Activity Report 2011

Section Application Domains

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4. Application Domains

4.1. High Performance Computing


4.1.1. Models and Algorithms for Coarse Grained Computation

With this work we aim at extending the coarse grained modeling (and the resulting algorithms) that we provide previously, see [6], to hierarchically composed machines such as clusters of clusters or clusters of multiprocessors.

To be usable in a Grid context this modeling has first of all to overcome a principal constraint of the existing models: the idea of an homogeneity of the processors and the interconnection network. Even if the long term goal is to target arbitrary architectures it would not be realistic to think to achieve this directly, but in different steps:

- Hierarchical but homogeneous architectures: these are composed of an homogeneous set of processors (or of the same computing power) interconnected with a non-uniform network or bus which is hierarchic (CC-Numa, clusters of SMP s).
- Hierarchical heterogeneous architectures: there is no established measurable notion of efficiency or speedup. Also most certainly not any arbitrary collection of processors will be useful for computation on the Grid. Our aim is to be able to give a set of concrete indications of how to construct an extensible Grid.

In parallel, we have to work upon the characterization of architecture-robust efficient algorithms, i.e., algorithms that are independent, up to a certain degree, of low-level components or the underlying middleware.

Asynchronous algorithms are very good candidates as they are robust to dynamic variations of the performances of the interconnection network used. Moreover, they are even tolerant to the loss of message related to the computations. However, as mentioned before they cannot be used in all cases. We will then focus on the feasibility to modify those schemes in order to widen their range of applicability while preserving a maximum of asynchronism.

Finally, as the number of components grows, so does the probability of having failures. Work has already been achieved to provide efficient fault tolerance solutions for some SPMD-with-communications and Master-Worker families of parallel applications (cf. Section 6.1.9). Being at the application level, these solutions seem suitable for the aforementioned heterogeneous architectures and may complement algorithmic-based fault tolerance such as the one naturally provided by asynchronous algorithms. We are currently investigating the compatibility of our fault tolerance solutions with some applications developed to run on clusters of GPGPUs (e.g.: American option pricer). We also see to extend our solutions to support and take advantage of asynchronous algorithms.

4.1.2. Irregular Problems

Irregular data structures like sparse graphs and matrices are in wide use in scientific computing and discrete optimization. The importance and the variety of application domains are the main motivation for the study of efficient methods on such type of objects. The main approaches to obtain good results are parallel, distributed and out-of-core computation.

We follow several tracks to tackle irregular problems: automatic parallelization, design of coarse grained algorithms and the extension of these to external memory settings.
In particular we study the possible management of very large graphs, as they occur in reality. Here, the notion of "networks" appears twofold: on one side many of these graphs originate from networks that we use or encounter (Internet, Web, peer-to-peer, social networks) and on the other side the handling of these graphs has to take place in a distributed Grid environment. The principal techniques to handle these large graphs will be provided by the coarse grained models. With the PRO model [6] and the parXXL library we already provide tools to better design algorithms (and implement them afterward) that are adapted to these irregular problems.

In addition we will be able to rely on certain structural properties of the relevant graphs (short diameter, small clustering coefficient, power laws). This will help to design data structures that will have good locality properties and algorithms that compute invariants of these graphs efficiently.

4.1.3. Heterogeneous Architecture Programming

Clusters of heterogeneous nodes, composed of CPUs and GPUs, require complex multi-grain parallel algorithms: coarse grain to distribute tasks on cluster nodes and fine grain to run computations on each GPU. Algorithms implementation is achieved on these architectures using a multi-paradigm parallel development environment, typically composed of MPI and CUDA libraries (compiling with both gcc and NVIDIA nvcc compilers).

We investigate the design of multi-grain parallel algorithm and multi-paradigm parallel development environment for GPU clusters, in order to achieve both speedup and size up on different kinds of algorithms and applications. Our main application targets are: financial computations, PDE solvers, and relaxation methods.

4.1.4. Energy

Nowadays, society is getting more and more aware of the problem of energy supply and is therefore concerned with reducing energy consumption. Computer science is not an exception and a lot of effort has to be made in our domain in order to optimize the energetic efficiency of our systems and algorithms.

In that context, we investigate the potential benefit of using intensively parallel devices such as GPUs in addition to CPUs. Although such devices present quite high instantaneous energy consumptions, their energetic efficiency, that is to say their ratio of flops/Watt is often much better than the one of CPUs.

We have studied the potential energetic gain of GPUs in different kinds of applications (pricer, PDE solver,...). Our experiments have pointed out that there is, in most cases, a complex frontier between the best energetic solutions (CPU alone, CPU + GPU) according to the problem parameters (problem size,...) and architecture configuration (number of nodes, network...). Then, we have designed a first set of models that allows for predicting the best combination of compute kernels according to a given context of use. Further investigations will be done in order to enhance the models and try to design a dynamic adaptive scheme to make a bi-objective optimization (computing performance and energy consumption).

4.1.5. Load balancing

Although load balancing in parallel computing has been intensively studied, it is still an issue in the most recent parallel systems whose complexity and dynamic nature regularly increase. For the grid in particular, where the nodes or the links may be intermittent, the demand is stronger and stronger for non-centralized algorithms.

In a joint work with the University of Franche-Comté, we study the design and optimal tuning of a fully decentralized load balancing scheme (see 8.2.8). In particular, we study the optimal load amount to migrate between neighboring nodes. We have developed a SimGrid program to study the impact of the different strategies and we are currently adapting our load balancing scheme to a real application of neural learning (AdaBoost). This code was initially developed by S. Genaud and V. Galtier to compare JavaSpace and P2P MPI.

Another aspect of load-balancing is also addressed by our team in the context of the Neurad project. Neurad is a multi-disciplinary project involving our team and some computer scientists and physicists from the University of Franche-Comté to tackle the planning of external radiotherapy against cancer. In that work, we have already proposed an original approach in which a neural network is used inside a numerical algorithm to provide
radiation dose deposits in any heterogeneous environments, see [42]. The interest of the Neurad software is to combine very small computation times (five minutes) with an accuracy close to the most accurate methods (Monte-Carlo) whereas these accurate methods take several hours to deliver their results.

In fact, in Neurad most of the computational cost is hidden in the learning of the internal neural network. This is why we work on the design of a parallel learning algorithm based on domain decomposition [25]. However, as learning the obtained sub-domains may take quite different times, a pertinent load-balancing is required in order to get approximately the same learning times for all the sub-domains. The work here is thus more focused on the decomposition strategy as well as the load estimator in the context of neural learning. We have recently proposed an efficient algorithm to perform the decomposition and the data selection of an initial learning set in order to obtain similar learning times of the induced sub-networks [20].

4.2. Providing Environments for Experiments

Participants: Sébastien Badia, Tomasz Buchert, Pierre-Nicolas Clauss, Sylvain Contassot-Vivier, El Mehdi Fekari, Jens Gustedt, Emmanuel Jeanvoine, Lucas Nussbaum, Martin Quinson, Tinaherinantenaina Rakotoariveloh, Cristian Rosa, Luc Sarzyniec, Christophe Thiéry, Stéphane Vialle.

4.2.1. Simulating Distributed Applications

We are major contributors to the SIMGrid framework (see 5.4 for the software description, and 6.2.1 for the new results of this year) a collaboration with the Univ. of Hawaii, Manoa, and INRIA Grenoble-Rhône-Alpes, France. It enables the simulation of distributed applications in large-scale settings for the specific purpose of evaluating and assessing algorithms. Simulations not only allow repeatable results (what is near to impossible when experimenting the applications on real experimental facilities) but also make it possible to explore wide ranges of platform and application scenarios. SIMGrid implements realistic fluid network models that result in very fast yet precise simulations. This is one of the main simulation tools used in the Grid Computing community.

4.2.2. Formally Assessing Distributed Algorithms

In joint research with Stephan Merz of the Veridis team of INRIA Nancy and LORIA, we are interested in the verification (essentially via model checking) of distributed and peer-to-peer algorithms. Whereas model checking is now routinely used for concurrent and embedded systems, existing algorithms and tools can rarely be effectively applied for the verification of asynchronous distributed algorithms and systems.

We are working on integrating these methods to the SIMGrid tool to make them more accessible to non-experts. The expected benefit of such an integration is that programmers can complement simulation runs by exhaustive state space exploration in order to detect defects that would be hard to reproduce by testing. Indeed, a simulation platform provides a controlled execution environment that mediates interactions between processes, and between processes and the environment, and thus provides the basic functionality for implementing a model checker. The principal challenge is the state explosion problem, as a naive approach to systematic generation of all possible process interleavings would be infeasible beyond the most trivial programs. Moreover, it is impractical to store the set of global system states that have already been visited: the programs under analysis are arbitrary C programs with full access to the heap, making even a hashed representation of system states very difficult and costly to implement.

4.2.3. Grid’5000

Grid’5000 is a scientific testbed for experimenting with a large variety of types of distributed systems, such as High Performance Computing, Clouds, P2P or Grids. It provides a unique combination of features to its users:

- deployment of user-provided operating system on bare hardware, with the Kadeploy tool developed in our team
- access to various technologies (CPUs, high performance networks, etc.) at a large scale
- dedicated network backbone, with monitoring and isolation features
- programmable API, for scripted experiments.
Grid’5000 is currently composed of 11 sites (one in Nancy, managed by our team, and two geographically close to Nancy, in Reims and Luxembourg). The Nancy site is one of the most important, both in terms of number of nodes and cores, and in terms of contribution to the technical team.

