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. Among these 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 for the stability of the plasma. The idea goes back to research by Tamm and Sakharov, two Russian physicists, in the 1950'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 fusion reactions, 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. The applications is electromagnetic simulations for the conception of antenna, 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 modeling 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 new PhD with CEREMA (Centre d'études et d'expertise sur les risques, l'environnement, la mobilité et l'aménagement) has started in October 2015 (thesis of Pierre Gerhard). The objective is to investigate the model reduction and to implement the resulting acoustic model in our DG solver.

<p style="text-align:center;color:red;font-weight:bold;">TOSCA Project-Team</p>

4. Application Domains

4.1. Domain

TOSCA is interested in developing stochastic models and probabilistic numerical methods. Our present motivations come from models with singular coefficients, with applications in Geophysics, Molecular Dynamics and Neurosciences; Lagrangian modeling in Fluid Dynamics and Meteorology; Population Dynamics, Evolution and Genetics; Neurosciences; and Financial Mathematics.

4.1.1. *Stochastic models with singular coefficients: Analysis and simulation*

Stochastic differential equations with discontinuous coefficients arise in Geophysics, Chemistry, Molecular Dynamics, Neurosciences, Oceanography, etc. In particular, they model changes of diffusion of fluids, or diffractions of particles, along interfaces.

For practioners in these fields, Monte Carlo methods are popular as they are easy to interpret — one follows particles — and are in general easy to set up. However, dealing with discontinuities presents many numerical and theoretical challenges. Despite its important applications, ranging from brain imaging to reservoir simulation, very few teams in mathematics worldwide are currently working in this area. The Tosca project-team has tackled related problems for several years providing rigorous approach. Based on stochastic analysis as well as interacting with researchers in other fields, we developed new theoretical and numerical approaches for extreme cases such as Markov processes whose generators are of divergence form with discontinuous diffusion coefficient.

The numerical approximation of singular stochastic processes can be combined with backward stochastic differential equations (BSDEs) or branching diffusions to obtain Monte Carlo methods for quasi-linear PDEs with discontinuous coefficients. The theory of BSDEs has been extensively developed since the 1980s, but the general assumptions for their existence can be quite restrictive. Although the probabilistic interpretation of quasi-linear PDEs with branching diffusions has been known for a long time, there have been only a few works on the related numerical methods.

Another motivation to consider stochastic dynamics in a discontinuous setting came to us from time evolution of fragmentation and coagulation phenomena, with the objective to elaborate stochastic models for the avalanche formation of soils, snow, granular materials or other geomaterials. Most of the models and numerical methods for avalanches are deterministic and involve a wide variety of physical parameters such as the density of the snow, the yield, the friction coefficient, the pressure, the basal topography, etc. One of these methods consists in studying the safety factor (or limit load) problem, related to the shallow flow of a visco-plastic fluid/solid with heterogeneous thickness over complex basal topography. The resulting nonlinear partial differential equation of this last theory involves many singularities, which motivates us to develop an alternative stochastic approach based on our past works on coagulation and fragmentation. Our approach consists in studying the evolution of the size of a typical particle in a particle system which fragments in time.

4.1.2. *Stochastic Lagrangian modeling in Computational Fluid Dynamics*

Stochastic Lagrangian models were introduced in the eighties to simulate complex turbulent flows, particularly two-phase flows. In Computational Fluid Dynamics (CFD), they are intensively used in the so-called Probability Density Functions (PDF) methods in order to model and compute the reaction-phase terms in the fundamental equations of fluid motions. The PDF methods are currently developed in various laboratories by specialists in scientific computation and physicists. However, to our knowledge, we are innovating in two ways:

- our theoretical studies are the pioneering mathematical analysis of Lagrangian stochastic models in CFD;
- our work on the Stochastic Downscaling Method (SDM) for wind simulation is the first attempt to solve the fundamental equations themselves by a fully 3D stochastic particle method.

We emphasize that our numerical analysis is essential to the SDM development which takes benefits from our deep expertise on numerical schemes for McKean-Vlasov-non-linear SDEs.

4.1.3. Population Dynamics, Evolution and Genetics

The activity of the team on stochastic modeling in population dynamics and genetics mainly concerns application in adaptive dynamics, a branch of evolutionary biology studying the interplay between ecology and evolution, ecological modeling, population genetics in growing populations, and stochastic control of population dynamics, with applications to cancer growth modeling. Stochastic modeling in these areas mainly considers individual-based models, where the birth and death of each individual is described. This class of model is well-developed in Biology, but their mathematical analysis is still fragmentary. Another important topic in population dynamics is the study of populations conditioned to non-extinction, and of the corresponding stationary distributions, called quasi-stationary distributions (QSD). This domain has been the object of a lot of studies since the 1960's, but we made recently significant progresses on the questions of existence, convergence and numerical approximation of QSDs using probabilistic tools rather than the usual spectral tools.

Our activity in population dynamics also involves a fully new research project on cancer modeling at the cellular level by means of branching processes. In 2010 the International Society for Protons Dynamics in Cancer was launched in order to create a critical mass of scientists engaged in research activities on Proton Dynamics in Cancer, leading to the facilitation of international collaboration and translation of research to clinical development. Actually, a new branch of research on cancer evolution is developing intensively; it aims in particular to understand the role of proteins acting on cancerous cells' acidity, their effects on glycolysis and hypoxia, and the benefits one can expect from controlling pH regulators in view of proposing new therapies.

4.1.4. Stochastic modeling in Neuroscience

It is generally accepted that many different neural processes that take place in the brain involve noise. Indeed, one typically observes experimentally underlying variability in the spiking times of an individual neuron in response to an unchanging stimulus, while a predictable overall picture emerges if one instead looks at the average spiking time over a whole group of neurons. Sources of noise that are of interest include ionic currents crossing the neural membrane, synaptic noise, and the global effect of the external environment (such as other parts of the brain).

