



RESEARCH CENTER
Grenoble - Rhône-Alpes

FIELD

Activity Report 2016

Section Application Domains

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AIRSEA Project-Team

4. Application Domains

4.1. The Ocean-Atmosphere System

The evolution of natural systems, in the short, mid, or long term, has extremely important consequences for both the global Earth system and humanity. Forecasting this evolution is thus a major challenge from the scientific, economic, and human viewpoints.

Humanity has to face the problem of **global warming**, brought on by the emission of greenhouse gases from human activities. This warming will probably cause huge changes at global and regional scales, in terms of climate, vegetation and biodiversity, with major consequences for local populations. Research has therefore been conducted over the past 15 to 20 years in an effort to model the Earth's climate and forecast its evolution in the 21st century in response to anthropic action.

With regard to short-term forecasts, the best and oldest example is of course **weather forecasting**. Meteorological services have been providing daily short-term forecasts for several decades which are of crucial importance for numerous human activities.

Numerous other problems can also be mentioned, like **seasonal weather forecasting** (to enable powerful phenomena like an El Niño event or a drought period to be anticipated a few months in advance), **operational oceanography** (short-term forecasts of the evolution of the ocean system to provide services for the fishing industry, ship routing, defense, or the fight against marine pollution) or the prediction of **floods**.

As mentioned previously, mathematical and numerical tools are omnipresent and play a fundamental role in these areas of research. In this context, the vocation of AIRSEA is not to carry out numerical prediction, but to address mathematical issues raised by the development of prediction systems for these application fields, in close collaboration with geophysicists.

ARIC Project-Team

4. Application Domains

4.1. Floating-point and Validated Numerics

Our expertise on validated numerics is useful to analyze and improve, and guarantee the quality of numerical results in a wide range of applications including:

- scientific simulation;
- global optimization;
- control theory.

Much of our work, in particular the development of correctly rounded elementary functions, is critical to the

- reproducibility of floating-point computations.

4.2. Cryptography, Cryptology, Communication Theory

Lattice reduction algorithms have direct applications in

- public-key cryptography;
- diophantine equations;
- communications theory.

AVALON Project-Team

4. Application Domains

4.1. Overview

The Avalon team targets applications with large computing and/or data storage needs, which are still difficult to program, maintain, and deploy. Those applications can be parallel and/or distributed applications, such as large scale simulation applications or code coupling applications. Applications can also be workflow-based as commonly found in distributed systems such as grids or clouds.

The team aims at not being restricted to a particular application field, thus avoiding any spotlight. The team targets different HPC and distributed application fields, which bring use cases with different issues. This will be eased by our various collaborations: the team participates to the INRIA-Illinois Joint Laboratory for Petascale Computing, the Physics, Radiobiology, Medical Imaging, and Simulation French laboratory of excellence, the E-Biothon project, the INRIA large scale initiative Computer and Computational Sciences at Exascale (C2S@Exa), and to BioSyL, a federative research structure about Systems Biology of the University of Lyon. Moreover, the team members have a long tradition of cooperation with application developers such as CERFACS and EDF R&D. Last but not least, the team has a privileged connection with CC IN2P3 that opens up collaborations, in particular in the astrophysics field.

In the following, some examples of representative applications we are targeting are presented. In addition to highlighting some application needs, they also constitute some of the use cases we will use to validate our theoretical results.

4.2. Climatology

The world's climate is currently changing due to the increase of the greenhouse gases in the atmosphere. Climate fluctuations are forecasted for the years to come. For a proper study of the incoming changes, numerical simulations are needed, using general circulation models of a climate system. Simulations can be of different types: HPC applications (*e.g.*, the NEMO framework [45] for ocean modelization), code-coupling applications (*e.g.*, the OASIS coupler [51] for global climate modeling), or workflows (long term global climate modeling).

As for most applications the team is targeting, the challenge is to thoroughly analyze climate-forecasting applications to model their needs in terms of programming model, execution model, energy consumption, data access pattern, and computing needs. Once a proper model of an application has been set up, appropriate scheduling heuristics could be designed, tested, and compared. The team has a long tradition of working with CERFACS on this topic, for example in the LEGO (2006-09) and SPADES (2009-12) French ANR projects.

4.3. Astrophysics

Astrophysics is a major field to produce large volume of data. For instance, the Large Synoptic Survey Telescope (<http://www.lsst.org/lsst/>) will produce 15 TB of data every night, with the goals of discovering thousands of exoplanets and of uncovering the nature of dark matter and dark energy in the universe. The Square Kilometer Array (<http://www.skatelescope.org/>) produces 9 Tbits/s of raw data. One of the scientific projects related to this instrument called Evolutionary Map of the Universe is working on more than 100 TB of images. The Euclid Imaging Consortium will generate 1 PB data per year.

Avalon collaborates with the *Institut de Physique Nucléaire de Lyon* (IPNL) laboratory on large scale numerical simulations in astronomy and astrophysics. Contributions of the Avalon members have been related to algorithmic skeletons to demonstrate large scale connectivity, the development of procedures for the generation of realistic mock catalogs, and the development of a web interface to launch large cosmological simulations on GRID'5000.

This collaboration, that continues around the topics addressed by the CLUES project (<http://www.clues-project.org>), has been extended thanks to the tight links with the CC-IN2P3. Major astrophysics projects execute part of their computing, and store part of their data on the resources provided by the CC-IN2P3. Among them, we can mention SNFactory, Euclid, or LSST. These applications constitute typical use cases for the research developed in the Avalon team: they are generally structured as workflows and a huge amount of data (from TB to PB) is involved.

4.4. Bioinformatics

Large-scale data management is certainly one of the most important applications of distributed systems in the future. Bioinformatics is a field producing such kinds of applications. For example, DNA sequencing applications make use of MapReduce skeletons.

The Avalon team is a member of BioSyL (<http://www.biosyl.org>), a Federative Research Structure attached to University of Lyon. It gathers about 50 local research teams working on systems biology. Moreover, the team cooperated with the French Institute of Biology and Chemistry of Proteins (IBCP <http://www.ibcp.fr>) in particular through the ANR MapReduce project where the team focuses on a bio-chemistry application dealing with protein structure analysis. Avalon have also starting working with the Inria Beagle team (<https://team.inria.fr/beagle/>) on artificial evolution and computational biology as the challenges are around high performance computation and data management.

BEAGLE Project-Team (section vide)

BIPOP Project-Team

4. Application Domains

4.1. Computational neuroscience

Modeling in neuroscience makes extensive use of nonlinear dynamical systems with a huge number of interconnected elements. Our current theoretical understanding of the properties of neural systems is mainly based on numerical simulations, from single cell models to neural networks. To handle correctly the discontinuous nature of integrate-and-fire networks, specific numerical schemes have to be developed. Our current works focus on event-driven, time-stepping and voltage-stepping strategies, to simulate accurately and efficiently neuronal networks. Our activity also includes a mathematical analysis of the dynamical properties of neural systems. One of our aims is to understand neural computation and to develop it as a new type of information science [16], [17].

4.2. Electronic circuits

Whether they are integrated on a single substrate or as a set of components on a board, electronic circuits are very often a complex assembly of many basic components with non linear characteristics. The IC technologies now allow the integration of hundreds of millions of transistors switching at GHz frequencies on a die of 1cm^2 . It is out of the question to simulate a complete IC with standard tools such as the SPICE simulator. We currently work on a dedicated plug-in able to simulate a whole circuit comprising various components, some modelled in a nonsmooth way [1].

4.3. Walking robots

As compared to rolling robots, the walking ones – for example hexapods – possess definite advantages whenever the ground is not flat or free: clearing obstacles is easier, holding on the ground is lighter, adaptivity is improved. However, if the working environment of the system is adapted to man, the biped technology must be preferred, to preserve good displacement abilities without modifying the environment. This explains the interest displayed by the international community in robotics toward humanoid systems, whose aim is to back man in some of his activities, professional or others. For example, a certain form of help at home to disabled persons could be done by biped robots, as they are able to move without any special adaptation of the environment.

4.4. Computer graphics animation

Computer graphics animation is dedicated to the numerical modeling and simulation of physical phenomena featuring a high visual impact. Typically, deformable objects prone to strong deformation, large displacements, complex and nonlinear or even nonsmooth behavior, are of interest for this community. We are interested in two main mechanical phenomena: on the one hand, the behavior of slender (nonlinear) structures such as rods, plates and shells; on the other hand, the effect of frictional contact between rigid or deformable bodies. In both cases the goal is to design realistic, efficient, robust, and controllable computational models. Whereas the problem of collision detection has become a mature field those recent years, simulating the collision response (in particular frictional contacts) in a realistic, robust and efficient way, still remains an important challenge. We have focussed in the past years on the simulation of heterogeneous objects such as granular or fibrous materials, both with a discrete element point of view [11], and, more recently, with a macroscopic (continuum) point of view [23]. We also pursue some study on the design of high-order models for slender structures such as rods, plates or shells. Our current activity includes the static inversion of mechanical objects, which is of great importance in the field of artistic design, for the making of movies and video games for example. Such problems typically involve geometric fitting and parameters identification issues, both resolved with the help of constrained optimization. Finally, we are interested in studying certain discrepancies (inexistence of solution) due to the combination of incompatible models such as contacting rigid bodies subject to Coulomb friction.

4.5. Multibody Systems: Modeling, Control, Waves, Simulation

Multibody systems are assemblies of rigid or flexible bodies, typically modeled with Newton-Euler or Lagrange dynamics, with bilateral and unilateral constraints, with or without tangential effects like friction. These systems are highly nonlinear and nonsmooth, and are therefore challenging for modeling aspects (impact dynamics, especially multiple –simultaneous– collisions), feedback control [10], state observation, as well as numerical analysis and simulation (software development) [2], [4], [5]. Biped robots are a particular, interesting subclass of multibody systems subject to various constraints. Granular materials are another important field, in which nonlinear waves transmissions are crucial (one celebrated example being Newton’s cradle) [15], [12], [6], [13]. Fibers assemblies [11], circuit breakers, systems with clearances, are also studied in the team.

4.6. Stability and Feedback Control

Lyapunov stability of nonsmooth, complementarity dynamical systems is challenging, because of possible state jumps, and varying system’s dimension (the system may live on lower-dimensional subspaces), which may induce instability if not incorporated in the analysis [8], [9], [7]. On the other hand, the nonsmoothness (or the set-valuedness) may be introduced through the feedback control, like for instance the well-known sliding-mode controllers or state observers. The time-discretisation of set-valued controllers is in turn of big interest [3]. The techniques we study originate from numerical analysis in Contact Mechanics (the Moreau-Jean time-stepping algorithm) and are shown to be very efficient for chattering suppression and Lyapunov finite-time stability.

CHROMA Team

4. Application Domains

4.1. Introduction

Applications in Chroma are organized in two main domains : **i) Future cars and transportation systems and ii) Services robotics**. These domains correspond to the experimental fields initiated in Grenoble (eMotion team) and in Lyon (CITI lab). However, the scientific objectives described in the previous sections are intended to apply equally to both applicative domains. Even our work on Bayesian Perception is today applied to the intelligent vehicle domain, we aim to generalize to any mobile robots. The same remark applies to the work on multi-agent decision making. We aim to apply algorithms to any fleet of mobile robots (service robots, connected vehicles, UAVs). This is the philosophy of the team since its creation.



Figure 4. Most of the Chroma platforms: the Pepper robot, a fleet of (22) Turtlebot 2, one of the 4 Bebop drones and the equipped Toyota Lexus.

4.2. Future cars and transportation systems

Thanks to the introduction of new sensor and ICT technologies in cars and in mass transportation systems, and also to the pressure of economical and security requirements of our modern society, this application domain is quickly changing. Various technologies are currently developed by both research and industrial laboratories. These technologies are progressively arriving at maturity, as it is witnessed by the results of large scale experiments and challenges such as the Google's car project and several future products announcements made by the car industry. Moreover, the legal issue starts to be addressed in USA (see for instance the recent laws in Nevada and in California authorizing autonomous vehicles on roads) and in several other countries (including France).

In this context, we are interested in the development of ADAS⁰ systems aimed at improving comfort and safety of the cars users (e.g., ACC, emergency braking, danger warnings), and of Fully Autonomous Driving functions for controlling the displacements of private or public vehicles in some particular driving situations and/or in some equipped areas (e.g., automated car parks or captive fleets in downtown centers or private sites).

⁰ Advanced Driver Assistance Systems

Since about 8 years, we are collaborating with Toyota and with Renault-Nissan on these applications (bilateral contracts, PhD Theses, shared patents), but also recently with Volvo group (PhD thesis started in 2016). We are also strongly involved (since 2012) in the innovation project Perfect of the IRT⁰ Nanoelec (transportation domain). In 2016, we have been awarded a European H2020 ECSEL project⁰ involving major European automotive constructors and car suppliers. In this project, Chroma is focusing on the embedded perception component (models and algorithms, including the certification issue), in collaboration with Renault, Valeo and also with the Inria team TAMIS (Rennes). Chroma is also involved in the ANR project "Valet" (2015-2018) coordinated by the Inria team RITS (Rocquencourt), dealing with automatic redistribution of car-sharing vehicles and parking valet; Chroma is involved in the pedestrian-vehicle interaction for a safe navigation.

In this context, Chroma has two experimental vehicles equipped with various sensors (a Toyota Lexus and a Renault Zoe, see Fig. 4 and Fig. 2), which are maintained by Inria-SED⁰ and that allow the team to perform experiments in realistic traffic conditions (Urban, road and highway environments). The Zoe car will be automated in December 2016 through our collaboration with the team of P. Martinet (IRCCyN Lab, Nantes) that will open us to new experiments and work.

4.3. Services robotics

Service robotics is an application domain quickly emerging, and more and more industrial companies (e.g., IS-Robotics, Samsung, LG) are now commercializing service and intervention robotics products such as vacuum cleaner robots, drones for civil or military applications, entertainment robots ... One of the main challenges is to propose robots which are sufficiently robust and autonomous, easily usable by non-specialists, and marked at a reasonable cost. We are involved in developing observation and surveillance systems, by using ground robots (Turtlebot fleet) or aerial ones (ANR VIMAD⁰), see Fig. 4.

A more recent challenge for the coming decade is to develop robotized systems for assisting elderly and/or disabled people. In the continuity of our work in the IPL PAL⁰, we aim to propose smart technologies to assist electric wheelchair users in their displacements (see Figure 2 for illustration). We address the problem of assisting the user for joining a group of people and navigating in crowded environments, in cooperation with Inria Lagadic team (Rennes).

Another emerging application to assist people is telepresence robot. In 2016 we started the TENSIVE project, funded by the Region, with the team of G. Bailly from GIPSA Lab (Grenoble) and with the Awabot and Hoomano companies (in Lyon). The project aims to improve the driving of such robots by providing a social and autonomous navigation (PhD of R. Cambuzat). Moreover, the project is supported by INSA-CITI Lab. through the acquisition of a Pepper robot (see Fig. 4).