With this combination of features, Grid’5000 is a world-leading testbed for research in its field, and plays a central role in our work on experimentation methodologies.

4.2.4. Emulation

Experimental testbeds such as Grid’5000 provide a stable environment which is important to allow reproducible experiments. However, sometimes, the experimental conditions provided by the testbed do not match the conditions required by an experiment, in terms of computing power, network bandwidth, latency and topology, etc.

We are working on a software tool called Distem (see 5.2) based on another tool that we developed previously, Wrekavoc (see 5.3). The goal of Distem is to emulate a heterogeneous environment consisting of nodes of different compute and memory capacity and varying network bandwidth and latency. On such an emulated environment, it is possible to execute a real, unmodified application.

Distem uses homogeneous Linux clusters and achieves this emulation by controlling the heterogeneity of a given platform by degrading CPU and network of each node composing this platform.

4.2.5. InterCell

InterCell aims at setting up a cluster (256 PCs) for interactive fine grain computation. It is granted by the Lorraine Region (CPER 2007), and managed at the Metz campus of SUPÉLEC.

The purpose is to allow easy fine grain parallel design, providing interactive tools for the visualization and the management of the execution (debug, step by step, etc). The parallelization effort is not visible to the user, since InterCell relies on the dedicated parXXL framework, see 5.1 below. Among the applications that are tested is the interactive simulation of PDEs in physics, based on the Escapade project, see [29].

4.2.6. Experimental platform of GPU clusters

We participate in the scientific exploitation of two experimental 16-node clusters of GPUs that are installed at the SUPELEC Metz site. One cluster has already GPU with "FERMI" architecture, and the second should be updated at the beginning of 2012. This platform allows the experimentation of scientific programming on GPU ("GPGPU"), and to track computing and energetic performances, with specific monitoring hardware.

Development environments available on these GPU clusters are mainly the gcc suite and its OpenMP library, OpenMPI and the CUDA environment of nVIDIA's nvcc compiler.
4. Application Domains

4.1. Scientific visualization

Participants: Guillaume Caumon, Nicolas Cherpeau, Samuel Hornus, Bruno Jobard, Bruno Lévy, Romain Merland, Vincent Nivoliers, Jeanne Pellerin, Nicolas Ray.

Besides developing new solutions for geometry processing and numerical light simulation, we aim at applying these solutions to real-size scientific and industrial problems. In this context, scientific visualization is our main applications domain. With the advances in acquisition techniques, the size of the data sets to be processed increases faster than Moore’s law, and represents a scientific and technical challenge. To ensure that our processing and visualization algorithms scale-up, we develop a combination of algorithmic, software and hardware architectures. Namely, we are interested in hierarchical function bases, and in parallel computation on GPUs (graphic processing units).

Our developments in parallel processing and GPU programming permit our geometry processing and light simulation solutions to scale-up, and handle real-scale data from other research and industry domains. The following applications are developed within the MIS (Modelization, Interaction, Simulation) and AOC (Analysis, Optimization and Control) programs, which are supported by the “Contrat de Plan État-Région Lorraine”.

4.2. Geology

Participants: Guillaume Caumon, Samuel Hornus, Bruno Jobard, Bruno Lévy, Romain Merland, Vincent Nivoliers, Jeanne Pellerin, Nicolas Ray.

This application domain is led by the Gocad consortium, created by Prof. Mallet, now headed by Guillaume Caumon. The consortium involves 48 universities and most of the major oil and gas companies. ALICE contributes to Gocad with numerical geometry and visualization algorithms for oil and gas engineering. The currently explored domains are complex and dynamic structural models construction, extremely large seismic volumes exploration, and drilling evaluation and planning. The solutions that we develop are transferred to the industry through Earth Decision Sciences. Several Ph.D. students are co-advised by researchers in GOCAD and ALICE.
4. Application Domains

4.1. Data analysis and local regression

Our expertise in data analysis and advanced statistics methods has given rise to a wide number of interdisciplinary collaborations. Among those, here are the most challenging at a scientific level:

(i) Peanut allergy: In the recent past, a direct application of factor analysis techniques has been concerned with a study about allergic patients. This project was focusing on allergies to peanut, and aimed at predicting the level of an allergic crisis according to some biological parameters. In this context, no rigorous discriminant analysis had been performed before, and the article [2] has been considered as an achievement in this direction.

(ii) Fetal pathology: An ongoing work concerning local regression techniques is related to Fetal Biometry, an investigation line suggested by a collaboration between our team and the Centre de Placentologie et Foetopathologie de la Maternité Régionale de Nancy, under the direction of Professor Bernard Foliguet. The methods involved in Fetal Biometry are usually based on the comparison of some measured values with the predicted values derived from reference charts or equations in a normal population. However, it happens that maternal and pregnancy characteristics have a significant influence on in-utero Fetal Biometry. We will thus produce some models allowing to construct customized fetal biometric size charts. In order to evaluate them, classical and polynomial regression can be used, but they are not the most appropriate to the kind data we have to handle. Hence, we plan to use local regression estimation in order to perform such an evaluation.

(iii) Cohorts analysis: Some medical teams in Nancy are faced with an overwhelming amount of data, for which a serious statistical assessment is needed. Among those let us mention the Stanislas cohort handled at the Centre Alexis Vautrin, which provides a huge amount of data potentially enabling a sharp identification of the biological characters involved in cardiovascular diseases. As in many instances in Biostatistics, one is then faced with a very high dimensional data, from which we hope to extract a reduced number of significant variables allowing to predict the cardiovascular risk accurately. Moreover, these characters should be meaningful to practitioners. The objective for us is thus to design an appropriate variable selection, plus a classification procedure in this demanding context.

Let also mention the starting collaboration with the INSERM team of Pr. Jean-Louis Guéant and the INRIA team Orpailleur (particularly with Marie-Dominique Desvignes and Malika Smail). The goal of this collaboration is to extract biological markers for different diseases (cognitive decline; inflammatory intestinal diseases; liver cancer). To this aim, the INSERM team provides us with several data cohorts with a high number of variables and subjects. As in the Stanislas cohort, the objective for us is to design an appropriate variable selection, plus a classification procedure in this demanding context. This work has the originality to combine our own techniques with those developed by the Orpailleur team, based on symbolic tools. We hope that this experience will enrich both points of view and give rise to new methods of data analysis.

4.2. Estimation for complex and biological systems

Our main application for this line of investigation is the photodynamic therapy developed by T. Bastogne. We shall also focus on bacteriophage therapies and subdiffusion within molecules.
(i) Photodynamic therapy. One of the main application we have in mind for our identification problems is to model photodynamic therapy. This promising cancer treatment involves selective uptake and retention of a photosensitive drug in a tumor, followed by irradiation with light at an appropriate wavelength. Photosensitizers are photoactive compounds such as for instance porphyrins and chlorins. The activated photosensitizer is thought to produce singlet oxygen at high doses and thereby to initiate apoptotic and necrotic death of tumor. Due to the lack of response reproducibility, the complexity of interactions between physical, chemical and biological aspects and the high cost of experiments, there is a real demand in good mathematical and physical models which might help to better control and understand PDT responses. We are particularly concerned with modeling the drug uptake into cancer cells, the photoreactions induced by light exposition and tumor growth kinetics.

(ii) Bacteriophage systems. A collaboration between our team, the Mathematics and the Genetics and Microbiology Departments at the Universitat Autònoma de Barcelona (UAB) is being set up, focusing on probabilistic aspects of bacteriophage therapies for animal diseases like hemorrhagic septicemia in cattle or atrophic rhinitis in swine. This kind of therapy consists in inoculating a (benign) virus to animals in order to kill the bacteria known to be responsible of the disease. It was in use in the Soviet Union until the 80s, and is now re-emerging, still at an experimental level, due to the progressive slowdown in antibiotic efficiency. Within this context, our analysis of a noisy predator-prey competition modeling the treatment helps to calibrate and to understand better the behavior of the system in terms of fluctuations around an equilibrium. Note that our preliminary contacts with the Genetics and Microbiology Departments at UAB also open the way to a particle model in order to represent the couple bacteria/virus living on a surface.

(iii) Subdiffusion into molecules. Our purpose here is a better understanding of the phenomena observed in nanoscale Biophysics, as explained in the series of papers [46]. The technological advances in nanoscale technologies allow the observation of single molecules, and thus the description of newly observed phenomenon. A typical example of this new kind of observation is given by the fluctuations in the folding of a protein-enzyme compound called Fre, which is involved in the DNA synthesis of the (canonical) bacterium E. Coli. More specifically, the paper [46] advocates for modeling this folding fluctuations by means of a Volterra type equation driven by a fractional Brownian motion. This convincing model is based on some experimental and physical evidences, and have also been observed in a wide number of recent biological experiments. However, the model exhibited in [46] also raises some unsolved questions: some stochastic equations appearing in the models are not properly defined and their long time behavior is still mysterious. The lack of a method in order to simulate and estimate coefficients of these equations on a solid mathematical ground should also be mentioned. This is the kind of topic we wish to address, for which a preliminary contact with S. Kou and N. Pillai (Princeton University, USA) has been established.