It is likely that these stochastic components play an important role in the function of both the neurons and the networks they form. The characterization of the noise in the brain, its consequences at a functional level and its role at both a microscopic (individual neuron) level and macroscopic level (network of thousands of neurons) is therefore an important step towards understanding the nervous system.

To this end, a large amount of current research in the neuroscientific literature has involved the addition of noise to classical purely deterministic equations resulting in new phenomena being observed. The aim of the project is thus to rigorously study these new equations in order to be able to shed more light on the systems they describe.

4.1.5. Stochastic modeling in Financial Mathematics

4.1.5.1. Technical Analysis

In the financial industry, there are three main approaches to investment: the fundamental approach, where strategies are based on fundamental economic principles; the technical analysis approach, where strategies are based on past price behavior; and the mathematical approach where strategies are based on mathematical models and studies. The main advantage of technical analysis is that it avoids model specification, and thus calibration problems, misspecification risks, etc. On the other hand, technical analysis techniques have limited theoretical justifications, and therefore no one can assert that they are risk-less, or even efficient.

4.1.5.2. Financial Risks Estimation and Hedging

Popular models in financial mathematics usually assume that markets are perfectly liquid. In particular, each trader can buy or sell the amount of assets he/she wants at the same price (the "market price"). They moreover assume that the decision taken by the trader does not affect the price of the asset (the small investor assumption). In practice, the assumption of perfect liquidity is never satisfied but the error due to liquidity is generally negligible with respect to other sources of error such as model error or calibration error, etc.

Derivatives of interest rates are singular for at least two reasons: firstly the underlying (interest rate) is not directly exchangeable, and secondly the liquidity costs usually used to hedge interest rate derivatives have large variation in times.

Due to recurrent crises, the problem of risk estimation is now a crucial issue in finance. Regulations have been enforced (Basel Committee II). Most asset management software products on the markets merely provide basic measures (VaR, Tracking error, volatility) and basic risk explanation features (e.g., "top contributors" to risk, sector analysis, etc).

4.1.5.3. Energy and Carbon Markets

With the rise of renewable energy generation (from solar, wind, waves...), engineers face new challenges which heavily rely on stochastic and statistical problems.

Besides, in the context of the beginning of the second phase (the Kyoto phase) in 2008 of the European carbon market, together with the fact that French carbon tax was scheduled to come into law on Jan. 1, 2010, the year 2009 was a key year for the carbon price modeling. Our research approach adopts the point of view of the legislator and energy producers. We used both financial mathematical tools and a game theory approach. Today, with the third phase of the EU-ETS, that didn't yet start, and the report form the Cour des Comptes (October 2013) that pointed out (among many others point) the lack of mathematical modeling on such carbon market design, we continue our research in this direction.

4.1.5.4. Optimal Stopping Problems

The theory of optimal stopping is concerned with the problem of taking a decision at the best time, in order to maximise an expected reward (or minimise an expected cost). We work on the general problem of optimal stopping with random discounting and additional cost of observation.

4.1.5.5. First hitting times distributions

Diffusion hitting times are of great interest in finance (a typical example is the study of barrier options) and also in Geophysics and Neurosciences. On the one hand, analytic expressions for hitting time densities are well known and studied only in some very particular situations (essentially in Brownian contexts). On the other hand, the study of the approximation of the hitting times for stochastic differential equtions is an active area of research since very few results still are available in the literature.

VEGAS Project-Team

3. Application Domains

3.1. Computer Graphics

We are interested in the application of our work to virtual prototyping, which refers to the many steps required for the creation of a realistic virtual representation from a CAD/CAM model.

When designing an automobile, detailed physical mockups of the interior are built to study the design and evaluate human factors and ergonomic issues. These hand-made prototypes are costly, time consuming, and difficult to modify. To shorten the design cycle and improve interactivity and reliability, realistic rendering and immersive virtual reality provide an effective alternative. A virtual prototype can replace a physical mockup for the analysis of such design aspects as visibility of instruments and mirrors, reachability and accessibility, and aesthetics and appeal.

Virtual prototyping encompasses most of our work on effective geometric computing. In particular, our work on 3D visibility should have fruitful applications in this domain. As already explained, meshing objects of the scene along the main discontinuities of the visibility function can have a dramatic impact on the realism of the simulations.

3.2. Solid Modeling

Solid modeling, i.e., the computer representation and manipulation of 3D shapes, has historically developed somewhat in parallel to computational geometry. Both communities are concerned with geometric algorithms and deal with many of the same issues. But while the computational geometry community has been mathematically inclined and essentially concerned with linear objects, solid modeling has traditionally had closer ties to industry and has been more concerned with curved surfaces.

Clearly, there is considerable potential for interaction between the two fields. Standing somewhere in the middle, our project has a lot to offer. Among the geometric questions related to solid modeling that are of interest to us, let us mention: the description of geometric shapes, the representation of solids, the conversion between different representations, data structures for graphical rendering of models and robustness of geometric computations.

VERIDIS Project-Team

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 and peer-to-peer networking 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.

Formal verification techniques can contribute to certifying the correctness of systems. In particular, they help assert under which assumptions an algorithm or system functions as required. For example, the highest levels of the Common Criteria for Information Technology Security Evaluation encourage the use of formal methods. While initially the requirements of certified development have mostly been restricted to safety-critical systems, the cost of unavailable services due to malfunctioning system components and software provides wider incentives for verification. For example, we are working on modeling and verifying medical devices that require closed-loop models of both the system and its environment.