⁰Institut de Recherche Technologique

⁰ENABLE-S3: European Initiative to Enable Validation for Highly Automated Safe and Secure Systems.

⁰Service Expérimentation et Développement

⁰Navigation autonome des drones aériens avec la fusion des données visuelles et inertielles, lead by A. Martinelli, Chroma.

⁰Personnally assisted Living

COMPSYS Team

4. Application Domains

4.1. Compilers for Embedded Computing Systems

The previous sections described our main activities in terms of research directions, but also placed Compsys within the embedded computing systems domain, especially in Europe. We will therefore not come back here to the importance, for industry, of compilation and embedded computing systems design.

In terms of application domain, the embedded computing systems we considered are mostly used for multimedia: phones, TV sets, game platforms, etc. But, more than the final applications developed as programs, our main application has always been the computer itself: how the system is organized (architecture) and designed, how it is programmed (software), how programs are mapped to it (compilation and high-level synthesis).

The industry that can be impacted by our research is thus all the companies that develop embedded processors, hardware accelerators (programmable or not), embedded systems, and those (the same plus other) that need software tools to map applications to these platforms, i.e., that need to use or even develop programming languages, program optimization techniques, compilers, operating systems. Compsys did not focus on all these critical parts, but our activities were connected to them.

4.2. Users of HPC Platforms and Scientific Computing

The convergence between embedded computing systems and high-performance computing (HPC) technologies offers new computing platforms and tools for the users of scientific computing (e.g., people working in numerical analysis, in simulation, modeling, etc.). The proliferation of “cheap” hardware accelerators and multicores makes the “small HPC” (as opposed to computing centers with more powerful computers, grid computing, and exascale computing) accessible to a larger number of users, even though it is still difficult to exploit, due to the complexity of parallel programming, code tuning, interaction with compilers, which result from the multiple levels of parallelism and of memories in the recent architectures. The link between compiler and code optimization research (as in Compsys) and such users are still to be reinforced, both to guarantee the relevance of compiler research efforts with respect to application needs, and to help users better interact with compiler choices and understand performance issues.

The support of Labex MILYON (through its thematic quarters, such as the thematic quarter on compilation we organized in 2013⁰, or the 2016 thematic quarter on high-performance computing, with a dedicated interdisciplinary spring school between numerical simulation and polyhedral compilation, see hereafter) and the activities of the LyonCalcul initiative⁰ are means to get closer to users of scientific computing, even if it is too early to know if Compsys will indeed be directly helpful to them.

⁰Thematic quarter on compilation: <http://labexcompilation.ens-lyon.fr/>

⁰Lyon Calcul federation: <http://lyoncalcul.univ-lyon1.fr>

CONVECS Project-Team

4. Application Domains

4.1. Application Domains

The theoretical framework we use (automata, process algebras, bisimulations, temporal logics, etc.) and the software tools we develop are general enough to fit the needs of many application domains. They are applicable to virtually any system or protocol that consists of distributed agents communicating by asynchronous messages. The list of recent case studies performed with the CADP toolbox (see in particular § 6.5) illustrates the diversity of applications:

- *Bioinformatics*: genetic regulatory networks, nutritional stress response, metabolic pathways,
- *Component-based systems*: Web services, peer-to-peer networks,
- *Databases*: transaction protocols, distributed knowledge bases, stock management,
- *Distributed systems*: virtual shared memory, dynamic reconfiguration algorithms, fault tolerance algorithms, cloud computing,
- *Embedded systems*: air traffic control, avionic systems, medical devices,
- *Hardware architectures*: multiprocessor architectures, systems on chip, cache coherency protocols, hardware/software codesign,
- *Human-machine interaction*: graphical interfaces, biomedical data visualization, plasticity,
- *Security protocols*: authentication, electronic transactions, cryptographic key distribution,
- *Telecommunications*: high-speed networks, network management, mobile telephony, feature interaction detection.

CORSE Project-Team

4. Application Domains

4.1. Transfer

The main industrial sector related to the research activities of CORSE is the one of semi-conductor (programmable architectures spanning from embedded systems to servers). Obviously any computing application which has the objective of exploiting as much as possible the resources (in terms of high-performance but also low energy consumption) of the host architecture is intended to take advantage of advances in compiler and runtime technology. These applications are based over numerical kernels (linear algebra, FFT, convolution...) that can be adapted on a large spectrum of architectures. Members of CORSE already maintain fruitful and strong collaborations with several companies such as STMicroelectronics, Bull, Kalray, or Aselta.

Applying our techniques to a specific real application domain is cherished by all members of the team. In particular we believe (multi-scale) computational mechanics (such as fluid mechanics, molecular dynamics) to be a challenging domain that could take advantage both of compiler and run-time technologies that we intend to develop in CORSE. The goal is to provide an end-to-end solution to the automatic optimization (thus targeting portability of optimized code) of a specific application that requires extensive computational power. If we succeed our research should contribute indirectly to advances in that domain. We are still in the process of prospecting for the most appropriate application.

CTRL-A Team

4. Application Domains

4.1. Distributed systems and High-Performance Computing

Distributed systems have grown to levels of scale and complexity where it is difficult to master their administration and resources management, in dynamic and open environments. One of the growing concerns is that the energy consumption has reached levels where it can not be considered negligible anymore, ecologically or economically. Data centers or high performance computing grids need to be controlled in order to combine minimized power needs with sustained performance and quality of service. As mentioned above, this motivates the automation of their management, and is the major topic of, amongst others, our ANR project Ctrl-Green.

Another challenge in distributed systems is in the fast growing amounts of data to process and store. Currently one of the most common ways of dealing with these challenges is the parallel programming paradigm MapReduce which is slowly becoming the de facto tool for Big Data analytics. While its use is already widespread in the industry, ensuring performance constraints while also minimizing costs provides considerable challenges. Current approaches to ensure performance in cloud systems can be separated into three categories: static, reactive, predictive and hybrid approaches. In the industry, static deployments are the standard and usually tuned based on the application peak demand and are generally over-provisioned. Reactive approaches are usually based on reacting to an input metric such as the current CPU utilisation, request rate, response time by adding and removing servers as necessary. Some public cloud providers offer reactive techniques such as the Amazon Auto Scaler. They provide the basic mechanisms for reactive controllers, but it is up to the user to define the static scaling thresholds which is difficult and not optimal. To deal with this issue, we propose a control theoretical approach, based on techniques that have already proved their usefulness for the control community.

In the domain of parallel systems and High Performance Computing, systems are traditionally less open and more controlled by administrators, but this trend is changing, as they are facing the same challenges in energy consumption, needs for adaptivity in reaction to changing workloads, and security issues in computation outsourcing. Topics of interest for us in this domain concern problem in dynamical management of memory and communications features, which we are exploring in the HPES project of the Labex Persybal-lab (see 9.1).

4.2. Reconfigurable architectures in embedded systems

Dynamically reconfigurable hardware has been identified as a promising solution for the design of energy efficient embedded systems. A common argument in favor of this kind of architecture is the specialization of processing elements, that can be adapted to application functions in order to minimize the delay, the control cost and to improve data locality. Another key benefit is the hardware reuse to minimise the area, and therefore the static power and cost. Further advantages such as hardware updates in long-life products and self-healing capabilities are also often mentioned. In presence of context changes (e.g. environment or application functionality), self-adaptive technique can be applied as a solution to fully benefit from the runtime reconfigurability of a system.

Dynamic Partial Reconfiguration (DPR) of FPGA is another accessible solution to implement and experiment reconfigurable hardware. It has been widely explored and detailed in literature. However, it appears that such solutions are not extensively exploited in practice for two main reasons: i) the design effort is extremely high and strongly depends on the available chip and tool versions; and ii) the simulation process, which is already complex for non-reconfigurable systems, is prohibitively large for reconfigurable architectures. As a result, new adequate methods are required to fully exploit the potential of dynamically reconfigurable and self-adaptive architectures. We are working in this topic, especially on the reconfiguration control aspect, in cooperation with teams specialized in reconfigurable architectures such as the former DaRT team at Inria Lille, and LabSticc in Lorient, as in the recently ended ANR project Famous.

A new ANR project in this application domain, starting end of 2015, is called HPeC, in cooperation with amongst others LabSticc in Lorient and Clermont-Ferrand U., will consider embedded video processing on drones (see [9.2.1](#)).

4.3. Smart environments and Internet of Things

Another application domain for autonomic systems design and control is the Internet of Things, and especially the design of smart environments, at the level of homes, buildings, or cities. These domains are often considered at the level of sensors networks, with a strong emphasis on the acquisition of data in massive scales. The infrastructures are sometimes also equipped with actuators, with a wide range of applications, for example concerning lighting or heating, or access and security aspects. We are interested in closing the control loop in such environments, which is less often studied. In particular, rule-based languages are often used to define the automated systems, and we want to contribute to the safe design of such controllers with guarantees on their behaviors. We are working in this topic in cooperation with teams specialized in infrastructures for smart environments at CEA LETI/DACLE and Orange labs (see [8.1](#)).

DANTE Project-Team

4. Application Domains

4.1. Life Science & Health

In parallel to the advances in modern medicine, health sciences and public health policy, epidemic models aided by computer simulations and information technologies offer an increasingly important tool for the understanding of transmission dynamics and of epidemic patterns. The increased computational power and use of Information and Communication Technologies make feasible sophisticated modelling approaches augmented by detailed in vivo data sets, and allow to study a variety of possible scenarios and control strategies, helping and supporting the decision process at the scientific, medical and public health level. The research conducted in the DANTE project finds direct applications in the domain of LSH since modelling approaches crucially depend on our ability to describe the interactions of individuals in the population. In the MOSAR/iBird project we are collaborating with the team of Pr. Didier Guillemot (Inserm/Institut. Pasteur/Université de Versailles). Within the TUBEXPO and ARIBO projects, we are collaborating with Pr. Jean-Christophe Lucet (Professeur des université Paris VII, Praticien hospitalier APHP).

4.2. Network Science / Complex networks

In the last ten years the science of complex networks has been assigned an increasingly relevant role in defining a conceptual framework for the analysis of complex systems. Network science is concerned with graphs that map entities and their interactions to nodes and links. For a long time, this mathematical abstraction has contributed to the understanding of real-world systems in physics, computer science, biology, chemistry, social sciences, and economics. Recently, however, enormous amounts of detailed data, electronically collected and meticulously catalogued, have finally become available for scientific analysis and study. This has led to the discovery that most networks describing real world systems show the presence of complex properties and heterogeneities, which cannot be neglected in their topological and dynamical description. This has called forth a major effort in developing the methodology to characterise the topology and temporal behaviour of complex networks, to describe the observed structural and temporal heterogeneities, to detect and measure emerging community structure, to see how the functionality of networks determines their evolving structure, and to determine what kinds of correlations play a role in their dynamics. All these efforts have brought us to a point where the science of complex networks has become advanced enough to help us to disclose the deeper roles of complexity and gain understanding about the behaviour of very complicated systems.

In this endeavour the DANTE project targets the study of dynamically evolving networks, concentrating on questions about the evolving structure and dynamical processes taking place on them. During the last year we developed several projects along these lines concerning three major datasets:

- Mobile telephony data: In projects with academic partners and Grandata we performed projects based on two large independent datasets collecting the telephone call and SMS event records for million of anonymised individuals. The datasets record the time and duration of mobile phone interactions and some coarse grained location and demographic data for some users. In addition one of the dataset is coupled with anonymised bank credit information allowing us to study directly the socioeconomic structure of a society and how it determines the communication dynamics and structure of individuals.
- Skype data: Together with Skype Labs/STACC and other academic groups we were leading projects in the subject of social spreading phenomena. These projects were based on observations taken from a temporally detailed description of the evolving social network of (anonymised) Skype users registered between 2003 and 2011. This data contains dates of registration and link creation together with gradual information about their location and service usage dynamics.

- Twitter data: In collaboration with ICAR-ENS Lyon we collected a large dataset about the microblogs and communications of millions of Twitter users in the French Twitter space. This data allows us to follow the spreading of fads/opinions/hashtags/ideas and more importantly linguistic features in online communities. The aim of this collaboration is to set the ground for a quantitative framework studying the evolution of linguistic features and dialects in an social-communication space mediated by online social interactions.

DATAMOVE Team

4. Application Domains

4.1. Data Aware Batch Scheduling

Large scale high performance computing platforms are becoming increasingly complex. Determining efficient allocation and scheduling strategies that can adapt to technological evolutions is a strategic and difficult challenge. We are interested in scheduling jobs in hierarchical and heterogeneous large scale platforms. On such platforms, application developers typically submit their jobs in centralized waiting queues. The job management system aims at determining a suitable allocation for the jobs, which all compete against each other for the available computing resources. Performances are measured using different classical metrics like maximum completion time or slowdown. Current systems make use of very simple (but fast) algorithms that however rely on simplistic platform and execution models, and thus, have limited performances.

For all target scheduling problems we aim to provide both theoretical analysis and complementary analysis through simulations. Achieving meaningful results will require strong improvements on existing models (on power for example) and the design of new approximation algorithms with various objectives such as stretch, reliability, throughput or energy consumption, while keeping in focus the need for a low-degree polynomial complexity.

4.1.1. Status of Current Algorithms

The most common batch scheduling policy is to consider the jobs according to the First Come First Served order (FCFS) with backfilling (BF). BF is the most widely used policy due to its easy and robust implementation and known benefits such as high system utilization. It is well-known that this strategy does not optimize any sophisticated function, but it is simple to implement and it guarantees that there is no starvation (i.e. every job will be scheduled at some moment).

More advanced algorithms are seldom used on production platforms due to both the gap between theoretical models and practical systems and speed constraints. When looking at theoretical scheduling problems, the generally accepted goal is to provide polynomial algorithms (in the number of submitted jobs and the number of involved computing units). However, with millions of processing cores where every process and data transfer have to be individually scheduled, polynomial algorithms are prohibitive as soon as the polynomial degree is too large. The model of *parallel tasks* simplifies this problem by bundling many threads and communications into single boxes, either rigid, rectangular or malleable. Especially malleable tasks capture the dynamicity of the execution. Yet these models are ill-adapted to heterogeneous platforms, as the running time depends on more than simply the number of allotted resources, and some of the common underlying assumptions on the speed-up functions (such as monotony or concavity) are most often only partially verified.

In practice, the job execution times depend on their allocation (due to communication interferences and heterogeneity in both computation and communication), while theoretical models of parallel jobs usually consider jobs as black boxes with a fixed (maximum) execution time. Though interesting and powerful, the classical models (namely, synchronous PRAM model, delay, LogP) and their variants (such as hierarchical delay), are not well-suited to large scale parallelism on platforms where the cost of moving data is significant, non uniform and may change over time. Recent studies are still refining such models in order to take into account communication contentions more accurately while remaining tractable enough to provide a useful tool for algorithm design.