(iv) Osteoporosis. During the year 2010-2011, C. Lacaux has been visiting the MAP 5 (Paris Descartes University) laboratory and joined the ANR Project MATAIM (Modèles Anisotropes de Textures. Applications à l’Imagerie Médicale). This project, which involves both mathematicians and practitioners, is in particular interested in the osteoporosis diagnostic. The paper [29] is a first step in the direction of modeling trabecular bone x-ray images by some operator scaling fields. Actually the estimation of the matrix, which characterizes the anisotropy of the model, is crucial for practical purposes. Hermine Biermé (Paris Descartes University) and Céline Lacaux are working on this problem using quadratic variations. Once the problem of estimation is solved, they plan a comparison of the theoretical model with real data provided by our Biologist colleagues of the MATAIM project. If the model corresponds to real data (as suggested in [29]), this approach may help for the diagnostic of osteoporosis: a numerical study has to be performed in order to find the parameter value which characterizes osteoporosis.
4. Application Domains

4.1. Thermonuclear fusion

Controlled fusion is one of the major prospects for a long term source of energy. Two main research directions are studied: magnetic fusion where the plasma is confined in tokamaks using a large external magnetic field and inertial fusion where the plasma is confined thanks to intense laser or particle beams. The simulation tools we develop can be applied for both approaches.

Controlled fusion is one of the major challenges of the 21st century that can answer the need for a long term source of energy that does not accumulate wastes and is safe. The nuclear fusion reaction is based on the fusion of atoms like Deuterium and Tritium. These can be obtained from the water of the oceans that is widely available and the reaction does not produce long-term radioactive wastes, unlike today’s nuclear power plants which are based on nuclear fission.

Two major research approaches are followed towards the objective of fusion based nuclear plants: magnetic fusion and inertial fusion. In order to achieve a sustained fusion reaction, it is necessary to confine sufficiently the plasma for a long enough time. If the confinement density is higher, the confinement time can be shorter but the product needs to be greater than some threshold value.

The idea behind magnetic fusion is to use large toroidal devices called tokamaks in which the plasma can be confined thanks to large applied magnetic field. The international project ITER is based on this idea and aims to build a new tokamak which could demonstrate the feasibility of the concept.

The inertial fusion concept consists in using intense laser beams or particle beams to confine a small target containing the Deuterium and Tritium atoms. The Laser Mégajoule which is being built at CEA in Bordeaux will be used for experiments using this approach.

Nonlinear wave-wave interactions are primary mechanisms by which nonlinear fields evolve in time. Understanding the detailed interactions between nonlinear waves is an area of fundamental physics research in classical field theory, hydrodynamics and statistical physics. A large amplitude coherent wave will tend to couple to the natural modes of the medium it is in and transfer energy to the internal degrees of freedom of that system. This is particularly so in the case of high power lasers which are monochromatic, coherent sources of high intensity radiation. Just as in the other states of matter, a high laser beam in a plasma can give rise to stimulated Raman and Brillouin scattering (respectively SRS and SBS). These are three wave parametric instabilities where two small amplitude daughter waves grow exponentially at the expense of the pump wave, once phase matching conditions between the waves are satisfied and threshold power levels are exceeded. The illumination of the target must be uniform enough to allow symmetric implosion. In addition, parametric instabilities in the underdense coronal plasma must not reflect away or scatter a significant fraction of the incident light (via SRS or SBS), nor should they produce significant levels of hot electrons (via SRS), which can preheat the fuel and make its isentropic compression far less efficient. Understanding how these deleterious parametric processes function, what non uniformities and imperfections can degrade their strength, how they saturate and interdepend, all can benefit the design of new laser and target configuration which would minimize their undesirable features in inertial confinement fusion. Clearly, the physics of parametric instabilities must be well understood in order to rationally avoid their perils in the varied plasma and illumination conditions which will be employed in the National Ignition Facility or LMJ lasers. Despite the thirty-year history of the field, much remains to be investigated.

1 http://www.iter.org
Our work in modelling and numerical simulation of plasmas and particle beams can be applied to problems like laser-matter interaction, the study of parametric instabilities (Raman, Brillouin), the fast ignitor concept in the laser fusion research as well as for the transport of particle beams in accelerators. Another application is devoted to the development of Vlasov gyrokinetic codes in the framework of the magnetic fusion programme in collaboration with the Department of Research on Controlled Fusion at CEA Cadarache. Finally, we work in collaboration with the American Heavy Ion Fusion Virtual National Laboratory, regrouping teams from laboratories in Berkeley, Livermore and Princeton on the development of simulation tools for the evolution of particle beams in accelerators.

4.2. Nanophysics

Kinetic models like the Vlasov equation can also be applied for the study of large nano-particles as approximate models when ab initio approaches are too costly.

In order to model and interpret experimental results obtained with large nano-particles, ab initio methods cannot be employed as they involve prohibitive computational times. A possible alternative resorts to the use of kinetic methods originally developed both in nuclear and plasma physics, for which the valence electrons are assimilated to an inhomogeneous electron plasma. The LPMIA (Nancy) possesses a long experience on the theoretical and computational methods currently used for the solution of kinetic equation of the Vlasov and Wigner type, particularly in the field of plasma physics.

Using a Vlasov Eulerian code, we have investigated in detail the microscopic electron dynamics in the relevant phase space. Thanks to a numerical scheme recently developed by Filbet et al. [66], the fermionic character of the electron distribution can be preserved at all times. This is a crucial feature that allowed us to obtain numerical results over long times, so that the electron thermalization in confined nano-structures could be studied.

The nano-particle was excited by imparting a small velocity shift to the electron distribution. In the small perturbation regime, we recover the results of linear theory, namely oscillations at the Mie frequency and Landau damping. For larger perturbations nonlinear effects were observed to modify the shape of the electron distribution.

For longer time, electron thermalization is observed: as the oscillations are damped, the center of mass energy is entirely converted into thermal energy (kinetic energy around the Fermi surface). Note that this thermalization process takes place even in the absence of electron-electron collisions, as only the electric mean-field is present.
4. Application Domains

4.1. Application Domains

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

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

- Program parallelization tries to distribute the workload equally among the cores. Thus an equivalent performance, or even a better performance, to a sequential higher frequency execution on one single core, can be obtained.

- Memory and memory accesses are high energy consumers. Lowering the memory consumption, lowering the number of memory accesses and maximizing the number of accesses in the low levels of the memory hierarchy (registers, cache memories) have a positive consequence on execution speed, but also on energy consumption.
4. Application Domains

4.1. Cryptology

The first application domain for our research is cryptology. This includes cryptography (constructive side) and cryptanalysis (breaking systems). For the cryptanalysis part, although it has practical implications, we do not expect any transfer in the classical sense of the term: it is more directed to governmental agencies and the end-users who build their trust, based on the cryptanalysis effort.

4.1.1. Cryptography

Our cryptographic contributions are related to multiple facets of the large realm of curve-based cryptology. While it is quite clear that a satisfying range of algorithms exists in order to provide cryptographers with elliptic curves having a suitably hard discrete logarithm (as found in cryptographic standards for instance), one must bear in mind that refinements of the requirements and extensions to curves of higher genus raise several interesting problems. Our work contributes to expanding the cryptographer’s capabilities in these areas.

In the context of genus-2 curves, our work aims at two goals. First, improvements on the group law on selected curves yield better speed for the associated cryptosystems. The cryptographic primitives, and then the whole suite of cryptographic protocols built upon such curves would be accelerated. The second goal is the expansion of the set of curves that can be built given a set of desired properties. Using point counting algorithms for arbitrary curves, a curve offering a 128-bit security level, together with nice properties for fast arithmetic, has been computed by CARAMEL[10]. Another natural target for construction of curves for cryptography is also the suitability of curves for pairings. We expect to be able to compute such curves.

Implementations of curve-based cryptography, both in hardware and software, are a necessary step on the way to assessing cryptographic speed. We plan to provide such implementations. In particular, on the hardware side, one of our goals is the design of a complete cryptographic coprocessor, including all the primitives for curve-based and pairing-based cryptography, providing optimized and configurable efficiency vs area trade-off.

4.1.2. Cryptanalysis

Our research on cryptanalysis is important for the cryptographic industry: by detecting weak instances, and setting new records we contribute to the definition of recommended families of systems together with their key sizes. The user’s confidence in a cryptographic primitive is also related to how well the underlying problem is studied by researchers.

In particular, our involvement in computations with “NFS-like” algorithms encompasses of course the task of assessing the computational limits for integer factorization and discrete-logarithm computations. The impact of the former is quite clear as it concerns the RSA algorithm; record-sized computations attract broad interest and determine updates on key-length recommendations. The latter are particularly important for pairing-based cryptography, since, in this context, one naturally encounters discrete-logarithm problems in extension fields of large degree.

4.1.3. Standardization

4.1.3.1. Floating-point arithmetic

The IEEE 754 standard for floating-point arithmetic was revised in 2008. The main new features are some new formats for decimal computations, and the recommendation of correctly rounded transcendental functions. The new decimal formats should not have an impact on our work, since we either use integer-only arithmetic, or arbitrary-precision binary floating-point arithmetic through the GNU MPFR library.
A new standard (P1788) is currently under construction for interval arithmetic. We are not officially involved in this standard, but we follow the discussions, to check in particular that the proposed standard will also cover arbitrary precision (interval) arithmetic.