Today, all algorithms in use in production systems are oblivious to communications. One of our main goals is to **design a new generation of scheduling algorithms fitting more closely job schedules according to platform topologies.**

4.1.2. Locality Aware Allocations

Recently, we developed modifications of the standard back-filling algorithm taking into account platform topologies. The proposed algorithms take into account locality and contiguity in order to hide communication patterns within parallel tasks. The main result here is to establish good lower bounds and small approximation ratios for policies respecting the locality constraints. The algorithms work in an online fashion, improving the global behavior of the system while still keeping a low running time. These improvements rely mainly on our past experience in designing approximation algorithms. Instead of relying on complex networking models and communication patterns for estimating execution times, the communications are disconnected from the execution time. Then, the scheduling problem leads to a trade-off: optimizing locality of communications on one side and a performance objective (like the makespan or stretch) on the other side.

In the perspective of taking care of locality, other ongoing works include the study of schedulers for platforms whose interconnection network is a static structured topology (like the 3D-torus of the BlueWaters platform we work on in collaboration with the Argonne National Laboratory). One main characteristic of this 3D-torus platform is to provide I/O nodes at specific locations in the topology. Applications generate and access specific data and are thus bounded to specific I/O nodes. Resource allocations are constrained in a strong and unusual way. This problem is close for actual hierarchical platforms. The scheduler needs to compute a schedule such that I/O nodes requirements are filled for each application while at the same time avoiding communication interferences. Moreover, extra constraints can arise for applications requiring accelerators that are gathered on the nodes at the edge of the network topology.

While current results are encouraging, they are however limited in performance by the low amount of information available to the scheduler. We look forward to extend ongoing work by progressively increasing application and network knowledge (by technical mechanisms like profiling or monitoring or by more sophisticated methods like learning). It is also important to anticipate on application resource usage in terms of compute units, memory as well as network and I/Os to efficiently schedule a mix of applications with different profiles. For instance, a simple solution is to partition the jobs as "communication intensive" or "low communications". Such a tag could be achieved by the users themselves or obtained by learning techniques. We could then schedule low communications jobs using leftover spaces while taking care of high communication jobs. More sophisticated options are possible, for instance those that use more detailed communication patterns and networking models. Such options would leverage the work proposed in Section 4.2 for gathering application traces.

4.1.3. Data-Centric Processing

Exascale computing is shifting away from the traditional compute-centric models to a more data-centric one. This is driven by the evolving nature of large scale distributed computing, no longer dominated by pure computations but also by the need to handle and analyze large volumes of data. These data can be large databases of results, data streamed from a running application or another scientific instrument (collider for instance). These new workloads call for specific resource allocation strategies.

Data movements and storage are expected to be a major energy and performance bottleneck on next generation platforms. Storage architectures are also evolving, the standard centralized parallel file system being complemented with local persistent storage (Burst Buffers, NVRAM). Thus, one data producer can stage data on some nodes' local storage, requiring to schedule close by the associated analytics tasks to limit data movements. This kind of configuration, often referred as *in situ analytics*, is expected to become common as it enables to switch from the traditional I/O intensive workflow (batch-processing followed by *post mortem* analysis and visualization) to a more storage conscious approach where data are processed as closely as possible to where and when they are produced (in situ processing is addressed in details in section 4.3). By reducing data movements and scheduling the extra processing on resources not fully exploited yet, in situ processing is expected to have also a significant positive energetic impact. Analytics codes can be executed in the same nodes than the application, often on dedicated cores commonly called helper cores, or on dedicated nodes called staging nodes. The results are either forwarded to the users for visualization or saved to disk through I/O nodes. In situ analytics can also take benefit of node local disks or burst buffers to reduce data movements.

Future job scheduling strategies should take into account in situ processes in addition to the job allocation to optimize both energy consumption and execution time. On the one hand, this problem can be reduced to an allocation problem of extra asynchronous tasks to idle computing units. But on the other hand, embedding analytics in applications brings extra difficulties by making the application more heterogeneous and imposing more constraints (data affinity) on the required resources. Thus, the main point here is to develop efficient algorithms for dealing with heterogeneity without increasing the global computational cost.

4.1.4. Learning

Another important issue is to adapt the job management system to deal with the bad effects of uncertainties, which may be catastrophic in large scale heterogeneous HPC platforms (jobs delayed arbitrarily far or jobs killed). A natural question is then: *is it possible to have a good estimation of the job and platform parameters in order to be able to obtain a better scheduling ?* Many important parameters (like the number or type of required resources or the estimated running time of the jobs) are asked to the users when they submit their jobs. However, some of these values are not accurate and in many cases, they are not even provided by the end-users. In DataMove, we propose to study new methods for a better prediction of the characteristics of the jobs and their execution in order to improve the optimization process. In particular, the methods well-studied in the field of big data (in supervised Machine Learning, like classical regression methods, Support Vector Methods, random forests, learning to rank techniques or deep learning) could and must be used to improve job scheduling in large scale HPC platforms. This topic received a great attention recently in the field of parallel and distributed processing. A preliminary study has been done recently by our team with the target of predicting the job running times (called wall times). We succeeded to improve significantly in average the reference EASY Back Filling algorithm by estimating the wall time of the jobs, however, this method leads to big delay for the stretch of few jobs. Even if we succeed in determining more precisely hidden parameters, like the wall time of the jobs, this is not enough to determine an optimized solution. The shift is not only to learn on dedicated parameters but also on the scheduling policy. The data collected from the accounting and profiling of jobs can be used to better understand the needs of the jobs and through learning to propose adaptations for future submissions. The goal is to propose extensions to further improve the job scheduling and improve the performance and energy efficiency of the application. For instance preference learning may enable to compute on-line new priorities to back-fill the ready jobs.

4.1.5. Multi-objective Optimization

Several optimization questions that arise in allocation and scheduling problems lead to the study of several objectives at the same time. The goal is then not a single optimal solution, but a more complicated mathematical object that captures the notion of trade-off. In broader terms, the goal of multi-objective optimization is not to externally arbitrate on disputes between entities with different goals, but rather to explore the possible solutions to highlight the whole range of interesting compromises. A classical tool for studying such multi-objective optimization problems is to use *Pareto curves*. However, the full description of the Pareto curve can be very hard because of both the number of solutions and the hardness of computing each point. Addressing this problem will opens new methodologies for the analysis of algorithms.

To further illustrate this point here are three possible case studies with emphasis on conflicting interests measured with different objectives. While these cases are good representatives of our HPC context, there are other pertinent trade-offs we may investigate depending on the technology evolution in the coming years. This enumeration is certainly not limitative.

Energy versus Performance. The classical scheduling algorithms designed for the purpose of performance can no longer be used because performance and energy are contradictory objectives to some extent. The scheduling problem with energy becomes a multi-objective problem in nature since the energy consumption should be considered as equally important as performance at exascale. A global constraint on energy could be a first idea for determining trade-offs but the knowledge of the Pareto set (or an approximation of it) is also very useful.

Administrators versus application developers. Both are naturally interested in different objectives: In current algorithms, the performance is mainly computed from the point of view of administrators, but the users should be in the loop since they can give useful information and help to the construction of better schedules. Hence, we face again a multi-objective problem where, as in the above case, the approximation of the Pareto set provides the trade-off between the administrator view and user demands. Moreover, the objectives are usually of the same nature. For example, *max stretch* and *average stretch* are two objectives based on the slowdown factor that can interest administrators and users, respectively. In this case the study of the norm of stretch can be also used to describe the trade-off (recall that the L_1 -norm corresponds to the average objective while the L_∞ -norm to the max objective). Ideally, we would like to design an algorithm that gives good approximate solutions at the same time for all norms. The L_2 or L_3 -norm are useful since they describe the performance of the whole schedule from the administrator point of view as well as they provide a fairness indication to the users. The hard point here is to derive theoretical analysis for such complicated tools.

Resource Augmentation. The classical resource augmentation models, i.e. speed and machine augmentation, are not sufficient to get good results when the execution of jobs cannot be frequently interrupted. However, based on a resource augmentation model recently introduced, where the algorithm may reject a small number of jobs, some members of our team have given the first interesting results in the non-preemptive direction. In general, resource augmentation can explain the intuitive good behavior of some greedy algorithms while, more interestingly, it can give ideas for new algorithms. For example, in the rejection context we could dedicate a small number of nodes for the usually problematic rejected jobs. Some initial experiments show that this can lead to a schedule for the remaining jobs that is very close to the optimal one.

4.2. Empirical Studies of Large Scale Platforms

Experiments or realistic simulations are required to take into account the impact of allocations and assess the real behavior of scheduling algorithms. While theoretical models still have their interest to lay the groundwork for algorithmic designs, the models are necessarily reflecting a purified view of the reality. As transferring our algorithm in a more practical setting is an important part of our creed, we need to ensure that the theoretical results found using simplified models can really be transposed to real situations. On the way to exascale computing, large scale systems become harder to study, to develop or to calibrate because of the costs in both time and energy of such processes. It is often impossible to convince managers to use a production cluster for several hours simply to test modifications in the RJMS. Moreover, as the existing RJMS production systems need to be highly reliable, each evolution requires several real scale test iterations. The consequence is that scheduling algorithms used in production systems are mostly outdated and not customized correctly. To circumvent this pitfall, we need to develop tools and methodologies for alternative empirical studies, from analysis of workload traces, to job models, simulation and emulation with reproducibility concerns.

4.2.1. Workload Traces with Resource Consumption

Workload traces are the base element to capture the behavior of complete systems composed of submitted jobs, running applications, and operating tools. These traces must be obtained on production platforms to provide relevant and representative data. To get a better understanding of the use of such systems, we need to look at both, how the jobs interact with the job management system, and how they use the allocated resources. We propose a general workload trace format that adds jobs resource consumption to the commonly used SWF⁰ workload trace format. This requires to instrument the platforms, in particular to trace resource consumptions like CPU, data movements at memory, network and I/O levels, with an acceptable performance impact. In a previous work we studied and proposed a dedicated job monitoring tool whose impact on the system has been measured as lightweight (0.35% speed-down) with a 1 minute sampling rate. Other tools also explore job monitoring, like TACC Stats. A unique feature from our tool is its ability to monitor distinctly jobs sharing common nodes.

⁰Standard Workload Format: <http://www.cs.huji.ac.il/labs/parallel/workload/swf.html>

Collected workload traces with jobs resource consumption will be publicly released and serve to provide data for works presented in Section 4.1 . The trace analysis is expected to give valuable insights to define models encompassing complex behaviours like network topology sensitivity, network congestion and resource interferences.

We expect to join efforts with partners for collecting quality traces (ATOS/Bull, Ciment meso center, Joint Laboratory on Extreme Scale Computing) and will collaborate with the Inria team POLARIS for their analysis.

4.2.2. Simulation

Simulations of large scale systems are faster by multiple orders of magnitude than real experiments. Unfortunately, replacing experiments with simulations is not as easy as it may sound, as it brings a host of new problems to address in order to ensure that the simulations are closely approximating the execution of typical workloads on real production clusters. Most of these problems are actually not directly related to scheduling algorithms assessment, in the sense that the workload and platform models should be defined independently from the algorithm evaluations, in order to ensure a fair assessment of the algorithms' strengths and weaknesses. These research topics (namely platform modeling, job models and simulator calibration) are addressed in the other subsections.

We developed an open source platform simulator within DataMove (in conjunction with the OAR development team) to provide a widely distributable test bed for reproducible scheduling algorithm evaluation. Our simulator, named Batsim, allows to simulate the behavior of a computational platform executing a workload scheduled by any given scheduling algorithm. To obtain sound simulation results and to broaden the scope of the experiments that can be done thanks to Batsim, we did not chose to create a (necessarily limited) simulator from scratch, but instead to build on top of the SimGrid simulation framework.

To be open to as many batch schedulers as possible, Batsim decouples the platform simulation and the scheduling decisions in two clearly-separated software components communicating through a complete and documented protocol. The Batsim component is in charge of simulating the computational resources behaviour whereas the scheduler component is in charge of taking scheduling decisions. The scheduler component may be both a resource and a job management system. For jobs, scheduling decisions can be to execute a job, to delay its execution or simply to reject it. For resources, other decisions can be taken, for example to change the power state of a machine i.e. to change its speed (in order to lower its energy consumption) or to switch it on or off. This separation of concerns also enables interfacing with potentially any commercial RJMS, as long as the communication protocol with Batsim is implemented. A proof of concept is already available with the OAR RJMS.

Using this test bed opens new research perspectives. It allows to test a large range of platforms and workloads to better understand the real behavior of our algorithms in a production setting. In turn, this opens the possibility to tailor algorithms for a particular platform or application, and to precisely identify the possible shortcomings of the theoretical models used.

4.2.3. Job and Platform Models

The central purpose of the Batsim simulator is to simulate job behaviors on a given target platform under a given resource allocation policy. Depending on the workload, a significant number of jobs are parallel applications with communications and file system accesses. It is not conceivable to simulate individually all these operations for each job on large platforms with their associated workload due to implied simulation complexity. The challenge is to define a coarse grain job model accurate enough to reproduce parallel application behavior according to the target platform characteristics. We will explore models similar to the BSP (Bulk Synchronous Program) approach that decomposes an application in local computation supersteps ended by global communications and a global synchronization. The model parameters will be established by means of trace analysis as discussed previously, but also by instrumenting some parallel applications to capture communication patterns. This instrumentation will have a significant impact on the concerned application performance, restricting its use to a few applications only. There are a lot of recurrent applications executed on HPC platform, this fact will help to reduce the required number of instrumentations and captures. To assign

each job a model, we are considering to adapt the concept of application signatures as proposed in. Platform models and their calibration are also required. Large parts of these models, like those related to network, are provided by Simgrid. Other parts as the filesystem and energy models are comparatively recent and will need to be enhanced or reworked to reflect the HPC platform evolutions. These models are then generally calibrated by running suitable benchmarks.

4.2.4. Emulation and Reproducibility

The use of coarse models in simulation implies to set aside some details. This simplification may hide system behaviors that could impact significantly and negatively the metrics we try to enhance. This issue is particularly relevant when large scale platforms are considered due to the impossibility to run tests at nominal scale on these real platforms. A common approach to circumvent this issue is the use of emulation techniques to reproduce, under certain conditions, the behavior of large platforms on smaller ones. Emulation represents a natural complement to simulation by allowing to execute directly large parts of the actual evaluated software and system, but at the price of larger compute times and a need for more resources. The emulation approach was chosen in to compare two job management systems from workload traces of the CURIE supercomputer (80000 cores). The challenge is to design methods and tools to emulate with sufficient accuracy the platform and the workload (data movement, I/O transfers, communication, applications interference). We will also intend to leverage emulation tools like Distem from the MADYNES team. It is also important to note that the Batsim simulator also uses emulation techniques to support the core scheduling module from actual RJMS. But the integration level is not the same when considering emulation for larger parts of the system (RJMS, compute node, network and filesystem).

Replaying traces implies to prepare and manage complex software stacks including the OS, the resource management system, the distributed filesystem and the applications as well as the tools required to conduct experiments. Preparing these stacks generate specific issues, one of the major one being the support for reproducibility. We propose to further develop the concept of reconstructability to improve experiment reproducibility by capturing the build process of the complete software stack. This approach ensures reproducibility over time better than other ways by keeping all data (original packages, build recipe and Kameleon engine) needed to build the software stack.

In this context, the Grid'5000 (see Sec. 5.3) experimentation infrastructure that gives users the control on the complete software stack is a crucial tool for our research goals. We will pursue our strong implication in this infrastructure.

4.3. Integration of High Performance Computing and Data Analytics

Data produced by large simulations are traditionally handled by an I/O layer that moves them from the compute cores to the file system. Analysis of these data are performed after reading them back from files, using some domain specific codes or some scientific visualisation libraries like VTK. But writing and then reading back these data generates a lot of data movements and puts under pressure the file system. To reduce these data movements, **the in situ analytics paradigm proposes to process the data as closely as possible to where and when the data are produced.** Some early solutions emerged either as extensions of visualisation tools or of I/O libraries like ADIOS. But significant progresses are still required to provide efficient and flexible high performance scientific data analysis tools. Integrating data analytics in the HPC context will have an impact on resource allocation strategies, analysis algorithms, data storage and access, as well as computer architectures and software infrastructures. But this paradigm shift imposed by the machine performance also sets the basis for a deep change on the way users work with numerical simulations. The traditional workflow needs to be reinvented to make HPC more user-centric, more interactive and turn HPC into a commodity tool for scientific discovery and engineering developments. In this context DataMove aims at investigating programming environments for in situ analytics with a specific focus on task scheduling in particular, to ensure an efficient sharing of resources with the simulation.

4.3.1. Programming Model and Software Architecture

In situ creates a tighter loop between the scientist and her/his simulation. As such, an in situ framework needs to be flexible to let the user define and deploy its own set of analysis. A manageable flexibility requires to favor simplicity and understandability, while still enabling an efficient use of parallel resources. Visualization libraries like VTK or Visit, as well as domain specific environments like VMD have initially been developed for traditional post-mortem data analysis. They have been extended to support in situ processing with some simple resource allocation strategies but the level of performance, flexibility and ease of use that is expected requires to rethink new environments. There is a need to develop a middleware and programming environment taking into account in its foundations this specific context of high performance scientific analytics.

Similar needs for new data processing architectures occurred for the emerging area of Big Data Analytics, mainly targeted to web data on cloud-based infrastructures. Google Map/Reduce and its successors like Spark or Stratosphere/Flink have been designed to match the specific context of efficient analytics for large volumes of data produced on the web, on social networks, or generated by business applications. These systems have mainly been developed for cloud infrastructures based on commodity architectures. They do not leverage the specifics of HPC infrastructures. Some preliminary adaptations have been proposed for handling scientific data in a HPC context. However, these approaches do not support in situ processing.

Following the initial development of FlowVR, our middleware for in situ processing, we will pursue our effort to develop a programming environment and software architecture for high performance scientific data analytics. Like FlowVR, the map/reduce tools, as well as the machine learning frameworks like TensorFlow, adopted a dataflow graph for expressing analytics pipe-lines. We are convinced that this dataflow approach is both easy to understand and yet expresses enough concurrency to enable efficient executions. The graph description can be compiled towards lower level representations, a mechanism that is intensively used by Stratosphere/Flink for instance. Existing in situ frameworks, including FlowVR, inherit from the HPC way of programming with a thinner software stack and a programming model close to the machine. Though this approach enables to program high performance applications, this is usually too low level to enable the scientist to write its analysis pipe-line in a short amount of time. The data model, i.e. the data semantics level accessible at the framework level for error check and optimizations, is also a fundamental aspect of such environments. The key/value store has been adopted by all map/reduce tools. Except in some situations, it cannot be adopted as such for scientific data. Results from numerical simulations are often more structured than web data, associated with acceleration data structures to be processed efficiently. We will investigate data models for scientific data building on existing approaches like Adios or DataSpaces.

4.3.2. Resource Sharing

To alleviate the I/O bottleneck, the in situ paradigm proposes to start processing data as soon as made available by the simulation, while still residing in the memory of the compute node. In situ processings include data compression, indexing, computation of various types of descriptors (1D, 2D, images, etc.). Per se, reducing data output to limit I/O related performance drops or keep the output data size manageable is not new. Scientists have relied on solutions as simple as decreasing the frequency of result savings. In situ processing proposes to move one step further, by providing a full fledged processing framework enabling scientists to more easily and thoroughly manage the available I/O budget.

The most direct way to perform in situ analytics is to inline computations directly in the simulation code. In this case, in situ processing is executed in sequence with the simulation that is suspended meanwhile. Though this approach is direct to implement and does not require complex framework environments, it does not enable to overlap analytics related computations and data movements with the simulation execution, preventing to efficiently use the available resources. Instead of relying on this simple time sharing approach, several works propose to rely on space sharing where one or several cores per node, called *helper cores*, are dedicated to analytics. The simulation responsibility is simply to handle a copy of the relevant data to the node-local in situ processes, both codes being executed concurrently. This approach often lead to significantly better performance than in-simulation analytics.

For a better isolation of the simulation and in situ processes, one solution consists in offloading in situ tasks from the simulation nodes towards extra dedicated nodes, usually called *staging nodes*. These computations are said to be performed *in-transit*. But this approach may not always be beneficial compared to processing on simulation nodes due to the costs of moving the data from the simulation nodes to the staging nodes.

FlowVR enables to mix these different resources allocation strategies for the different stages of an analytics pipeline. Based on a component model, the scientist designs analytics workflows by first developing processing components that are next assembled in a dataflow graph through a Python script. At runtime the graph is instantiated according to the execution context, FlowVR taking care of deploying the application on the target architecture, and of coordinating the analytics workflows with the simulation execution.

But today the choice of the resource allocation strategy is mostly ad-hoc and defined by the programmer. We will investigate solutions that enable a cooperative use of the resource between the analytics and the simulation with minimal hints from the programmer. In situ processings inherit from the parallelization scale and data distribution adopted by the simulation, and must execute with minimal perturbations on the simulation execution (whose actual resource usage is difficult to know a priori). We need to develop adapted scheduling strategies that operate at compile and run time. Because analysis are often data intensive, such solutions must take into consideration data movements, a point that classical scheduling strategies designed first for compute intensive applications often overlook. We expect to develop new scheduling strategies relying on the methodologies developed in Section 4.1.5 . Simulations as well as analysis are iterative processes exposing a strong spatial and temporal coherency that we can take benefit of to anticipate their behavior and then take more relevant resources allocation strategies, possibly based on advanced learning algorithms or as developed in Section 4.1 .

In situ analytics represent a specific workload that needs to be scheduled very closely to the simulation, but not necessarily active during the full extent of the simulation execution and that may also require to access data from previous runs (stored in the file system or on specific burst-buffers). Several users may also need to run concurrent analytics pipe-lines on shared data. This departs significantly from the traditional batch scheduling model, motivating the need for a more elastic approach to resource provisioning. These issues will be conjointly addressed with research on batch scheduling policies (Section 4.1).

4.3.3. Co-Design with Data Scientists

Given the importance of users in this context, it is of primary importance that in situ tools be co-designed with advanced users, even if such multidisciplinary collaborations are challenging and require constant long term investments to learn and understand the specific practices and expectations of the other domain.

We will tightly collaborate with scientists of some application domains, like molecular dynamics or fluid simulation, to design, develop, deploy and assess in situ analytics scenarios, as already done with Marc Baaden, a computational biologist from LBT.

We recently extended our collaboration network. We started in 2015 a PhD co-advised with CEA DAM to investigate in situ analytics scenarios in the context of atomistic material simulations. CEA DAM is a French energy lab hosting one of the largest european supercomputer. They gather physicists, numerical scientists as well as high performance computer engineers, making it a very interesting partner for developing new scientific data analysis solutions. We also got a national grant (2015-2018) to compute in situ statistics for multi-parametric parallel studies with the research department of French power company EDF. In this context we collaborate with statisticians and fluid simulation experts to define in situ scenarios, revisit the statistic operators to be amenable to in situ processing, and define an adapted in situ framework.

DICE Team

4. Application Domains

4.1. Two-Sided Market

Intermediation platforms operate in two-sided markets, that is in environments with two types of actors, producers of good or services on one side, and consumers on the other side. Intermediaries play a fundamental role by allowing the connection of both thypes of actors. If intermediaries already existed in the pre-digital era — banks constitute a historical example of intermediaries — it is really only the advent of digital technologies which boosts the development of intermediation. A large number of activity sectors fall in such a framework, including transportation, press, education, health, etc. We decided to focus on some of them in greater details for their particular relevance.

4.2. Education platforms

Education institutions are at stake because of the new technologies that not only change the access to knowledge, and therefore the traditional euilibrium between teachers and students, but also provide new means to produce knowledge, and share studying experiences.

Our objective is to develop a platform - called Jumplyn - that offers disruptive services for students, helps them produce their work, connects them to other students in the same area, and preserves their contribution online. The platforms targets students. It also aims at offering services on the other side of the education market, i.e. to institutions, by allowing them to organise the work of their students, as well as their evaluation. Jumplyn is accessible online and, as other platforms, evolves continuously.

4.3. Decentralised Voting

Online voting systems are controversial. They are advocated for their simplicity, which could contribute to enhance participation, but criticised for their failure to ensure the same properties as traditional voting systems. We propose an alternative path to online voting relying on decentralised systems with no concentration of data. A patent is under evaluation for the BitBallot protocol.

4.4. City Administration

The team is actively participating to the Inria International Project Lab IPL CityLab on smart cities. We work also with the metropole of Lyon, and its Chief Data Officer in particular, to better understand the equilibrium between online plateforms and the public administration, and the policy regarding data and its accessibility to other parties.

4.5. Metrics for digital economy

While economic metrics based on trade of goods and services, as well as financial exchanges are well-established, exchanges of data, and more generally transborder activities on platforms are not included in standard economic measurements. Defining such metrics both theoretically and practically with means to evaluate them is of great relevance in economy, and beyond.

DRACULA Project-Team

4. Application Domains

4.1. Normal hematopoiesis

4.1.1. Introduction

Modelling normal hematopoiesis will allow us to explore the dynamical appearance of the various cell types, originating from the stem cell compartment, through the bone marrow development up to the blood stream. The differentiated cell types will both fulfill physiological functions, and play a key role on the feedback control on homeostasis (balance of the system) in their own lineages. We will describe the hematopoiesis from three different points of view:

- The initial cell type, the hematopoietic stem cell (HSC);
- The lineage choice question;
- Three differentiated lineages that are responsible for specific function, namely oxygen transport, immune response and coagulation.

The basic mechanisms of our modelling approach are as follows:

- Any cell type can have two possibilities at each time step: to divide or to die.
- At any division step, the cell can either give rise to two daughter cells which are identical to the mother cell (self-renewal) or that are more advanced in their differentiation.

All these processes will be first modelled at the cellular level. In parallel, we will develop models of intra-cellular molecular networks (as some proteins controlling the cell cycle) influencing this decision making process, so as to be able to describe both micro-to-macro effects (molecules influencing the global cell behaviour) as well as macro-to-micro effects (like the global state of the cell population influencing the molecular behaviour).

4.1.2. Hematopoietic stem cells (HSC)

Although widely studied by biologists, HSC are still poorly understood and many questions remain open: How fast and how frequently do they divide? How many of them are in the bone marrow and where? How is their behaviour modified under stress conditions such as blood loss or transfusion?

Our modelling approach will be based on two methods: deterministic and stochastic differential equations with delays (discrete and distributed), on one hand, and the DPD method using the individual based modelling on the other hand. The differential equation models based on the work initiated by Mackey [39] will describe the HSC compartment in normal conditions and the behaviour of these cells under some stress. The DPD method, as a complementary approach, will emphasize the spatial regulation of stem cell behaviour, and we will focus our attention to give a possible answer regarding their location in the bone marrow and the roles of the niche, their number in the system, their possible role under stress (that is their reaction under the different feedback controls).

4.1.3. Blood cell functions

(i) O₂ transport: red lineage

O₂ transport is provided by red blood cells (RBC) also called erythrocytes. Many different stages of maturity (including progenitors, precursors, reticulocytes and erythrocytes) are necessary to achieve the complete formation of RBC. These latter are then released in the blood stream where they transport oxygen. The whole process is tightly dependent on a robust well-balanced equilibrium called homeostasis.

It has been shown in the 1990's that apoptosis is regulated by EPO, a growth factor released by the kidneys under hypoxia. But also, under severe stress (like an important blood loss) some other molecules known as glucocorticoids can be released leading to an increase of the self-renewing rate for each generation. This led to the formulation of a first model, demonstrating the role of self-renewal.

The study of the red blood cell lineage will involve different scale levels, from the molecular one, with the effects of the hormones on the surface and internal parts of the cell, the cell contacts in each stage of RBC formation, and the red branch population in its whole with all the interactions taken into account (see Figure 3) in normal and stress conditions.

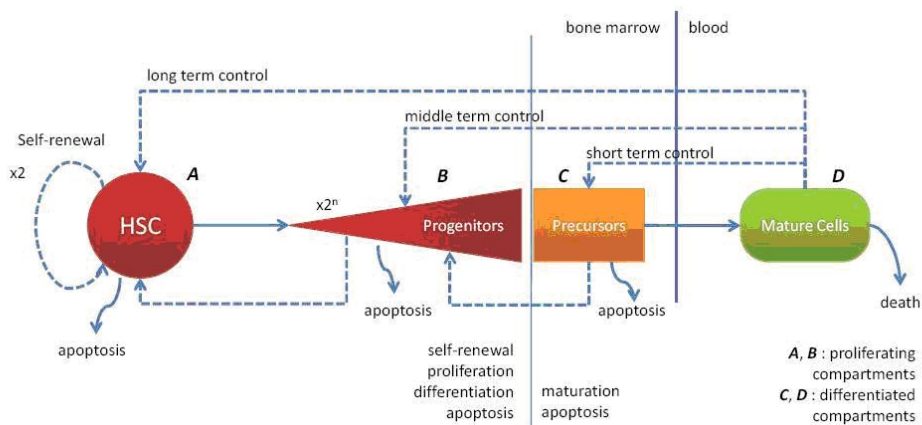


Figure 3. Scheme of Erythropoiesis Modelling ([27]). Without considering explicitly growth factor mediated regulation, all controls (proliferation, self-renewal, differentiation, apoptosis) are mediated by cell populations (dashed arrows). Mature cells can either regulate immature (HSC, progenitors) or almost mature (precursors) cells, precursors may act on progenitor dynamics, etc..

In order to couple the cellular behaviour to explicit molecular events, we will describe the events through a molecular network that is based upon the work of [44]. A first version of this model is shown in Figure 2 .

(ii) Immune response

We will focus on the production of T-cells during an immune response. This represents an important activity of the lymphoid branch, part of leucopoiesis (white blood cell production). Several models of the myeloid branch of leucopoiesis have been investigated in the frame of specific diseases (for instance cyclical neutropenia ([38], [32]), chronic myelogenous leukemia [40]).