4.1.3.2. Curve-based cryptography

Elliptic-curve cryptography has been standardized for almost 10 years now, in the IEEE P1363 standard. This standard provides key agreement, signature and encryption schemes, based on integer factorization, discrete logarithm in finite fields and in elliptic curves. There is another standardization effort, called SECG, which is mostly lead by the Certicom company, with the goal to maintain interoperability between different implementations. In particular, the SECG documents give explicit elliptic curves that can be used for cryptography. Similarly, some elliptic curves have been standardized by the US government; the latest version comes from the NSA Suite B that includes only elliptic curves defined over prime fields.

In the long term, those standards are a natural place to promote genus-2 curve cryptography, and by the time we consider that the curves we propose are mature enough, we will look for an industrial partner to help us pushing towards their standardization.

4.1.3.3. Pairing-based cryptography

Despite their very recent discovery, identity-based cryptosystems—and more generally pairing-based cryptosystems—have already spawned several international standardization efforts.

The first standard, part of ISO/IEC 14888-3, was published in 2006. However, it almost exclusively focuses on protocols and therefore is of little interest to us. On the other hand, the IEEE P1363.3 standard, which is still in preparation, is planned to offer more details as to the considered curves and pairings on which the protocols are based.

Although we are not officially involved in the elaboration of this standard, we have already participated in the review process of its first draft.

4.1.4. Computer algebra systems

Some of our software libraries are being used by computer algebra systems. Most of those libraries are free software, with a license that allows proprietary systems to link them. This gives us a maximal visibility, with a large number of users.

4.1.4.1. Magma

Magma is a very large computational algebra package. It provides a mathematically rigorous environment for computing with algebraic, number-theoretic, combinatoric, and geometric objects. It is developed in Sydney, by the team around John Cannon. It is non-commercial (in the sense that its goal is not to make profit), but is not freely distributed and is not open-source.

Several members of the team have visited Sydney — a few years ago — to contribute to the development of Magma, by implementing their algorithms or helping in integrating their software. Our link to Magma exists also via the libraries it uses: it currently links GNU MPFR and MPC for its floating-point calculations, and links GMP-ECM as part of its factorization suite.

4.1.4.2. Pari-GP

Pari/GP is a computational number theory system that is composed of a C library and an interpreter on top of it. It is developed in Bordeaux, where Karim Belabas from the LFANT project-team is the main maintainer. Its license is GPL. Although we do not directly contribute to this package, we have good contact with the developers and in the future, GNU MPFR and MPC could be included.

4.1.4.3. Sage

Sage is a fairly large scale and open-source computer algebra system written in Python. Sage aggregates a large amount of existing free software, aiming at the goal of selecting the fastest free software package for each given task. The motto of Sage is that instead of “reinventing the wheel” all the time, Sage is “building the car”. To date, Sage links GNU MPFR, GMP-ECM, and MPC as optional package since 2010 (this was the result of a huge work done by Philippe Théveny in the MPtools ODL which finished in 2009). Plans exist to link GF2X and CADO-NFS into Sage.
4. Application Domains

4.1. Computer Virology

Nowadays, our thoughts lead us to define four different research tracks, that we are describing below.

4.1.1. The theoretical track.

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

4.1.2. The virus detection track.

The crucial question is how to detect viruses or self-replicating malwares. Cohen demonstrated that this question is undecidable. The anti-virus heuristics are based on two methods. The first one consists in searching for virus signatures. A signature is a regular expression, which identifies a family of viruses. There are obvious defects. For example, an unknown virus will not be detected, like ones related to a 0-day exploit. We strongly suggest to have a look at the independent audit [49] in order to understand the limits of this method. The second one consists in analysing the behavior of a program by monitoring it. Following [51], this kind of methods is not yet really implemented. Moreover, the large number of false-positive implies this is barely usable. To end this short survey, intrusion detection encompasses virus detection. However, unlike computer virology, which has a solid scientific foundation as we have seen, the IDS notion of “malwares” with respect to some security policy is not well defined. The interested reader may consult [70].

4.1.3. The virus protection track.

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

4.1.4. The experimentation track.

This study on computer virology leads us to propose and construct a “high security lab” in which experiments can be done in respect with the French law. This project of “high security lab” in one of the main project of the CPER 2007-2013.

4.2. Computations and Dynamical Systems

4.2.1. Continuous computation theories

Understanding computation theories for continuous systems leads to studying hardness of verification and control of these systems. This has been used to discuss problems in fields as diverse as verification (see e.g. [33]), control theory (see e.g. [40]), neural networks (see e.g. [71]), and so on.

We are interested in the formal decidability of properties of dynamical systems, such as reachability [61], the Skolem-Pisot problem [36], the computability of the $\omega$-limit set [60]. Those problems are analogous to verification of safety properties.
Due to the difficulty of their analysis, the study of dynamical systems is often impossible without computer simulations. Nevertheless those simulations are often heuristic and due to round-off errors, what is observed on the screen is not guaranteed to reflect the actual behavior of the original mathematical system. Computable analysis has the advantage of getting rid of the truncation problems, integrating the management of errors to the computation. We then use this theory to investigate the possibility to compute characteristics of dynamical systems that are fundamental objects in the mathematical theory, such as attractors or invariant measures. Being asymptotic objects, they might not be always computable: for instance it has been proved in [41] that some Julia sets (see Figure 1) cannot be computed at all, i.e. there is no program that would plot such sets up to any resolution.

![Figure 1. A Julia set: the set of points $z \in \mathbb{C}$ that do not go to $\infty$ when iterating $z \mapsto z^2 + c$ (here $c = -0.835 - 0.2321i$).](image)

In [18] we prove that there exist computable systems for which the statistical long-term behavior (technically the invariant measures) is not computable.

In contrast with the discrete setting, it is of utmost importance to compare the various models of computation over the reals, as well as their associated complexity theories. In particular, we focus on the General Purpose Analog Computer of Claude Shannon [72], on recursive analysis [78], on the algebraic approach [68] and on computability in a probabilistic context [63].

A crucial point for future investigations is to fill the gap between continuous and discrete computational models. This is one deep motivation of our work on computation theories for continuous systems.

### 4.2.2. Analysis and verification of adversary systems

The other research direction on dynamical systems we are interested in is the study of properties of adversary systems or programs, i.e. of systems whose behavior is unknown or indistinct, or which do not have classical expected properties. We would like to offer proof and verification tools, to guarantee the correctness of such systems.

On one hand, we are interested in continuous and hybrid systems. In a mathematical sense, a hybrid system can be seen as a dynamical system, whose transition function does not satisfy the classical regularity hypotheses, like continuity, or continuity of its derivative. The properties to be verified are often expressed as reachability properties. For example, a safety property is often equivalent to (non-)reachability of a subset of unsure states from an initial configuration, or to stability (with its numerous variants like asymptotic stability, local stability,
mortality, etc ...). Thus we will essentially focus on verification of these properties in various classes of dynamical systems.

We are also interested by rewriting techniques, used to describe dynamic systems, in particular in the adversary context. As they were initially developed in the context of automated deduction, the rewriting proof techniques, although now numerous, are not yet adapted to the complex framework of modelization and programming. An important stake in the domain is then to enrich them to provide realistic validation tools, both in providing finer rewriting formalisms and their associated proof techniques, and in developing new validation concepts in the adversary case, i.e. when usual properties of the systems like, for example, termination are not verified.

For several years, we have been developing specific procedures for property proofs of rewriting, for the sake of programming, in particular with an inductive technique, already applied with success to termination under strategies [52], [53], [54], to weak termination [55], sufficient completeness [57] and probabilistic termination [56].

The last three results take place in the context of adversary computations, since they allow for proving that even a divergent program, in the sense where it does not terminate, can give the expected results.

A common mechanism has been extracted from the above works, providing a generic inductive proof framework for properties of reduction relations, which can be parametrized by the property to be proved [58], [59]. Provided program code can be translated into rule-based specifications, this approach can be applied to correctness proof of software in a larger context.

A crucial element of safety and security of software systems is the problem of resources. We are working in the field of Implicit Computational Complexity. Interpretation based methods like Quasi-interpretations (QI) or sup-interpretations, are the approach we have been developing these last five years, see [65], [66], [67]. Implicit complexity is an approach to the analysis of the resources that are used by a program. Its tools come essentially from proof theory. The aim is to compile a program while certifying its complexity.
4. Application Domains

4.1. Verification of Security Protocols

Security protocols such as SET, TLS and Kerberos, are designed for establishing the confidence of electronic transactions. They rely on cryptographic primitives, the purpose of which is to ensure integrity of data, authentication or anonymity of participants, confidentiality of transactions, etc.

Experience has shown that the design of those protocols is often erroneous, even when assuming that cryptographic primitives are perfect, i.e., that an encoded message cannot be decrypted without the appropriate key. An intruder can intercept, analyze and modify the exchanged messages with very few computations and therefore, for example, generate important economic damage.