Time evolution of T-cell counts during an infection is well known: following the antigen presentation, the number of cells quickly increases (expansion), then decreases more slowly (contraction) and stabilizes around a value higher than the initial value. Memory cells have been produced, and will allow a faster response when encountering the antigen for a second time. Mechanisms that regulate this behaviour are however not well known.

A recent collaboration just started with immunologists (J. Marvel, Ch. Arpin) from the INSERM U851 in Lyon, who provide experimental data that are essential to assess the significance of models, based on strongly nonlinear ordinary differential equations, that can be proposed for T-cell production (Figure 4). By considering molecular events leading to cell activation when encountering a virus, we will propose a multi-scale model of the immune response.

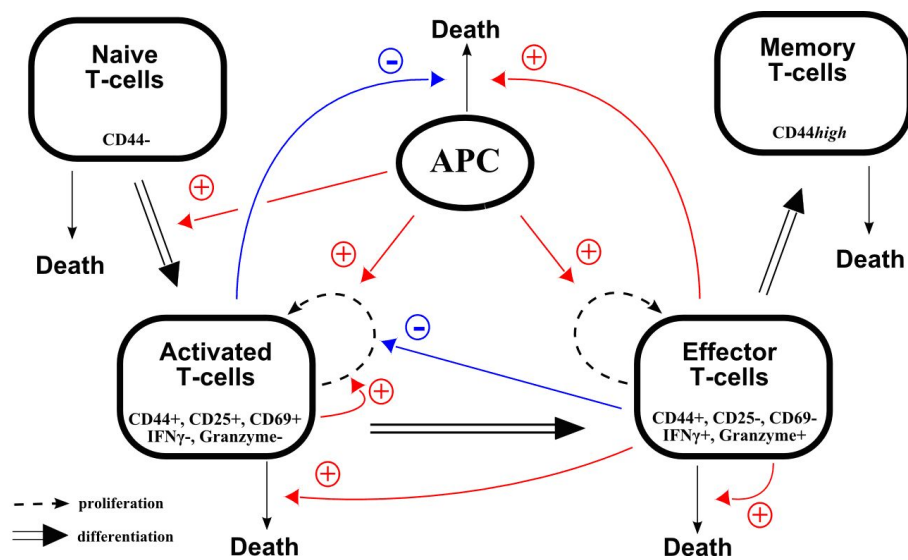


Figure 4. Model of the immune response resulting in the generation of CD8 memory T cells. The response starts with a viral infection resulting in the presentation of viral antigens through antigen presenting cells (APC) to naive T-cells. These latter, once activated, differentiate into activated cells which, under specific feedback loops will either die, differentiate into effector cells or self-renew. Differentiation of effector cells (killer cells) will result in the production of memory cells.

(iii) Coagulation: platelet lineage

Thrombopoiesis, the process of production and regulation of platelets, is similar to erythropoiesis although important differences are observed. These two processes have an immature progenitor (MEP) in common. Platelets are involved in blood coagulation, and can be the source of blood diseases (thrombopenia, thrombocytosis). Their production is mainly regulated by thrombopoietin (TPO), a growth factor similar to EPO.

It is important to mention that very few experimental data exist in the literature, and mathematical modelling of thrombopoiesis did not attract so much attention in the past 20 years. However, collaboration with some leading hematologists in this domain will allow us to get updated and new data regarding this process.

Deterministic models, in the form of structured transport partial differential equations, will be proposed to describe platelet dynamics, through the description of HSC, megakaryocytic progenitor and megakaryocyte (platelet precursor) compartments. Circulating TPO, regulated by platelets, will induce feedback loops in thrombopoiesis, and we will investigate the dynamics of platelet production and emergence of platelet-related diseases.

4.2. Pathological hematopoiesis

The knowledge of hematopoiesis and related diseases has evolved to become a great deal in the past years, and Mackey's previous models (ref. [30]) do not allow us to correctly answer current questions that are clearly oriented toward the investigation of cell signalling pathways. These models nevertheless bring relevant ideas about the essential features of such modelling. It is also noteworthy that even though models of hematopoiesis have existed for quite a long time, their application to questions of explanation and prediction of hematopoiesis dynamics that are encountered in the clinic is still not sufficiently frequent, even though much progress has been achieved in the cooperation between hematologists and mathematicians [41]. This is in the optic of testable experimental predictions that the multi-scale model for pathological hematopoiesis will be developed. For instance, we will concentrate on myeloid leukemias (CML and AML) and their treatment.

4.2.1. Leukemia Modelling

(i) Chronic Myeloid Leukemia

The strong tyrosine kinase activity of the BCR-ABL protein is the basis for the main cell effects that are observed in CML: significant proliferation, anti-apoptotic effect, disruption of stroma adhesion properties, genomic instability. This explains the presence in CML blood of a very important number of cells belonging to the myeloid lineage, at all stages of maturation.

We will consider models based on ordinary differential equations for the action of the main intra- and extra-cellular proteins involved in CML (as BCR-ABL protein), and of transport equations (with or without delay, physiologically structured or not to represent healthy and leukemic cell populations, take into account many interactions between proteins (especially BCR-ABL), cells (anti-apoptotic effect, etc.), and their environment (disruption of stroma adhesion properties, for example). Transport pertains thus to cells from one compartment (or a group of compartments) to another compartment, with a determined speed of aging or maturation. These compartments may be detailed or not: the less mature are stem cells, then progenitor cells, etc.

(ii) Acute Myeloid Leukemia

The natural history of CML leads to its transformation ("blast crisis") in acute myeloid leukemia (AML), following supplementary genetic alterations that produce a maturation arrest (myeloid in 3/4 of cases, lymphoid in 1/4 of cases, confirming the insult to pluripotent stem cells), leading to an accumulation of immature cells in the bone marrow and in the general circulation, resulting in deep medullary impairment and fast fatal outcome, in spite of chemotherapy. This phenomenon is the same as the one observed in de novo AML, i.e., AML without a previous chronic phase.

The different modelling methods of AML will be similar to the ones described for CML, with some exceptions: the appearance of BCR-ABL mutations, which are not relevant in the case of AML, the appearance of a gene (*spi-1*) involved in the differentiation arrest, and constitutive activation of EPO receptor or Kit activating mutations promote proliferation and survival. This explains the accumulation of immature cells in the bone marrow and in the blood stream.

4.2.2. Treatment

As far as treatment of pathological hematopoiesis is concerned, two main strategies currently exist that aim at slowing down or eliminating damaged cell proliferation. The first of these strategies consists in launching the apoptotic process during the cell division cycle. This process is activated, for example when the cell is unable to repair damages, e.g., after exposure to cytostatic drugs. A typical example is apoptosis induced by chemotherapy-induced DNA damage: The damage is recognised by the cell, which then activates the sentinel protein p53 ("guardian of the genome") that arrests the cell cycle to allow, if possible, damage repair. If the latter is unrecoverable, then p53 activates the endogenous apoptotic processes.

The second strategy aims at pushing damaged cells toward the differentiation that has been stopped in the course of their genetic mutation. Since a few years back, a new approach has been developed around the strategy of differentiation therapy. This therapy relies on molecules (growth factors and specific cytokines) that are able to re-initialise the cell differentiation programs that have been modified during malignant transformation. The cancer that is most concerned by the development of this differentiation therapy is AML whose malignant cells present highly undifferentiated features and the ones that present a translocation responsible for the differentiation (PML/RAR of the promyelocytic form, AML1/ETO and CBFbeta/MyH11, involving Core Binding Factors alpha and beta).

Mathematical models based on ordinary differential equations will be developed to describe the action of drugs (in the two cases mentioned above). They will take into account interactions between drugs and their environment. Our goal will be the optimization of possible synergies between drugs acting on distinct cellular targets, and the control of resistances to these treatments as well as their toxicities.

Curative and palliative strategies must take into account the dynamics of healthy and leukemic hematopoietic cells at multiple scales. In time, from optimal scheduling of combination therapy (hours) to avoiding the development of resistances and relapse (months to years). In space, from the stem cell niche to circulating blood. In organization, from gene and signalling networks (JAK/STAT, BCR-ABL) to cell populations and cytokine regulation (EPO, CSFs). Several recent qualitative models have provided insight in the complex dynamics of the disease and the response to treatments. Many of these models focus on the control or regulation processes that promote homeostasis or oscillatory behavior in cell number. However, as A. Morley points out, "once the control-systems features of hematopoiesis are accepted, the ability to construct a model that shows oscillatory behavior, even if the model incorporates the latest advances in hematopoietic cell biology, really adds little new knowledge. Rather, the challenge to modellers would seem to be to provide detailed predictions for the input-output characteristics of the different parts of the various control systems so that these predictions can be tested by experimental hematologists and a truly quantitative description of hematopoiesis can emerge".

We propose for instance, to use models in the form of structured transport partial differential equations (with or without delay, physiologically structured or not) to represent the competition between target, resistant and healthy cell populations. The resulting models to describe the dynamic of these cell populations under the action of drugs are multi-scale systems of the form (Hyperbolic PDE)-ODE or DDE-ODE. For instance, we will develop mathematical models of chronotherapy and pharmacotherapy for CML and AML.

ERABLE Project-Team

4. Application Domains

4.1. Biology

The main area of application of ERABLE is biology understood in its more general sense, with a special focus on symbiosis and on intracellular interactions.

EXMO Project-Team

4. Application Domains

4.1. Semantic web technologies

The main application context motivating our work is the “semantic web” infrastructure.

Internet technologies support organisations and people in accessing and sharing knowledge, often difficult to access in a documentary form. However, these technologies quickly reach their limits: web site organisation is expensive and full-text search inefficient. Content-based information search is becoming a necessity. Content representation enables computers to manipulate knowledge on a more formal ground and to carry out similarity or generality search. Knowledge representation formalisms are good candidates for expressing content.

The vision of a “semantic web” [17] complements the web, with formal knowledge representation spanning across sites. Taking advantage of this semantic web requires the manipulation of various knowledge representation formats. EXMO concerns are thus central to the semantic web implementation. Our work aims at enhancing content understanding, including the intelligibility of communicated knowledge and formal knowledge transformations.

In addition, EXMO considers more specific uses of semantic web technologies in wider contexts.

IBIS Project-Team (section vide)

IMAGINE Project-Team (section vide)

MAVERICK Project-Team

4. Application Domains

4.1. Application Domains

The natural application domain for our research is the production of digital images, for example for movies and special effects, virtual prototyping, video games...

Our research have also been applied to tools for generating and editing images and textures, for example generating textures for maps.

Our current application domains are:

- Offline and real-time rendering in movie special effects and video games;
- Virtual prototyping;
- Scientific visualization;
- Content modeling and generation (e.g. generating texture for video games, capturing reflectance properties, etc);
- Image creation and manipulation.

MISTIS Project-Team

4. Application Domains

4.1. Image Analysis

Participants: Alexis Arnaud, Aina Frau Pascual, Florence Forbes, Stephane Girard, Pascal Rubini, Alessandro Chiancone, Thomas Perret, Pablo Mesejo Santiago, Jaime Eduardo Arias Almeida, Pierre-Antoine Rodesch.

As regards applications, several areas of image analysis can be covered using the tools developed in the team. More specifically, in collaboration with team PERCEPTION, we address various issues in computer vision involving Bayesian modelling and probabilistic clustering techniques. Other applications in medical imaging are natural. We work more specifically on MRI and functional MRI data, in collaboration with the Grenoble Institute of Neuroscience (GIN) and the NeuroSpin center of CEA Saclay. We also consider other statistical 2D fields coming from other domains such as remote sensing, in collaboration with Laboratoire de Planétologie de Grenoble. We worked on hyperspectral images. In the context of the "pole de compétitivité" project I-VP, we worked on images of PC Boards. We also address reconstruction problems in tomography with CEA Grenoble.

4.2. Multi sensor Data Analysis

Participants: Jean-Michel Becu, Florence Forbes.

A number of our methods are at the intersection of data fusion, statistics, machine learning and acoustic signal processing. The context can be the surveillance and monitoring of a zone acoustic state from data acquired at a continuous rate by a set of sensors that are potentially mobile and of different nature (eg WIFUZ project with the ACOEM company in the context of a DGA-rapid initiative). Typical objectives include the development of prototypes for surveillance and monitoring that are able to combine multi sensor data coming from acoustic sensors (microphones and antennas) and optical sensors (infrared cameras) and to distribute the processing to multiple algorithmic blocs. Our interest in acoustic data analysis mainly started from past European projects, POP and Humavips, in collaboration with the PERCEPTION team (PhD theses of Vassil Khalidov, Ramya Narasimha, Antoine Deleforge, Xavier alameda, and Israel Gebru).

4.3. Biology, Environment and Medicine

Participants: Pablo Mesejo Santiago, Aina Frau Pascual, Florence Forbes, Stephane Girard, Seydou Nourou Sylla, Emeline Perthame, Jean-Baptiste Durand, Clement Albert, Julyan Arbel, Jean-Michel Becu, Thibaud Rahier, Brice Olivier, Karina Ashurbekova.

A third domain of applications concerns biology and medicine. We considered the use of missing data models in epidemiology. We also investigated statistical tools for the analysis of bacterial genomes beyond gene detection. Applications in neurosciences are also considered. In the environmental domain, we considered the modelling of high-impact weather events.

MORPHEO Project-Team

4. Application Domains

4.1. 4D modeling

Modeling shapes that evolve over time, analyzing and interpreting their motion has been a subject of increasing interest of many research communities including the computer vision, the computer graphics and the medical imaging communities. Recent evolutions in acquisition technologies including 3D depth cameras (Time-of-Flight and Kinect), multi-camera systems, marker based motion capture systems, ultrasound and CT scans have made those communities consider capturing the real scene and their dynamics, create 4D spatio-temporal models, analyze and interpret them. A number of applications including dense motion capture, dynamic shape modeling and animation, temporally consistent 3D reconstruction, motion analyzes and interpretation have therefore emerged.

4.2. Shape Analysis

Most existing shape analysis tools are local, in the sense that they give local insight about an object's geometry or purpose. The use of both geometry and motion cues makes it possible to recover more global information, in order to get extensive knowledge about a shape. For instance, motion can help to decompose a 3D model of a character into semantically significant parts, such as legs, arms, torso and head. Possible applications of such high-level shape understanding include accurate feature computation, comparison between models to detect defects or medical pathologies, and the design of new biometric models or new anthropometric datasets.

4.3. Human Motion Analysis

The recovery of dense motion information enables the combined analyses of shapes and their motions. Typical examples include the estimation of mean shapes given a set of 3D models or the identification of abnormal deformations of a shape given its typical evolutions. The interest arises in several application domains where temporal surface deformations need to be captured and analysed. It includes human body analyses for which potential applications are anyway numerous and important, from the identification of pathologies to the design of new prostheses.

4.4. Interaction

The ability to build models of humans in real time allows to develop interactive applications where users interact with virtual worlds. The recent evolutions of HMDs, e.g. Oculus Rift, HTC Vibe and Microsoft Hololens, offer now efficient solutions to visualize virtual worlds, which dramatically increases the need for new contents as well as new interactive and immersive solutions. Challenging issues in this domain include the development of real time applications for interactivity and the design of new interactive applications such as virtual fitting rooms.

NANO-D Project-Team

4. Application Domains

4.1. Overview

NANO-D is *a priori* concerned with all applications domains involving atomistic representations, including chemistry, physics, electronics, material science, biology, etc.

Historically, though, our first applications have been in biology, as the next two sections detail. Thanks to the development of algorithms to efficiently simulate reactive force fields, as well as to perform interactive quantum mechanical calculations, however, we now have the possibility to address problems in chemistry, and physics.

4.2. Structural Biology

Structural biology is a branch of molecular biology, biochemistry, and biophysics concerned with the molecular structure of biological macromolecules, especially proteins and nucleic acids. Structural biology studies how these macromolecules acquire the structures they have, and how alterations in their structures affect their function. The methods that structural biologists use to determine the structure typically involve measurements on vast numbers of identical molecules at the same time, such as X-Ray crystallography, NMR, cryo-electron microscopy, etc. In many cases these methods do not directly provide the structural answer, therefore new combinations of methods and modeling techniques are often required to advance further.

We develop a set of tools that help biologists to model structural features and motifs not resolved experimentally and to understand the function of different structural fragments.

- Symmetry is a frequent structural trait in molecular systems. For example, most of the water-soluble and membrane proteins found in living cells are composed of symmetrical subunits, and nearly all structural proteins form long oligomeric chains of identical subunits. Only a limited number of symmetry groups is allowed in crystallography, and thus, in many cases the native macromolecular conformation is not present on high-resolution X-ray structures. Therefore, to understand the realistic macromolecular packing, modeling techniques are required.
- Many biological experiments are rather costly and time-demanding. For instance, the complexity of mutagenesis experiments grows exponentially with the number of mutations tried simultaneously. In other experiments, many candidates are tried to obtain a desired function. For example, about 250,000 candidates were tested for the recently discovered antibiotic Platensimycin. Therefore, there is a vast need in advance modeling techniques that can predict interactions and foresee the function of new structures.
- Structure of many macromolecules is still unknown. For other complexes, it is known only partially. Thus, software tools and new algorithms are needed by biologists to model missing structural fragments or predict the structure of those molecule, where there is no experimental structural information available.

4.3. Pharmaceutics and Drug Design

Drug design is the inventive process of finding new medications based on the knowledge of the biological target. The drug is most commonly an organic small molecule which activates or inhibits the function of a biomolecule such as a protein, which in turn results in a therapeutic benefit to the patient. In the most basic sense, drug design involves design of small molecules that are complementary in shape and charge to the biomolecular target to which they interact and therefore will bind to it. Drug design frequently relies on computer modeling techniques. This type of modeling is often referred to as computer-aided drug design.

Structure-based drug design attempts to use the structure of proteins as a basis for designing new ligands by applying accepted principles of molecular recognition. The basic assumption underlying structure-based drug design is that a good ligand molecule should bind tightly to its target. Thus, one of the most important principles for designing or obtaining potential new ligands is to predict the binding affinity of a certain ligand to its target and use it as a criterion for selection.

We develop new methods to estimate the binding affinity using an approximation to the binding free energy. This approximation is assumed to depend on various structural characteristics of a representative set of native complexes with their structure solved to a high resolution. We study and verify different structural characteristics, such as radial distribution functions, and their affect on the binding free energy approximation.

4.4. Nano-engineering

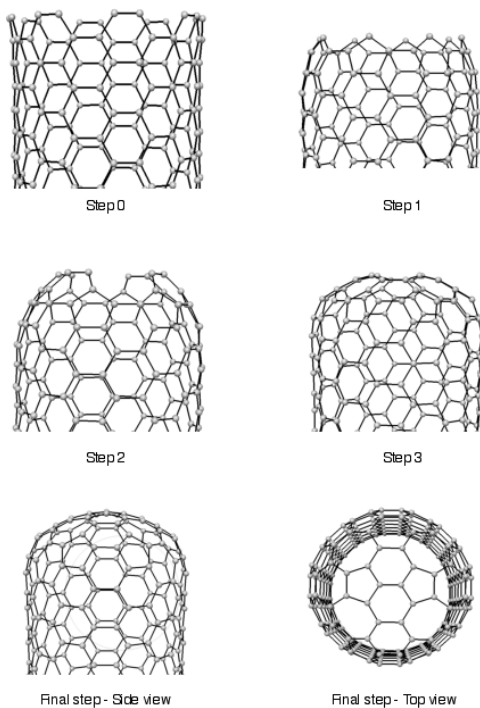


Figure 1. Snapshots of a nanotube capping process with the adaptive interactive modeler. Thanks to the adaptive methodology, this operation can be done in a few minutes.

In general, we want to develop methods to ease nano-engineering of artificial nanosystems, such as the ones described above (DNA nanotechnology, nano-mechanisms, etc.). We have shown, for example, that our incremental and adaptive algorithms allow us to easily edit and model complex shapes, such as a nanotube (Fig. 1) and the “nano-pillow” below (Fig. 2). Please read more about the SAMSON software platform for more examples.

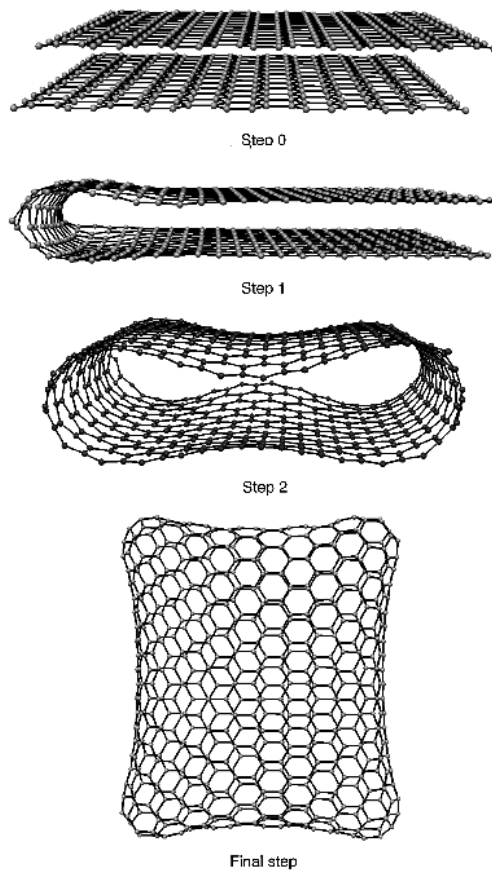


Figure 2. Different steps to prototype a “nano-pillow” with the adaptive interactive modeler.

NECS Project-Team

4. Application Domains

4.1. A large variety of application domains

Sensor and actuator networks are ubiquitous in modern world, thanks to the advent of cheap small devices endowed with communication and computation capabilities. Potential application domains for research in networked control and in distributed estimation are extremely various, and include the following examples.

- Intelligent buildings, where sensor information on CO_2 concentration, temperature, room occupancy, etc. can be used to control the heating, ventilation and air conditioning (HVAC) system under multi-objective considerations of comfort, air quality, and energy consumption.
- Smart grids: the operation of electrical networks is changing from a centralized optimization framework towards more distributed and adaptive protocols, due to the high number of small local energy producers (e.g., solar panels on house roofs) that now interact with the classic large power-plants.
- Disaster relief operations, where data collected by sensor networks can be used to guide the actions of human operators and/or to operate automated rescue equipment.
- Surveillance using swarms of Unmanned Aerial Vehicles (UAVs), where sensor information (from sensors on the ground and/or on-board) can be used to guide the UAVs to accomplish their mission.
- Environmental monitoring and exploration using self-organized fleets of Autonomous Underwater Vehicles (AUVs), collaborating in order to reach a goal such as finding a pollutant source or tracing a seabed map.
- Infrastructure security and protection using smart camera networks, where the images collected are shared among the cameras and used to control the cameras themselves (pan-tilt-zoom) and ensure tracking of potential threats.

In particular, NECS team is currently focusing in the areas described in detail below.

4.2. Intelligent transportation systems

Throughout the world, roadways are notorious for their congestion, from dense urban network to large freeway systems. This situation tends to get worse over time due to the continuous increase of transportation demand whereas public investments are decreasing and space is lacking to build new infrastructures. The most obvious impact of traffic congestion for citizens is the increase of travel times and fuel consumption. Another critical effect is that infrastructures are not operated at their capacity during congestion, implying that fewer vehicles are served than the amount they were designed for. Using macroscopic fluid-like models, the NECS team has initiated new researches to develop innovative traffic management policies able to improve the infrastructure operations. The research activity is on two main challenges: (1) modeling and forecasting, so as to provide accurate information to users, e.g., travel times; and (2) control, via ramp-metering and/or variable speed limits. The Grenoble Traffic Lab (see <http://necs.inrialpes.fr/pages/grenoble-traffic-lab.php>) is an experimental platform, collecting traffic infrastructure information in real time from Grenoble South Ring, together with innovative software e.g. for travel-time prediction, and a show-case where to graphically illustrate results to the end-user. This activity is done in close collaboration with local traffic authorities (DIR-CE, CG38, La Metro), and with the start-up company Karrus (<http://www.karrus-its.com/>)

4.3. Inertial navigation

Since 2014, the team is exploring techniques for pedestrian navigation and algorithms for attitude estimation, in collaboration with the Tyrex team (Inria-Rhône-Alpes). The goal is to use such algorithms in augmented reality with smartphones. Inertial navigation is a research area related to the determination of 3D attitude and position of a rigid body. Attitude estimation is usually based on data fusion from accelerometers, magnetometers and gyroscopes, sensors that we find usually in smartphones. These algorithms can be used also to provide guidance to pedestrians, e.g., to first responders after a disaster, or to blind people walking in unfamiliar environments. This task is particularly challenging for indoor navigation, where no GPS is available.

4.4. Multi-robot collaborative coordination

Due to the cost or the risks of using human operators, many tasks of exploration, or of after-disaster intervention are performed by un-manned drones. When communication becomes difficult, e.g., under water, or in spatial exploration, such robots must be autonomous. Complex tasks, such as exploration, or patrolling, or rescue, cannot be achieved by a single robot, and require a self-coordinated fleet of autonomous devices. NECS team has studied the marine research application, where a fleet of Autonomous Underwater Vehicles (AUVs) self-organize in a formation, adapting to the environment, and reaching a source, e.g., of a pollutant. This has been done in collaboration with IFREMER, within the national project ANR CONNECT and the European FP7 project FeedNetBack [1]. On-going research in the team concerns source localization, with a fleet of mobile robots, including wheeled land vehicles.

4.5. Control design of hydroelectric powerplants

We have started a collaboration with ALSTOM HYDRO, on collaborative and reconfigurable resilient control design of hydroelectric power plants. This work is within the framework of the joint laboratory Inria/ALSTOM (see <http://www.inria.fr/innovation/actualites/laboratoire-commun-inria-alstom>). A first concrete collaboration has been established with the CIFRE thesis of Simon Gerwig, who has studied how to improve performance of a hydro-electric power-plant outside its design operation conditions, by adaptive cancellation of oscillations that occur in such operation range.

NUMED Project-Team (section vide)

PERCEPTION Project-Team (section vide)

PERSVASIVE INTERACTION Team

4. Application Domains

4.1. Smart Energy Systems

Participants: Amr Alyafi, Patrick Reignier Partners: UMR G-SCOP, UMR LIG (Persuasive Interaction, IIHM), CEA Liten, PACTE, Vesta Systems and Elithis.

Work in this area explores techniques for a user centric energy management system, where user needs and tacit knowledge drive the search of solutions. These are calculated using a flexible energy model of the living areas. The system is personified by energy consultants with which building actors such as building owners, building managers, technical operators but also occupants, can interact with in order to co-define energy strategies, benefiting of both assets: tacit knowledge of human actors, and measurement with computation capabilities of calculators. Putting actors in the loop, i.e. making energy not only visible but also controllable is the needed step before large deployment of energy management solutions. It is proposed to develop interactive energy consultants for all the actors, which are energy management aided systems embedding models in order to support the decision making processes. MIRROR (interactive monitoring), WHAT-IF (interactive quantitative simulation), EXPLAIN (interactive qualitative simulation), SUGGEST-AND-ADJUST (interactive management) and RECOMMEND (interactive diagnosis) functionalities will be developed.

4.2. E-Textile

Participant: Sabine Coquillart

Partner: LIMSI

Collaboration with the HAPCO team from LIMSI on e-textiles.

4.3. Interaction with Pervasive Media

Participants: Sabine Coquillart, Jingtao Chen

Partners: Inria GRA, GIPSA, G-SCOP

Pseudo-haptic feedback is a technique aiming to simulate haptic sensations without active haptic feedback devices. Pseudo-haptic techniques have been used to simulate various haptic feedbacks such as stiffness, torques, and mass. In the framework of Jingtao Chen PhD thesis, a novel pseudo-haptic experiment has been set up. The aim of this experiment is to study the EMG signals during a pseudo-haptic task. A stiffness discrimination task similar to the one published in Lecuyer's PhD thesis has been chosen. The experimental set-up has been developed, as well as the software controlling the experiment. Pre-tests are under way. They will be followed by the tests with subjects.

4.4. Bayesian Reasoning

Participants: Emmanuel Mazer, Marvin Faix

The development of modern computers is mainly based on increase of performances and decrease of size and energy consumption, with no notable modification of the basic principles of computation. In particular, all the components perform deterministic and exact operations on sets of binary signals. These constraints obviously impede further sizable progresses in terms of speed, miniaturization and power consumption. The main goal of the project MicroBayes is to investigate a radically different approach, using stochastic bit streams to perform computations. The aim of this project is to show that stochastic architectures can outperform standard computers to solve complex inference problems both in terms of execution speed and of power consumption. We will demonstrate the feasibility on two applications involving low level information processing from sensor signals, namely sound source localization and separation.

POLARIS Team

4. Application Domains

4.1. Large Computing Infrastructures

Supercomputers typically comprise thousands to millions of multi-core CPUs with GPU accelerators interconnected by complex interconnection networks that are typically structured as an intricate hierarchy of network switches. Capacity planning and management of such systems not only raises challenges in term of computing efficiency but also in term of energy consumption. Most legacy (SPMD) applications struggle to benefit from such infrastructure since the slightest failure or load imbalance immediately causes the whole program to stop or at best to waste resources. To scale and handle the stochastic nature of resources, these applications have to rely on dynamic runtimes that schedule computations and communications in an opportunistic way. Such evolution raises challenges not only in terms of programming but also in terms of observation (complexity and dynamicity prevents experiment reproducibility, intrusiveness hinders large scale data collection, ...) and analysis (dynamic and flexible application structures make classical visualization and simulation techniques totally ineffective and require to build on *ad hoc* information on the application structure).