Analyzing cryptographic protocols is complex because the set of configurations to consider is very large, and can even be infinite: one has to consider any number of sessions, any size of messages, sessions interleaving, some algebraic properties of encryption or data structures.

Our objective is to automatize as much as possible the analysis of protocols starting from their specification. This consists in designing a tool that is easy to use, enables the specification of a large number of protocols thanks to a standard high-level language, and can either look for flaws in a given protocol or check whether it satisfies a given property. Such a tool is essential for verifying existing protocols, but also for helping in designing new ones. For our tool to be easy to use, it has to provide a graphical interface allowing a user to easily perform push-button verification.

Our tools for verifying security protocols are available as components of the AVISPA platform. As an extension of the AVISPA specification language, we are working on a new environment called CASRUL for handling more general protocols like e-business protocols for example.

4.2. Automated Boundary Testing from Formal Specifications

We have introduced a new approach for test generation from set-oriented formal specifications: the BZ-TT method. This method is based on Constraint Logic Programming (CLP) techniques. The goal is to test every operation of the system at every boundary state using all input boundary values of that operation. It has been validated in several industry case studies for smart card OS and application validation (GSM 11-11 standard [78] and Java Card Virtual Machine Transaction mechanism [80]), information system and for embedded software [88].

This test generation method can be summed up as follows: from the formal model, the system computes boundary values to create boundary states; test cases are generated by traversal of the state space with a preamble part (sequences of operations from the initial state to a boundary state), a body part (critical invocations), an identification part (observation and oracle state computation) and a post-amble part (return path to initial or boundary state). Then, an executable test script file is generated using a test pattern and a table of correspondence between abstract operations (from the model) and concrete ones. This approach differs in several main points from previous works (e.g. [84]): first, using boundary goals as test objectives avoids the complete construction of the reachability graph; second, this process is fully automated and the test engineer could just drive it at the boundary value computation level or for the path computation.

The BZ-TT method is fully supported by the BZ-Testing-Tools tool-set. This environment is a set of tools dedicated to animation and test cases generation from B, Z or State-Chart formal specifications. It is based on the CLPS constraint solver, able to simulate the execution of the specification. By execution, we mean that the solver computes a so-called constrained state by applying the pre- and post-condition of operations. A constrained state is a constraint store where state variables and also input and output variables support constraints.
One orientation of the current work is to go beyond the finiteness assumption limitations by using symbolic constraint propagation during the test generation process. Second orientation is to extend the result to object oriented specifications as UML/OCL. Third orientation is to extend the coverage of method for security aspect.

4.3. Program Debugging and Verification

Catching bugs in programs is difficult and time-consuming. The effort of debugging and proving correct even small units of code can surpass the effort of programming. Bugs inserted while “programming in the small” can have dramatic consequences for the consistency of a whole software system as shown, e.g., by viruses which can spread by exploiting buffer overflows, a bug which typically arises while coding a small portion of code. To detect this kind of errors, many verification techniques have been put forward such as static analysis and software model checking.

Recently, in the program verification community, there seems to be a growing demand for more declarative approaches in order to make the results of the analysis readily available to the end user. To meet this requirement, a growing number of program verification tools integrate some form of theorem proving.

The goals of our research are twofold. First, we perform theoretical investigations of various combinations of propositional and first-order satisfiability checking in order to automate the theorem proving activity required to solve a large class of program analysis problems which can be encoded as first-order formulae. Second, we experimentally investigate how our techniques behave on real problems in order to make program analysis more precise and scalable. Building tools capable of providing a good balance between precision and scalability is one of the crucial challenges to transfer theorem proving technology to the industrial domains.

4.4. Verification of Web Services

Driven by rapidly changing requirements and business needs, IT systems and applications are undergoing a paradigm shift: components are replaced by services, distributed over the network, and composed and reconfigured dynamically in a demand-driven way into service-oriented architectures. Exposing services in future network infrastructures means a wide range of trust and security issues need to be addressed. Solving them is extremely hard since making the service components trustworthy is not sufficient: composing services leads to new subtle and dangerous vulnerabilities due to interference between component services and policies, the shared communication layer, and application functionality. Thus, one needs validation of both the service components and their composition into secure service architectures. In this context, there is an obvious need of applying formal methods. Our project aims at applying our proof and constraint solving techniques to reason on web services. More precisely, we focus on the composition problem in the presence of security policies.

4.5. Model-Checking of Collaborative Systems

Collaborative systems constitute a class of distributed systems where real human interactions are predominant. In these systems, users at geographically distributed sites interact by simultaneously manipulating shared objects like, text documents, XML trees, filesystems, etc. To improve data availability, the shared objects are replicated so that the users update their local replicas and exchange their updates between them. One of the main challenges here is how to ensure the data consistency when the updates are executed in arbitrary orders at different replicas. Operational Transformation (OT) is an optimistic technique which has been proposed to overcome the consistency problem. This technique consists of an application-dependent protocol to enforce the out-of-order execution of updates even though these updates do not naturally commute. The data consistency relies crucially on the correctness of OT protocols whose proof is extremely hard. Indeed, possibly infinitely many cases should be tested. Our research work aims at applying symbolic model-checking techniques to automatically verify OT protocols. Most importantly, we are interested in finding under which conditions the model-checking problem can be reduced to a finite-state model.

1 see e.g. http://osoa.org/display/Main/Service+Component+Architecture+Home
4. Application Domains

4.1. Panorama

As we already stressed in the previous sections the robust control of infinite dimensional systems is an emerging theory. Our aim is to develop tools applicable to a large class of problems which will be tested on models of increasing complexity. We describe below only the applications in which the members of our team have recently obtained important achievements.

4.2. Biology and Medicine

4.2.1. Medicine

We began this year to study a new class of applications of observability theory. The investigated issues concern inverse problems in Magnetic Resonance Imaging (MRI) of moving bodies with emphasis on cardiac MRI. The main difficulty we tackle is due to the fact that MRI is, comparatively to other cardiac imaging modalities, a slow acquisition technique, implying that the object to be imaged has to be still. This is not the case for the heart where physiological motions, such as heart beat or breathing, are of the same order of magnitude as the acquisition time of an MRI image. Therefore, the assumption of sample stability, commonly used in MRI acquisition, is not respected. The violation of this assumption generally results in flow or motion artifacts. Motion remains a limiting factor in many MRI applications, despite different approaches suggested to reduce or compensate for its effects Welch et al. [85]. Mathematically, the problem can be stated as follows: can we reconstruct a moving image by measuring at each time step a line of its Fourier transform? From a control theoretic point of view this means that we want to identify the state of a dynamical system by using an output which is a small part of its Fourier transform (this part may change during the measurement).

There are several strategies to overcome these difficulties but most of them are based on respiratory motion suppression with breath-hold. Usually MRI uses ECG information to acquire an image over multiple cardiac cycles by collecting segments of Fourier space data at the same delay in the cycle Lanzer et al. [76], assuming that cardiac position over several ECG cycles is reproducible. Unfortunately, in clinical situations many subjects are unable to hold their breath or maintain stable apnea. Therefore breath-holding acquisition techniques are limited in some clinical situations. Another approach, so called real-time, uses fast, but low resolution sequences to be faster than heart motion. But these sequences are limited in resolution and improper for diagnostic situations, which require small structure depiction as for coronary arteries.

4.3. Simulation of viscous fluid-structure interactions

Participants: Bruno Pinçon, Jean-François Scheid [correspondant].

A number of numerical codes for the simulation for fluids and fluid-structure problems has been developed by the team. These codes are mainly written in MATLAB Software with the use of C++ functions in order to improve the sparse array process of MATLAB. We have focused our attention on 3D simulations which require large CPU time resources as well as large memory storage. An efficient 3D Stokes sparse solver for MATLAB is now available. An important work has been performed for the study and the development of a class of preconditioners for iterative solver of 3D Stokes problem. Efficient preconditioner of block preconditioned conjugate gradient type (BPCG) is now implemented. The use of this preconditioner significantly reduces the CPU time for the solution of linear system coming from the Stokes equations. This work has been developed in collaboration with Marc Fuentes, research engineer at INRIA Nancy Grand Est. M. Fuentes has also written a PYTHON version of the 3D Stokes solver. A 3D characteristics method for the nonlinear Navier-Stokes equations is now in progress.
4.4. Biohydrodynamics MATLAB Toolbox (BHT)

**Participants:** Alexandre Munnier [correspondant], Bruno Pinçon.

Understanding the locomotion of aquatic animals fascinated the scientific community for a long time. This constant interest has grown from the observation that aquatic mammals and fishes evolved swimming capabilities superior to what has been achieved by naval technology. A better understanding of the biomechanics of swimming may allow one to improve the efficiency, manoeuvrability and stealth of underwater vehicles. During the last fifty years, several mathematical models have been developed. These models make possible the qualitative analysis of swimming propulsion as a continuation of the previously developed quantitative theories. Based on recent mathematical advances, Biohydrodynamics MATLAB Toolbox (BHT) is a collection of M-Files for design, simulation and analysis of articulated bodies’ motions in fluid. More widely, BHT allows also to perform easily any kind of numeric experiments addressing the motion of solids in ideal fluids (simulations of so-called fluid-structure interaction systems).