4.2. Next-Generation Wireless Networks

Considerable interest has arisen from the seminal prediction that the use of multiple-input, multiple-output (MIMO) technologies can lead to substantial gains in information throughput in wireless communications, especially when used at a massive level. In particular, by employing multiple inexpensive service antennas, it is possible to exploit spatial multiplexing in the transmission and reception of radio signals, the only physical limit being the number of antennas that can be deployed on a portable device. As a result, the wireless medium can accommodate greater volumes of data traffic without requiring the reallocation (and subsequent re-regulation) of additional frequency bands. In this context, throughput maximization in the presence of interference by neighboring transmitters leads to games with convex action sets (covariance matrices with trace constraints) and individually concave utility functions (each user's Shannon throughput); developing efficient and distributed optimization protocols for such systems is one of the core objectives of Theme 5.

Another major challenge that occurs here is due to the fact that the efficient physical layer optimization of wireless networks relies on perfect (or close to perfect) channel state information (CSI), on both the uplink and the downlink. Due to the vastly increased computational overhead of this feedback – especially in decentralized, small-cell environments – the ongoing transition to fifth generation (5G) wireless networks is expected to go hand-in-hand with distributed learning and optimization methods that can operate reliably in feedback-starved environments. Accordingly, one of POLARIS' application-driven goals will be to leverage the algorithmic output of Theme 5 into a highly adaptive resource allocation framework for next-generation wireless systems that can effectively "learn in the dark", without requiring crippling amounts of feedback.

4.3. Energy and Transportation

Participant: Nicolas Gast.

This work is mainly done within the Quanticol European project.

Smart urban transport systems and smart grids are two examples of collective adaptive systems. They consist of a large number of heterogeneous entities with decentralised control and varying degrees of complex autonomous behaviour. Within the QUANTICOL project, we develop an analysis tools to help to reason about such systems. Our work relies on tools from fluid and mean-field approximation to build decentralized algorithms that solve complex optimization problems. We focus on two problems: decentralized control of electric grids and capacity planning in vehicle-sharing systems to improve load balancing.

PRIVATICS Project-Team

3. Application Domains

3.1. Domain 1: Privacy in smart environments.

Privacy in smart environments. One illustrative example is our latest work on privacy-preserving smart-metering [2]. Several countries throughout the world are planning to deploy smart meters in house-holds in the very near future. Traditional electrical meters only measure total consumption on a given period of time (i.e., one month or one year). As such, they do not provide accurate information of when the energy was consumed. Smart meters, instead, monitor and report consumption in intervals of few minutes. They allow the utility provider to monitor, almost in real-time, consumption and possibly adjust generation and prices according to the demand. Billing customers by how much is consumed and at what time of day will probably change consumption habits to help matching energy consumption with production. In the longer term, with the advent of smart appliances, it is expected that the smart grid will remotely control selected appliances to reduce demand. Although smart metering might help improving energy management, it creates many new privacy problems. Smart-meters provide very accurate consumption data to electricity providers. As the interval of data collected by smart meters decreases, the ability to disaggregate low-resolution data increases. Analysing high-resolution consumption data, Non-intrusive Appliance Load Monitoring (NALM) can be used to identify a remarkable number of electric appliances (e.g., water heaters, well pumps, furnace blowers, refrigerators, and air conditioners) employing exhaustive appliance signature libraries. We developed DREAM, Differentially privatE smArt Metering, a scheme that is private under the differential privacy model and therefore provides strong and provable guarantees. With our scheme, an (electricity) supplier can periodically collect data from smart-meters and derive aggregated statistics while learning only limited information about the activities of individual households. For example, a supplier cannot tell from a user's trace when he watched TV or turned on heating.

3.2. Domain 2: Big Data and Privacy

We believe that another important problem will be related to privacy issues in big data. Public datasets are used in a variety of applications spanning from genome and web usage analysis to location-based and recommendation systems. Publishing such datasets is important since they can help us analyzing and understanding interesting patterns. For example, mobility trajectories have become widely collected in recent years and have opened the possibility to improve our understanding of large-scale social networks by investigating how people exchange information, interact, and develop social interactions. With billion of handsets in use worldwide, the quantity of mobility data is gigantic. When aggregated, they can help understand complex processes, such as the spread of viruses, and build better transportation systems. While the benefits provided by these datasets are indisputable, they unfortunately pose a considerable threat to individual privacy. In fact, mobility trajectories might be used by a malicious attacker to discover potential sensitive information about a user, such as his habits, religion or relationships. Because privacy is so important to people, companies and researchers are reluctant to publish datasets by fear of being held responsible for potential privacy breaches. As a result, only very few of them are actually released and available. This limits our ability to analyze such data to derive information that could benefit the general public. It is now an urgent need to develop Privacy-Preserving Data Analytics (PPDA) systems that collect and transform raw data into a version that is immunized against privacy attacks but that still preserves useful information for data analysis. This is one of the objectives of Privatics. There exists two classes of PPDA according to whether the entity that is collecting and anonymizing the data is trusted or not. In the trusted model, that we refer to as Privacy-Preserving Data Publishing (PPDP), individuals trust the publisher to which they disclose their data. In the untrusted model, that we refer to as Privacy-Preserving Data Collection (PPDC), individuals do not trust the data publisher. They may add some noise to their data to protect sensitive information from the data publisher.

Privacy-Preserving Data Publishing: In the trusted model, individuals trust the data publisher and disclose all their data to it. For example, in a medical scenario, patients give their true information to hospitals to receive proper treatment. It is then the responsibility of the data publisher to protect privacy of the individuals' personal data. To prevent potential data leakage, datasets must be sanitized before possible release. Several proposals have been recently proposed to release private data under the Differential Privacy model [25, 56, 26, 57, 50]. However most of these schemes release a "snapshot" of the datasets at a given period of time. This release often consists of histograms. They can, for example, show the distributions of some pathologies (such as cancer, flu, HIV, hepatitis, etc.) in a given population. For many analytics applications, "snapshots" of data are not enough, and sequential data are required. Furthermore, current work focusses on rather simple data structures, such as numerical data. Release of more complex data, such as graphs, are often also very useful. For example, recommendation systems need the sequences of visited websites or bought items. They also need to analyse people connection graphs to identify the best products to recommend. Network trace analytics also rely on sequences of events to detect anomalies or intrusions. Similarly, traffic analytics applications typically need sequences of visited places of each user. In fact, it is often essential for these applications to know that user A moved from position 1 to position 2, or at least to learn the probability of a move from position 1 to position 2. Histograms would typically represent the number of users in position 1 and position 2, but would not provide the number of users that moved from position 1 to position 2. Due to the inherent sequentiality and high-dimensionality of sequential data, one major challenge of applying current data sanitization solutions on sequential data comes from the uniqueness of sequences (e.g., very few sequences are identical). This fact makes existing techniques result in poor utility. Schemes to privately release data with complex data structures, such as sequential, relational and graph data, are required. This is one the goals of Privatics. In our current work, we address this challenge by employing a variable-length n-gram model, which extracts the essential information of a sequential database in terms of a set of variable-length n - grams [15]. We then intend to extend this approach to more complex data structures.

Privacy-Preserving Data Collection: In the untrusted model, individuals do not trust their data publisher. For example, websites commonly use third party web analytics services, such as Google Analytics to obtain aggregate traffic statistics such as most visited pages, visitors' countries, etc. Similarly, other applications, such as smart metering or targeted advertising applications, are also tracking users in order to derive aggregated information about a particular class of users. Unfortunately, to obtain this aggregate information, services need to track users, resulting in a violation of user privacy. One of our goals is to develop Privacy-Preserving Data Collection solutions. We propose to study whether it is possible to provide efficient collection/aggregation solutions without tracking users, i.e. without getting or learning individual contributions.

ROMA Project-Team

4. Application Domains

4.1. Applications of sparse direct solvers

Sparse direct (multifrontal) solvers have a wide range of applications as they are used at the heart of many numerical methods in computational science: whether a model uses finite elements or finite differences, or requires the optimization of a complex linear or nonlinear function, one often ends up solving a linear system of equations involving sparse matrices. There are therefore a number of application fields, among which some of the ones cited by the users of our sparse direct solver MUMPS (see Section 6.1) are: structural mechanics, biomechanics, medical image processing, tomography, geophysics, electromagnetism, fluid dynamics, econometric models, oil reservoir simulation, magneto-hydro-dynamics, chemistry, acoustics, glaciology, astrophysics, circuit simulation, and work on hybrid direct-iterative methods.

SOCRATE Project-Team (section vide)

SPADES Project-Team

4. Application Domains

4.1. Industrial Applications

Our applications are in the embedded system area, typically: transportation, energy production, robotics, telecommunications, systems on chip (SoC). In some areas, safety is critical, and motivates the investment in formal methods and techniques for design. But even in less critical contexts, like telecommunications and multimedia, these techniques can be beneficial in improving the efficiency and the quality of designs, as well as the cost of the programming and the validation processes.

Industrial acceptance of formal techniques, as well as their deployment, goes necessarily through their usability by specialists of the application domain, rather than of the formal techniques themselves. Hence, we are looking to propose domain-specific (but generic) realistic models, validated through experience (*e.g.*, control tasks systems), based on formal techniques with a high degree of automation (*e.g.*, synchronous models), and tailored for concrete functionalities (*e.g.*, code generation).

4.2. Industrial Design Tools

The commercially available design tools (such as UML with real-time extensions, MATLAB/ SIMULINK/ dSPACE⁰) and execution platforms (OS such as VXWORKS, QNX, real-time versions of LINUX ...) start now to provide besides their core functionalities design or verification methods. Some of them, founded on models of reactive systems, come close to tools with a formal basis, such as for example STATEMATE by iLOGIX.

Regarding the synchronous approach, commercial tools are available: SCADE⁰ (based on LUSTRE), CONTROLBUILD and RT-BUILDER (based on SIGNAL) from GEENYSYS⁰ (part of DASSAULTSYSTEMES), specialized environments like CELLCONTROL for industrial automatism (by the INRIA spin-off ATHYS– now part of DASSAULTSYSTEMES). One can observe that behind the variety of actors, there is a real consistency of the synchronous technology, which makes sure that the results of our work related to the synchronous approach are not restricted to some language due to compatibility issues.

4.3. Current Industrial Cooperations

Regarding applications and case studies with industrial end-users of our techniques, we cooperate with Thales on schedulability analysis for evolving or underspecified real-time embedded systems, with Orange Labs on software architecture for cloud services and with Daimler on reduction of nondeterminism and analysis of deadline miss models for the design of automotive systems.

⁰<http://www.dspaceinc.com>

⁰<http://www.esterel-technologies.com>

⁰<http://www.geensoft.com>

STEPP Project-Team

4. Application Domains

4.1. Introduction

In the context described in the previous sections, we can distinguish two connected and complementary strategies for analyzing environmental pressures: a sectorial approach and a spatial one. The first one is more directly connected to ecological accounting, the second one has more direct relations to urban economy and land cover modelling. Let us start by describing the former.

4.2. Ecological accounting for sectorial pressure assessment

One of the major issues in the assessment of the long-term sustainability of urban areas is related to the concept of “imported sustainability”. Cities bring in from the outside most of their material and energy resources, and reject to the outside the waste produced by their activity. The modern era has seen a dramatic increase in both volume and variety of these material flows and consumption as well as in distance of origin and destination of these flows, usually accompanied by a spectacular increase in the associated environmental impacts. A realistic assessment of the sustainability of urban areas requires to quantify both local and distant environmental impacts; greenhouse gas emissions are only one aspect of this question. Such an assessment brings to light the most relevant direct and indirect lines of action on these issues. In this respect, it is useful to introduce the alternative concepts of consumer versus producer responsibility (or point of view).

The producer point of view is the most useful to pinpoint relevant direct lines of actions on environmental pressures due to production. In other respects, any territory imports and exports goods and services from and to the rest of the world. The consumer point of view provides information on the indirect pressures associated with these exchanges, as production responds to a final demand. Tracking the various supply chains through the analysis of the structure of the local economy and its relations and dependencies to the external world allows us to identify critically important contributions to environmental pressures; this also enables us to define fair environmental indicators in order not to attribute environmental pressures to producers only (whose responsibility is the easier to quantify of the two). In this approach, the producer responsibility follows directly from the measurement of its energy and material uses, while the consumer responsibility is established indirectly through an allocation of the impacts of production to the final consumers, but this second mode of allocation is to some extent virtual and partly subjective. Four methods stand out:

- Material Flow Analysis (MFA)
- Input-Output Analysis (IOA)
- Life-Cycle Analysis (LCA)
- Ecological Footprint (EF)

Each of these is based on a well-defined structuring element: mass conservation for MFA, measure of industrial inter-dependencies for IOA, identification of all the steps from cradle to grave for LCA, measure of biocapacity demand for EF. The different methods have preferred areas of application. For example, EF is more relevant for analyzing primary production such as agricultural staples, wood, etc. IOA is more focused on whole industrial sectors, while LCA is geared towards end-user products, taken as functional units; finally, primary materials (such as metals), waste and emissions are more easily characterized through MFA. Methodological choices are driven by the type of question one needs to address, data availability and collection method and the spatial scales under consideration. Indeed, data can be used in two different ways: bottom-up or top-down. The bottom-up data is more precise, but in general precludes comprehensiveness; on the contrary, the top-down data is by nature more comprehensive, but is not suited for a detailed, fine-scale analysis of the results.

STEEP is pursuing its research program on this theme with three major goals: 1) Creating a comprehensive database enabling pressure analyses; 2) Developing methodologies and models resolving scaling issues, and developing algorithms allowing us to rigorously and automatically obtain adequate assessments; 3) Providing a synthetic analysis of environmental pressures associated to the major material flows, at various geographic levels (employment catchment area, *département* and *région*, for France), with the explicit aim of incorporating this type of information in the public decision process on environmental issues, via specifically designed decision-help procedures.

4.3. Urban economy and land use/land cover changes: assessment of spatial distributions of the pressures

The preceding section was focused on territorial metabolism, in particular on the analysis of supply chains. Here territories are examined with a more prominent emphasis on their spatial dimension, with attention to: the spatial distribution of local pressures previously identified (from a land use point of view), and the modeling of future land use and activity location (from an economic point of view). These two questions correspond to very different modeling strategies: the first one is more statistical in nature, extrapolating future land use from past evolution combined with global territory scenarios; the other one has a more fundamental flavor and focuses on an understanding of the processes driving urbanization. For this, we focus more precisely on the question of household and businesses choices of localization, as well as on spatial fluxes within the territory (transportation of goods and persons). The critical point here is to understand and manage urban sprawl and its environmental effects (GHG emission, loss of arable land, ecosystem fragmentation, and so on).

4.3.1. Land Use/Land Cover Change models (LUCC)

LUCC models are mostly used in environmental sciences, e.g. to evaluate the impact of climate change on agriculture, but they can also be used to analyze urban sprawl. There is a variety of models, static or dynamic, grid- or agent- based, local or global, etc., and with varying degrees of sophistication concerning spatio-temporal analysis or decision structures incorporated in the model.