This software is available at [http://bht.gforge.inria.fr/](http://bht.gforge.inria.fr/).
4. Application Domains

4.1. Overview

Our application domain is twofold:

On one hand, neuro-scientists are end-users of our researches. Data analysis is one issue, but the main outcomes concern modeling, namely the validation of biological assumptions either at a theoretical level or via numerical experiments and simulation of bio-processes. This includes algorithmic expertises and dedicated softwares.

On the other hand, science and technology of information processing is impacted. This concerns embedded systems such as in-silico implementations of bio-inspired processes, focusing on spatial and distributed computing. This also concerns embodied systems such as robotic implementation of sensori-motor loops, the bio-inspiration yielding such interesting properties as adaptivity and robustness.
4. Application Domains

4.1. Mobile, ad-hoc and constrained networks

The results coming out from MADYNES can be applied to any dynamic infrastructure that contributes to the delivery of value added services. While this is a potentially huge application domain, we focus on the following environments at the network level:

1. multicast services,
2. ad-hoc networks,
3. mobile devices and IPv6 networks,
4. voice over IP infrastructure.

All these selected application areas exhibit different dynamicity features. In the context of multicast services, we focus on distribution, monitoring and accounting of key distribution protocols. On ad-hoc and dynamic networks we are investigating the provisioning, monitoring, configuration and performance management issues.

Concerning mobile devices, we are interested in their configuration, provisioning and monitoring. IPv6 work goes on in Information Models and, combined with SNMPv3, on self-configuration of the agents.

4.2. Dynamic service infrastructures

At the service level, dynamics is also increasing very fast. We apply the results of our work on autonomous management on infrastructures which support dynamic composition and for which self-instrumentation and management automation is required.

The target service environments are:

- Voice over IP networks,
- peer-to-peer infrastructures,
- ambient environments.
4. Application Domains

4.1. Augmented reality

We have a significant experience in the AR field especially through the European project ARIS (2001–2004) which aimed at developing effective and realistic AR systems for e-commerce and especially for interior design. Beyond this restrictive application field, this project allowed us to develop nearly real time camera tracking methods for multi-planar environments. Since then, we have amplified our research on multi-planar environments in order to obtain effective and robust AR systems in such environments. We currently investigate both automatic and interactive techniques for scene reconstruction/structure from motion methods in order to be able to consider large and unknown environments.

4.2. Medical Imaging

For 15 years, we have been working in close collaboration with University Hospital of Nancy and GE Healthcare in interventional neuroradiology. Our common aim is to develop a multimodality framework to help therapeutic decisions and interventional gestures. In particular, we aim at developing tools allowing the physicians to take advantage of the various existing imaging modalities on the brain in their clinical practice: 2D subtracted angiography (2DSA), 3D rotational angiography (3DRA), fluoroscopy, MRI,...Recent works concern the use of AR tools for neuronavigation and the development of simulation tools of the interventional act for training or planning. This last project is developed in collaboration with the EPI Shacra.

4.3. Augmented head

Visual information on a speaker, especially jaws and lips but also tongue position, noticeably improves speech intelligibility. Hence, having a realistic augmented head displaying both external and internal articulators could help language learning technology progress in giving the student a feedback on how to change articulation in order to achieve a correct pronunciation. The long term aim of the project is the acquisition of articulation data and the design of a 3D+t articulatory model from various image modalities: external articulators are extracted from stereovision data, the tongue shape is acquired through ultrasound imaging, 3D images of all articulators can be obtained with MRI for sustained sounds, magnetic sensors are used to recover the tip of the tongue.
MAIA Project-Team (section vide)
4. Application Domains

4.1. Metapopulation models

Heterogeneity plays an important role in many infectious disease processes. For instance, spatial heterogeneity is a strong determinant of host-parasite relationships. In modeling spatial or geographic effects on the spread of a disease, a distinction is usually made between diffusion and dispersal models. In diffusion models, spread is to immediately adjacent zones, hence the phenomenon of traveling waves can appear. These models traditionally use partial differential equations. However, there are some important situations that cannot be modeled by PDE. This is the case when the space considered is discrete. For example, when we have to consider sparsely populated regions, the human population is located in patches. The organization of human-hosts into well-defined social units such as families, villages or cities, are good examples of patches. Another example arises in the study of the human African Trypanosomiasis. The vector is the tse-tse fly, and it is known that flies take fewer blood meals in villages than in coffee plantations where the villagers work during the day. For such situations where human or vectors can travel a long distance in a short period of time, dispersal models are more appropriate. These models consider migration of individuals between patches. The infection does not take place during the migration process. The situation is that of a directed graph, where the vertices represent the patches and the arcs represent the links between patches. Recently, there has been increased interest in these deterministic metapopulation disease models. We have generalized to $n$ patches the Ross-Macdonald model which describes the dynamics of malaria. We incorporate in our model the fact that some patches can be vector free. We assume that the hosts can migrate between patches, but not the vectors. The susceptible and infectious individuals have the same dispersal rate. We compute the basic reproduction ratio $R_0$. We prove that if $R_0 \leq 1$, then the disease-free equilibrium is globally asymptotically stable. When $R_0 > 1$, we prove that there exists a unique endemic equilibrium, which is globally asymptotically stable on the biological domain minus the disease-free equilibrium.

MASAIE is developing, in the framework of the CAPES-COFECUB project (see international program), a metapopulation model for dengue. This model is for the state of Rio and is using the data of foundation FIOCRUZ.

4.2. Estimating total parasite load in falciparum malaria patients

We give a brief review of the biological features of malaria. Malaria in a human begins with an inoculum of *Plasmodium* parasites (sporozoites) from a female *Anopheles* mosquito. The sporozoites enter the liver within minutes. After a period of asexual reproduction in the liver, the parasites (merozoites) are released in the bloodstream where the asexual erythrocyte cycle begins. The merozoites enter red blood cells (RBC), grow and reproduce over a period of approximately 48 hours after which the erythrocyte ruptures releasing daughter parasites that quickly invade a fresh erythrocyte to renew the cycle. This blood cycle can be repeated many times, in the course of which some of the merozoites instead develop in the sexual form of the parasites : gametocytes. Gametocytes are benign for the host and are waiting for the mosquitoes. An important characteristic of *Plasmodium falciparum*, the most virulent malaria parasite, is sequestration. At the half-way point of parasite development, the infected erythrocyte leaves the circulating peripheral blood and binds to the endothelium in the microvasculature of various organs where the cycle is completed. A measurement of *Plasmodium falciparum* parasitaemia taken from a blood smear therefore samples young parasites only. Physician treating malaria use the number of parasites in peripheral blood smears as a measure of infection, this does not give the total parasite burden of the patient. Moreover antimalarial drugs are known to act preferentially on different stages of parasite development. Our work consists in developing tools for estimating the sequestered parasites and hence the total parasite burden of the patient.
4. Application Domains

4.1. Life Sciences


Glossary

Knowledge discovery in life sciences is a process for extracting knowledge units from large biological databases, e.g. collection of genes.

One major application domain which is currently investigated by Orpailleur team is related to life sciences, with particular emphasis on biology, medicine, and chemistry. The understanding of biological systems provides complex problems for computer scientists, and, when they exist, solutions bring new research ideas for biologists and for computer scientists as well. Accordingly, the Orpailleur team includes biologists, chemists, and a physician, making Orpailleur a very original EPI at INRIA.

Knowledge discovery is gaining more and more interest and importance in life sciences for mining either homogeneous databases such as protein sequences and structures, or heterogeneous databases for discovering interactions between genes and environment, or between genetic and phenotypic data, especially for public health and pharmacogenomics domains. The latter case appears to be one main challenge in knowledge discovery in biology and involves knowledge discovery from complex data and thus KDDK. The interactions between researchers in biology and researchers in computer science improve not only knowledge about systems in biology, chemistry, and medicine, but knowledge about computer science as well. Solving problems for biologists using KDDK methods involves the design of specific modules that, in turn, leads to adaptations of the KDDK process, especially in the preparation of data and in the interpretation of the extracted units.

4.2. Knowledge Management in Medicine

Participants: Julien Cojan, Nicolas Jay, Jean Lieber, Thomas Meilender, Amedeo Napoli.

The Kasimir research project holds on decision support and knowledge management for the treatment of cancer [ 97 ]. This is a multidisciplinary research project in which participate researchers in computer science (Orpailleur), experts in oncology (“Centre Alexis Vautrin” in Vandœuvre-lès-Nancy), Oncolor (a healthcare network in Lorraine involved in oncology), and A2Zi (a company working in Web technologies and involved in several projects in the medical informatics domain, http://www.a2zi.fr/ ). For a given cancer localization, a treatment is based on a protocol similar to a medical guideline, and is built according to evidence-based medicine principles. For most of the cases (about 70%), a straightforward application of the protocol is sufficient and provides a solution, i.e. a treatment, that can be directly reused. A case out of the 30% remaining cases is “out of the protocol”, meaning that either the protocol does not provide a treatment for this case, or the proposed solution raises difficulties, e.g. contraindication, treatment impossibility, etc. For a case “out of the protocol”, oncologists try to adapt the protocol. Actually, considering the complex case of breast cancer, oncologists discuss such a case during the so-called “breast cancer therapeutic decision meetings”; including experts of all specialties in breast oncology, e.g. chemotherapy, radiotherapy, and surgery.

The semantic Web technologies have been used and adapted in the Kasimir project for several years. Currently, technologies of the semantic Wikis are adapted for the management of decision protocols [ 66 ] More precisely, the migration from the static HTML site of Oncolor to a semantic wiki (with limited editing rights and unlimited reading rights) is about to be finished. This has consequences on the editorial chain of the published protocols which is more collaborative. A decision tree editor that has been integrated into the wiki and that has an export facility to formalized protocols in OWL DL has also been developed [ 67 ].
4.3. Cooking


The origin of the Taaable project is the Computer Cooking Contest (CCC). A contestant of the CCC is a system that answers queries of recipes, using a recipe base; if no recipe exactly matches the query, then the system adapts another recipe. Taaable is a case-based reasoning system that uses various technologies used and developed in the Orpailleur team, such as technologies of the semantic web, knowledge discovery techniques, knowledge representation and reasoning techniques, etc. From a research viewpoint it enables to test the scientific results on an application domain that is at the same time simple to understand and raising complex issues, and to study the complementarity of various research domains. Taaable has been at the origin of the project Kolflow of the ANR CONTINT program, whose application domain is WikiTaaable, the semantic wiki of Taaable. It is also used for other projects under submission.
4. Application Domains

4.1. Application Domains

Beside the theoretical transfer that can be performed via the cooperations or the scientific publications, an important part of the research done in the Pareo group team is published within software. Tom is our flagship implementation. It is available via the INRIA Gforge (http://gforge.inria.fr) and is one of the most visited and downloaded projects. The integration of high-level constructs in a widely used programming language such as Java may have an impact in the following areas:

- Teaching: when (for good or bad reasons) functional programming is not taught nor used, Tom is an interesting alternative to exemplify the notions of abstract data type and pattern-matching in a Java object oriented course.
- Software quality: it is now well established that functional languages such as Caml are very successful to produce high-assurance software as well as tools used for software certification. In the same vein, Tom is very well suited to develop, in Java, tools such as provers, model checkers, or static analyzers.
- Symbolic transformation: the use of formal anchors makes possible the transformation of low-level data structures such as C structures or arrays, using a high-level formalism, namely pattern matching, including associative matching. Tom is therefore a natural choice each time a symbolic transformation has to be implemented in C or Java for instance. Tom has been successfully used to implement the Rodin simplifier, for the B formal method.
- Prototyping: by providing abstract data types, private types, pattern matching, rules and strategies, Tom allows the development of quite complex prototypes in a short time. When using Java as the host-language, the full runtime library can be used. Combined with the constructs provided by Tom, such as strategies, this procures a tremendous advantage.

One of the most successful transfer is certainly the use of Tom made by Business Objects/SAP. Indeed, after benchmarking several other rule based languages, they decided to choose Tom to implement a part of their software. Tom is used in Paris, Toulouse and Vancouver. The standard representation provided by Tom is used as an exchange format by the teams of these sites.
4. Application Domains

4.1. Application Domains

Our research is applied in a variety of fields from ASR to paramedical domains. Speech analysis methods will contribute to the development of new technologies for language learning (for hearing-impaired persons and for the teaching of foreign languages) as well as for hearing aids. In the past, we developed a set of teaching tools based on speech analysis and recognition algorithms of the group (cf. the ISAEUS project of the EU that ended in 2000). We are continuing this effort towards the diffusion of a course on Internet.

Speech is likely to play an increasing role in man-machine communication. Actually, speech is a natural mean of communication, particularly for non-specialist persons. In a multimodal environment, the association of speech and designation gestures on touch screens can, for instance, simplify the interpretation of spatial reference expressions. Besides, the use of speech is mandatory in many situations where a keyboard is not available: mobile and on-board applications (for instance in the framework of the HIWIRE European project for the use of speech recognition in a cockpit plane), interactive vocal servers, telephone and domestic applications, etc.

Most of these applications will necessitate to integrate the type of speech understanding process that our group is presently studying. Furthermore, speech to speech translation concerns all multilingual applications (vocal services, audio indexing of international documents). The automatic indexing of audio and video documents is a very active field that will have an increasing importance in our group in the forthcoming years, with applications such as economic intelligence, keyword spotting and automatic categorization of mails.
4. Application Domains

4.1. E-government

E-government is now a well established domain that provides its own requirements in the field of service and information management. From our perspective, mostly processes, e-government applications have very strong requirements regarding security, privacy and interoperability between different organizations, belonging potentially to different countries. One of the prominent contributions we have made in this domain is related to our collaboration with SAP on the relationship between processes, security policies and the problem of delegation that we considered as important for organizational flexibility. This work resonate also with its current continuation in crisis management.

Crisis management is a special case of e-government application as it involves mostly governmental agencies in coordination with other organizations like the Red Cross or other NGO. Moreover, it brings with it a lot of requirements that are very interesting for us in the domain of coordination: a crisis process shall be very flexible, adaptable and distributed. It is mostly human driven and can be critical. In this domain, we are collaborating with SAP to define a new model of coordination that should support people involved in crisis resolution.

4.2. E-learning, Collaborative Knowledge Building

Collaborative knowledge building process is a distributed social process [29]. During this process, knowledge is built by a constellation of communities, each community being a node in the knowledge building network. Each node in the network is autonomous and has its own knowledge that can be exchanged and negotiate with other communities. A peer-to-peer architecture is more compatible with social architecture of knowledge building processes [30]. In addition, knowledge is basically created by individuals involved in social process [26]. Therefore, it is fundamental to support personal knowledge building in a collaborative knowledge building environment.

We develop distributed semantic wikis for collaborative knowledge building. These environments support the distributed social process of knowledge building and support personal knowledge building.

4.3. Groupware Systems and CASE Tools

Software engineering can be seen as distributed collaborative systems. Software Forges are social software. They transform stranger into collaborators, sometimes into developers. Forges are online services that allow instantiating, composing and managing collaborative services. Traditionally, provided collaborative services are version control systems, issue trackers, forums, mailing lists or wikis. We are applying our research results on coordination and data sharing into this context.
4. Application Domains

4.1. Application Domains

The present proposal focuses on the semantics of natural language, including the semantic analysis of discourses. Consequently, our applicative domains concern natural language processing applications that rely on a deep semantic analysis. For instance, one may cite the following ones:

- textual entailment and inference;
- dialogue systems;
- semantic-oriented query systems;
- content analysis of unstructured documents;
- (semi) automatic knowledge acquisition.

In fact, the need for semantics seems to be ubiquitous. There is, however, a challenge here. We need to find applications for which a deep semantic analysis results in a real improvement over non semantic-based techniques.

Nevertheless, the possible applications one may imagine are numerous, but we do not want to be too specific about it, at this stage. We intend to develop applications in the framework of collaborations. Therefore, the actual applicative developments we will undertake will depend of the partners we are currently seeking.
4. Application Domains

4.1. Grammar building and Linguistic Analysis

Developing large scale computational grammars permits a precise documentation and analysis of natural language phenomena. In collaboration with Calligramme, Talaris has developed a grammar compiler (XMG, Extended Metagrammar) which supports the computational specification of large scale, multi-dimensional tree grammars. One long term application pursued by Talaris in the domain of computational linguistics is the development of a large scale Feature Based Lexicalised Tree Adjoining Grammar describing both the syntax and the semantics of French.

4.2. Surface Realization

As mentioned above, the tree adjoining grammars developed by Talaris associate with each natural language expression not only a syntactic tree but also a semantic representation. In addition, because these grammars are unification based, they can be used either to derive a semantic representation from a sentence (analysis) or to generate a sentence from a semantic representation (generation). We are actively exploring how the grammars we develop, can be used to support data-to-text generation. After having developed several sentence generation algorithms (GenI, RTGen and D-RTGen), we are currently investigating: how to further optimise them; how to use them to verbalise knowledge bases and queries on knowledge bases; and how to evaluate their output.

4.3. Hybrid Automated Deduction

TALARIS’s main contribution in this topic has been the design of resolution and tableaux calculi for hybrid logics, calculi that were then implemented in the HYLORES and HTAB theorem provers. For example, TALARIS members have proved that the resolution calculus for hybrid logics can be enhanced with optimisations of order and selection functions without losing completeness. Moreover, a number of ‘effective’ (i.e., directly implementable) termination proofs for the hybrid logic $\mathcal{H}(\emptyset)$ has been established, for both resolution and tableaux based approaches, and the techniques are being extended to more expressive languages. Current work includes adding a temporal reasoning component to the provers, extending the architecture to allow querying against a background theory without having to explore again the theory with each new query, and testing the hybrid provers performance against dedicated state-of-the-art provers from other domains (firs-order logic, description logics) using suitable translations.

Moreover, we are interested in providing a range of inference services beyond satisfiability checking. For example, the current version of HYLORES and HTAB includes model generation (i.e., the provers can generate a model when the input formula is satisfiable).

We have also started to explore other decision methods (e.g., game based decision methods) which are useful for non-standard semantics like topological semantics. The prover HYLOBAN is an example of this work.