The models of interest here are statistical in nature but spatially explicit. Following decades of development, they are robust, versatile and mature. In principle, agent-models have a larger potential for representing decision processes, but in practice this advantage results in a loss of universality of the models. Among the most well-known and most mature models, one can mention the CLUE family of models, DINAMIC, or LCM (Land Change Modeler). These models are well described in the literature, and will only be briefly presented here.

These models analyze change in land use in a statistical way; they are structured around three different modules:

- The first module determines the probability of change of pixels of the territory (pixels are typically tens to hundreds of meters in size).
- The second module defines the global changes between the various land uses of interest per time step (usually, a few years), based on global scenarios of evolution of the territory under study. These first two modules are independent of one another.
- The last module distributes changes of land use in an explicit manner, pixel per pixel, at each time step, on the basis of the information provided by the first two modules.

Probabilities of change are calibrated on past evolution, from the differences between two past maps of land use in the more favorable cases, or from a single map otherwise (under the assumption that the logic of occupation changes is the same as the logic of land use at this single date). Such changes are then characterized in a statistical way with the help of modeling variables identified by the modeler as having potential explaining or structuring power (typically, a few to a dozen variables are used for one type of land use change). For example, in the case of urban sprawl, typical explaining factors are the distance to existing urbanized zones or distances to roads and other means of transportation, elements of real estate costs, etc. Global scenarios are quantified in terms of global changes in land use over the whole studied area (e.g., how many hectares are

transformed from agricultural to urban uses in a given number of years, how does this evolve over time...); this is done either from academic expert knowledge, or from information provided by local planning agencies. Whenever feasible, models are validated by comparing the model predictions with actual evolution at a later date. Therefore, such models need from one to three land use maps at different dates for calibration and validation purposes (the larger the number of maps, the more robust and accurate the model). A large array of statistical tools is available in the literature to perform the calibration and validation of the model.

The horizon of projections of such models is limited in time, typically 20-30 years, due to the inherent uncertainty in such models, although they are occasionally used on longer time-scales. Climate change constraints are included, when needed, through scenarios, as it is not in the scope of such models to incorporate ecological processes that may translate climate change constraints into land cover change dynamics. Note that on such short time-scales, climate change is not dominated by the mean climate evolution but by decade variations which average out on longer time-scales and are not modeled in the global climate models used e.g. for IPCC projections for the end of the century; as a consequence, the various IPCC climate scenarios cannot be distinguished on such a short time horizon.

With regard to LUCC, the STEEP team has been involved for four years in the ESNET project whose funding came to a close in July of 2016, but the scientific production of the project is still underway. This project bears on the characterization of local Ecosystem Services networks; the project has been coordinated by LECA (*Laboratoire d'Ecologie Alpine*), in collaboration with a number of other research laboratories (most notably, IRSTEA Grenoble, besides our team), and in close interaction with a panel of local stakeholders; the scale of interest is typically a landscape (in the ecologic/geographic sense, i.e., a zone a few kilometers to a few tens of kilometers wide). The project aims at developing a generic modelling framework of ecosystem services, and studying their behavior under various scenarios of coupled urban/environment evolution, at the 2030/2040 horizon, under constraints of climate change. The contribution of the STEEP team is centered on the Land Use/Land Cover Change (LUCC) model that will be one of the major building blocks of the whole project modelling effort, with the help of an ESNET funded post-doctoral researcher. In the process, areas of conceptual and methodological improvements of statistical LUCC models have been identified; implementing these improvements will be useful for the LUCC community at large, independently of the ESNET project needs.

4.3.2. *Models for Land-Use and Transportation Interactions (LUTI)*

Urban transport systems are intricately linked to urban structure and activities, i.e., to land use. Urbanization generally implies an increased travel demand. Cities have traditionally met this additional demand by extending transportation supply, through new highways and transit lines. In turn, an improvement of the accessibility of ever-farther land leads to an expansion of urban development, resulting in a significant feedback loop between transportation infrastructure and land use, one of the main causes of urban sprawl. Transportation models allow us to address questions generally limited to the impacts of new infrastructures, tolls and other legislation on traffic regulation⁰, on user behavior⁰, or on the environment⁰. LUTI models (Land-Use and Transport Integrated models) can answer a much broader spectrum of issues. For example, they allow us to understand how the localization of households and of economic activities (which generate transportation demand) adapt to changes of transportation supply. They also allow us to assess the impacts of such changes on the increase in real estate value, or more generally on their effects on the economic development of a specific sector or neighborhood. An economic vision interprets all these interactions in terms of equilibrium between demand and supply. Modelling the localization of households and employments (companies) relies on capturing the way stakeholders arbitrate between accessibility, real estate prices, and attractiveness of different areas.

State of the art and operability of LUTI models. The first model that proved able to analyze the interactions between transport and urbanization was developed by Lowry. Since then theories and models have become increasingly complex over time. They can be classified according to different criteria. A first classification

⁰Congestion, cost and time spent for the transport, etc.

⁰Changes in modality choice.

⁰CO2 emissions, air pollution, noise nuisance, etc.

retraces the historic path of these theories and models. They can be associated with one or several of the approaches underlying all present theories: economic base theory and gravity models, Input/Output models and theory of urban rent, and micro-simulations. A second possibility consists in classifying the models according to their aims and means.

Significant scientific progress has been made over the last thirty years. Nevertheless, modelling tools remain largely restricted to the academic world. Today, only seven models have at least had one recent application outside academia or are commercialized or potentially marketable, in spite of the important needs expressed by the urban planning agencies: Cube Land, DELTA, MARS, OPUS/UrbanSim, PECAS, TRANUS and Pirandello.

To guide their choice of a modelling framework, users can rely on various criteria such as the strength of the theoretical framework, the quality and the diversity of the available documentation, the accessibility of the models (is the model freely available? is the code open source? is the software regularly updated and compatible with the recent operating systems?), the functionality and friendliness of user interfaces (existence of graphic user interface, possibility of interfacing with Geographic Information Systems), existence of technical assistance, volume and availability of the data required to implement the model, etc. For example, among the seven models mentioned above, only two are open source and mature enough to meet professional standards: TRANUS and UrbanSim⁰. These two models are very different but particularly representative of the main current philosophies and trends in this scientific domain. Their comparison is informative.

STEPP implication in LUTI modelling. As yet, very few local planning authorities make use of these strategic models, mostly because they are difficult to calibrate and validate. Systematic improvement on these two critical steps would clearly increase the level of confidence in their results; these limitations hinder their dissemination in local agencies. One of the major goals of STEEP is therefore to meet the need for better calibration and validation strategies and algorithms. This research agenda lies at the core of our project CITiES (*ANR Modèles Numériques*). As for LUTI modeling, we have been using the TRANUS model since the creation of our team. We have also been working on UrbanSim from the beginning of the CITiES project. In this framework we work in close collaboration with AURG⁰, the local urban planning agency of Grenoble (*Agence d'Urbanisme de la Région Grenobloise*) in order to better understand and to improve the relevance of these tools for such territorial agencies.

⁰<http://www.urbansim.org>

⁰<http://www.aurg.org/>

THOTH Project-Team

4. Application Domains

4.1. Visual applications

Any solution to automatically understanding images and videos on a semantic level will have an immediate impact on a wide range of applications. For example:

- Semantic-level image and video access is highly relevant for visual search on the Web, in professional archives and personal collections.
- Visual data organization is applicable to organizing family photo and video albums as well as to large-scale information retrieval.
- Visual object recognition has potential applications ranging from surveillance, service robotics for assistance in day-to-day activities as well as the medical domain.
- Action recognition is highly relevant to visual surveillance, assisted driving and video access.
- Real-time scene understanding is relevant for human interaction through devices such as HoloLens, Oculus Rift.

TYREX Project-Team

4. Application Domains

4.1. Web Programming Technologies

Despite the major social and economic impacts of the web revolution, current web programming methods and content representation are lagging behind and remain severely limited and in many respects archaic. Dangerously, designing web applications even becomes increasingly complex as it relies more and more on a jungle of programming languages, tools and data formats, each targeted toward a different application layer (presentation, application and storage). This often yields complex and opaque applications organized in silos, which are costly, inefficient, hard to maintain and evolve, and vulnerable to errors and security holes. In addition, the communication aspects are often handled independently via remote service invocations and represent another source of complexity and vulnerability. We believe that we reached a level where there is an urgent need and a growing demand for alternative programming frameworks that capture the essence of web applications: advanced content, data and communication. Therefore, successful candidate frameworks must capture rich document formats, data models and communication patterns. A crucial aspect is to offer correction guarantees and flexibility in the application architecture. For instance, applications need to be checked, optimized and managed as a whole while leveraging on the consistency of their individual components and data fragments. For all these reasons, we believe that a new generation of tools must be created and developed in order to overcome the aforementioned limitations of current web technologies.

4.2. Multimedia and Augmented Environments

The term Augmented Environments refers collectively to ubiquitous computing, context-aware computing, and intelligent environments. The goal of our research on these environments is to introduce personal Augmented Reality (AR) devices, taking advantage of their embedded sensors. We believe that personal AR devices such as mobile phones or tablets will play a central role in augmented environments. These environments offer the possibility of using ubiquitous computation, communication, and sensing to enable the presentation of context-sensitive information and services to the user. AR applications often rely on 3D content and employ specialized hardware and computer vision techniques for both tracking and scene reconstruction and exploration. Our approach tries to seek a balance between these traditional AR contexts and what has come to be known as mobile AR browsing. It first acknowledges that mobile augmented environment browsing does not require that 3D content be the primary means of authoring. It provides instead a method for HTML5 and audio content to be authored, positioned in the surrounding environments and manipulated as freely as in modern web browsers. The applications we develop to guide and validate our concepts are pedestrian navigation techniques and applications for cultural heritage visits. Features found in augmented environments are demanding for the other activities in the team. They require all kinds of multimedia information, that they have to combine. This information has to be processed efficiently and safely, often in real time, and it also, for a significant part, has to be created by human users.

URBANET Team

4. Application Domains

4.1. Smart urban infrastructure

Unlike the communication infrastructure that went through a continuous development in the last decades, the distribution networks in our cities including water, gas and electricity are still based on 19th century infrastructure. With the introduction of new methods for producing renewable but unpredictable energy and with the increased attention towards environmental problems, modernizing distribution networks became one of the major concerns in the urban world. An essential component of these enhanced systems is their integration with information and communications technology, the result being a smart distribution infrastructure, with improved efficiency and reliability. This evolution is mainly based on the increased deployment of automatic equipment and the use of machine-to-machine and sensor-to-actuator communications that would allow taking into account the behavior and necessities of both consumers and suppliers

Another fundamental urban infrastructure is the transportation system. The progress made in the transportation industry over the last century has been an essential factor in the development of today's urban society, while also triggering the birth and growth of other economic branches. However, the current transportation system has serious difficulties coping with the continuous growth in the number of vehicles, especially in an urban environment. As a major increase in the capacity of a city road infrastructure, already in place for tens or even hundreds of years, would imply dissuasive costs, the more realistic approach is to optimize the use of the existing transportation system. As in the case of distribution networks, the intelligence of the system can be achieved through the integration of information and communication capabilities. However, for smart transportation the challenges are somehow different, because the intelligence is no longer limited to the infrastructure, but propagates to vehicles themselves. Moreover, the degree of automation is reduced in transportation systems, as most actions resulting in reduced road congestion, higher reliability or improved safety must come from the human driver (at least in the foreseeable future)

Finally, smart spaces are becoming an essential component of our cities. The classical architecture tools used to design and shape the urban environment are more and more challenged by the idea of automatically modifying private and public spaces in order to adapt to the requirements and preferences of their users. Among the objectives of this new urban planning current, we can find the transformation of the home in a proactive health care center, fast reconfigurable and customizable workplaces, or the addition of digital content in the public spaces in order to reshape the urban scene. Bringing these changing places in our daily lives is conditioned by a major shift in the construction industry, but it also involves important advancements in digital infrastructure, sensing, and communications

4.2. Urban participatory sensing

Urban sensing can be seen as the same evolution of the environment digitalization as social networking has been for information flows. Indeed, besides dedicated and deployed sensors and actuators, still required for specific sensing operations such as the real-time monitoring of pollution levels, there is a wide range of relevant urban data that can be collected without the need for new communication infrastructures, leveraging instead on the pervasiveness of smart mobile terminals. With more than 80% of the population owning a mobile phone, the mobile market has a deeper penetration than electricity or safe drinking water. Originally designed for voice transmitted over cellular networks, mobile phones are today complete computing, communication and sensing devices, offering in a handheld device multiple sensors and communication technologies.

Mobile devices such as smartphones or tablets are indeed able to gather a wealth of informations through embedded cameras, GPS receivers, accelerometers, and cellular, WiFi and bluetooth radio interfaces. When collected by a single device, such data may have small value per-se, however its fusion over large scales could prove critical for urban sensing to become an economically viable mainstream paradigm.

This is even more true when less traditional mobile terminals are taken into account: privately-owned cars, public transport means, commercial fleets, and even city bikes are starting to feature communication capabilities and the Floating Car Data (FCD) they generate can bring a dramatic contribution to the cause of urban sensing. Indeed, other than enlarging the sensing scope even further, e.g., through Electronic Control Units (ECUs), these mobile terminals are not burdened by strong energy constraints and can thus significantly increase the granularity of data collection. This data can be used by authorities to improve public services, or by citizens who can integrate it in their choices. However, in order to kindle this hidden information, important problems related to data gathering, aggregation, communication, data mining, or even energy efficiency need to be solved.

4.3. Human-centric networks

Combining location awareness and data recovered from multiple sources like social networks or sensing devices can surface previously unknown characteristics of the urban environment, and enable important new services. As a few examples, one could think of informing citizens about often disobeyed (and thus risky) traffic signs, polluted neighborhoods, or queue waiting times at current exhibitions in the urban area.

Beyond letting their own devices or vehicles autonomously harvest data from the environment through embedded or onboard sensors, mobile users can actively take part in the participatory sensing process because they can, in return, benefit from citizen-centric services which aim at improving their experience of the urban life. Crowdsourcing applications have the potential to turn citizens into both sources of information and interactive actors of the city. It is not a surprise that emerging services built on live mobile user feedback are rapidly meeting a large success. In particular, improving everyone's mobility is probably one of the main services that a smart city shall offer to its inhabitants and visitors. This implies providing, through network broadcast data or urban smart-furniture, an accurate and user-tailored information on where people should head in order to find what they are looking for (from a specific kind of shop to a free parking slot), on their current travel time estimates, on the availability of better alternate means of transport to destination. Depending on the context, such information may need to be provided under hard real-time constraints, e.g., in presence of road accidents, unauthorized public manifestations, or delayed public transport schedules.

In some cases, information can also be provided to mobile users so as to bias or even enforce their mobility: drivers can be alerted of the arrival of an emergency vehicle so that they leave the leftmost lane available, or participants leaving vast public events can be directed out of the event venue through diverse routes displayed on their smartphones so as to dynamically balance the pedestrian flows and reduce their waiting times.