4.4. Multimedia

MLIF (Multi Lingual Information Framework) is intended to be a generic ISO-based mechanism for representing and dealing with multilingual textual information. A preliminary version of MLIF has been associated with digital media within the ISO/IEC MPEG context and dealing with subtitling of video content, dialogue prompts, menus in interactive TV, and descriptive information for multimedia scenes. MLIF comprises a flexible specification platform for elementary multilingual units that may be either embedded in other types of multimedia content or used autonomously to localise existing content.
4.5. Interfacing Virtual Worlds and Natural Language Processing

In 2010, Talaris addressed a new application domain namely, the integration of deep natural language processing (NLP) techniques with 3D worlds and games. A first foray into that theme has been the submission of two systems to the international GIVE (Giving instructions in a virtual environment). Two recently accepted EU funded projects (Interreg project Allegro and Eurostar project Emo-Speech) on that theme will permit a fully blown exploration of the research issues and of the technological problems arising in this area. This new theme builds on the tools and techniques developed by Talaris over the last 5 years for deep NLP and in particular, on the availability of an expressive grammar writing environment (XMG), of wide coverage deep grammars for French and English (SemTAG and SemXTAG), of a grammar based surface realiser (GenI) and of parsers (LLP2, SemConst) using these grammars.
4. Application Domains

4.1. Application Domains

TOSCA is interested in developing stochastic models and probabilistic numerical methods. Our present motivations come from Finance, Neuroscience and Biology, Fluid Mechanics and Meteorology, Chemical Kinetics, Diffusions in random media, Transverse problems, Software and Numerical experiments.

Finance  For a long time now TOSCA has collaborated with researchers and practitioners in various financial institutions and insurance companies. We are particularly interested in calibration problems, risk analysis (especially model risk analysis), optimal portfolio management, Monte Carlo methods for option pricing and risk analysis, asset and liabilities management. We also work on the partial differential equations related to financial issues, for example the stochastic control Hamilton–Jacobi–Bellman equations. We study existence, uniqueness, qualitative properties and appropriate deterministic or probabilistic numerical methods. At the moment we pay special attention to the financial consequences induced by modelling errors and calibration errors on hedging strategies and portfolio management strategies.

Neuroscience and Biology  The interest of TOSCA in biology is developing in three main directions: neuroscience, molecular dynamics and population dynamics. In neuroscience, stochastic methods are developed to analyze stochastic resonance effects and to solve inverse problems. For example, we are studying probabilistic interpretations and Monte Carlo methods for divergence form second-order differential operators with discontinuous coefficients, motivated by the 3D MEG inverse problem. Our research in molecular dynamics focuses on the development of Monte Carlo methods for the Poisson-Boltzmann equation which also involves a divergence form operator, and of original algorithms to construct improved simulation techniques for protein folding or interaction. Finally, our interest in population dynamics comes from ecology, evolution and genetics. For example, we are studying the emergence of diversity through the phenomenon of evolutionary branching in adaptive dynamics. Some collaborations in biostatistics on cancer problems are also being initiated.

Fluid Mechanics and Meteorology  In Fluid Mechanics we develop probabilistic methods to solve vanishing vorticity problems and to study the behavior of complex flows at the boundary, and their interaction with the boundary. We elaborate and analyze stochastic particle algorithms. Our studies concern the convergence analysis of these methods on theoretical test cases and the design of original schemes for applicative cases. A first example concerns the micro-macro model of polymeric fluids (the FENE model). A second example concerns Pope’s Lagrangian modelling of turbulent flows, motivated by the problem of modelling and computing characteristic properties of the local wind activity in areas where windmills are built. Our goal is to estimate local energy resources which are subject to meteorological randomness by combining large scale wind models and small scale Monte Carlo techniques, and to simulate management strategies of wind resources.

Chemical Kinetics  The TOSCA team is studying coagulation and fragmentation models, that have numerous areas of applications (polymerization, aerosols, cement industry, copper industry, population dynamics...). Our current motivation comes from the industrial copper crushers in Chile. We aim to model and calibrate the process of fragmentation of brass particles of copper in industrial crushers, in order to improve their efficiency at a low cost.

Diffusions in random media  A random medium is a material with a lot of heterogeneity which can be described only statistically. Typical examples are fissured porous media within rocks of different types, turbulent fluids or unknown or deficient materials in which polymers evolve or waves propagate. For the last few years, the TOSCA team has been collaborating with the Geophysics
community on problems related to underground diffusions, especially those which concern waste transport or oil extraction. We are extending our previous results on the simulation of diffusion processes generated by divergence form operators with discontinuous coefficients. Such an operator appears for example in the Darcy law for the behavior of a fluid in a porous media. We are also developing another class of Monte Carlo methods to simulate diffusion phenomena in discontinuous media.

**Transverse problems** Several of the topics of interest of TOSCA do not only concern a single area of application. This is the case in particular for long time simulation methods of nonlinear McKean-Vlasov PDEs, the problem of simulation of multivalued models, variance reduction techniques or stochastic partial differential equations. For example, multivalued processes have applications in random mechanics or neuroscience, and variance reduction techniques have applications in any situation where Monte Carlo methods are applicable.

**Software, numerical experiments** TOSCA is interested in designing algorithms of resolution of specific equations in accordance with the needs of practitioners. We benefit from our strong experience of the programming of probabilistic algorithms of various architectures including intensive computation architectures. In particular, our activity will concern the development of grid computing techniques to solve large dimensional problems in Finance. We are also interested in intensively comparing various Monte Carlo methods for PDEs and in the development of open source libraries for our numerical methods in Fluid Mechanics, Meteorology, MEG or Chemical Kinetics.
4. Application Domains

4.1. Application Domains

Four main application domains can be underlined.

- **In-vehicle embedded systems.** A lot of work developed in TRIO is oriented towards transportation systems (cars, autonomous vehicles, etc.). They mainly cover two points. The first one is the specification of what must be modeled in such a system and how to reach a good accuracy of a model; this leads to investigate topics like Architecture Description Languages and automatic generation of models. The second point concerns the verification of dependability properties and temporal properties required by these applications and, consequently, the development of new fault tolerant on-line mechanisms to include in an application or the automatic generation of a standard middleware.

- **Compilation, memory management and low-power issues for real time embedded systems.** It becomes mandatory to design embedded systems that respect performances and reliability constraints while minimizing the energy consumption. Hence, TRIO is involved, on the one hand, in the definition of ad-hoc memory management at compilation time and on the other hand, in joint study of memory management strategies and tasks scheduling for real time critical systems.

- **Code analyses and software visualization for embedded systems.** Despite important advances, it is still impossible to develop and optimize automatically all the programs with all their variety, especially when deployment constraints are considered. Software design and implementation thus remain highly ad-hoc, poorly automated activities, with a human being in the loop. TRIO is thus involved in the design of better tools for software engineering focusing on helping the human developer understand and develop the system, thanks to powerful automated program analyses and advanced visualizations techniques.

- **Quality of services (QoS) of protocols and telecommunications.** In many application domains, the evaluation and, when required, the improvement of the quality of services provided by the used communication protocols is a way to ensure the respect of real time and dependability properties. In this context, we model and analyze some protocols for Internet and Cyber Physical Systems (CPS) and aim to define the optimal configuration of their characteristics (protocols for the QoS guarantee for multimedia applications or ambient assisted living applications). Although WSN (Wireless Sensors Network) technology is economically a very interesting solution for building CPS, unfortunately its current QoS is not sufficient for supporting such applications. Adaptive QoS seems to be an interesting approach to this problem. This could be achieved in two coordinated directions: one is to develop the on-line adaptive QoS management in network to cope with the time varying performance requirement of an application; another is to make applications to adapt to the network working condition changes if they go beyond the network QoS control range. We follow a pragmatic approach by assuming the use of the COTS components (e.g. IEEE802.15.4/Zigbee) at the lower levels. The adaptive QoS are mainly studied at the routing level with cross-layer optimization and by defining and developing a QoS middleware allowing the necessary on-line interaction between the network and the application.
VEGAS Project-Team

4. Application Domains

4.1. Computer graphics

Our main application domain is photorealistic rendering in computer graphics. We are especially interested in the application of our work to virtual prototyping, which refers to the many steps required for the creation of a realistic virtual representation from a CAD/CAM model.

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

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

4.2. Solid modeling

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

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

4. Application Domains

4.1. Application Domains

Our work focuses on distributed algorithms and protocols. These are or will be found at all levels of computing infrastructure, from many-core processors and systems-on-chip to wide-area networks. We are particularly interested in novel paradigms, for example ad-hoc networks that underly mobile and low-power computing or overlay networks and peer-to-peer networking that provide services for telecommunication or cloud computing services. Distributed protocols underly computing infrastructure that must be highly available and mostly invisible to the end user, therefore correctness is important. One should note that standard problems of distributed computing such as consensus, group membership or leader election have to be reformulated for the dynamic context of these modern systems. We are not ourselves experts in the design of distributed algorithms, but work together with domain experts on the modeling and verification of these protocols. These collaborations help us focus on concrete algorithms and ensure that our work is relevant to the distributed algorithm community.

Formal verification techniques that we study can contribute to certify the correctness of systems. In particular, they help assert under which assumptions an algorithm or system functions as required. For example, the highest levels of the Common Criteria for Information Technology Security Evaluation require code analysis, based on mathematically precise foundations. While initially the requirements of certified development have mostly been restricted to safety-critical systems, they are becoming more and more common due to the cost associated with malfunctioning system components and software.