Activity Report 2011

Section New Results

Edition: 2012-03-22
1. ADAM Project-Team ................................................................. 4
2. ATEAMS Project-Team .......................................................... 6
3. BONSAI Project-Team ............................................................ 8
4. DART Project-Team ............................................................... 10
5. DOLPHIN Project-Team .......................................................... 18
6. MINT Team ........................................................................... 24
7. MODAL Team ........................................................................ 29
8. MOSTRARE Project-Team ....................................................... 32
9. NON-A Team ......................................................................... 34
10. POPS Project-Team ............................................................... 39
11. RMOD Project-Team ............................................................... 47
12. S.H.A.M.A.N Team ................................................................. 52
13. SEQUEL Project-Team ........................................................... 57
14. SIMPAF Project-Team ............................................................. 66
6. New Results

6.1. Adaptive Middleware


In 2011, we pursued our goal to demonstrate that general and high level concepts and solutions can be proposed to design multi-scale middleware systems. The multi-scale aspect has particularly been put forward and we obtained several interesting results: we showed that the concepts of service, component, and software architecture can be successfully used, in the small for wireless sensor middleware platforms [19], [43] with applications to the Internet of Things (IoT) [27] and for embedded systems [14], in mid-size distributed environments such as digital home networks [17], and in the large in cloud computing platforms [30]. We focus below on two achievements which are illustrative in the sense that they address both ends of the targeted spectrum of sizes.

At the scale of small systems, we proposed the REMORA platform [19], [43], [27] which defines a lightweight event-based programming model for wireless sensor networks. A C-like language for component implementation and an extension of the state-of-the-art Service Component Architecture (SCA) standard for service-oriented systems are proposed. The platform has been successfully deployed on the Contiki operating system. We showed that despite the characteristics of such resource-constrained environments, we are still able to obtain reconfigurability and adaptability properties for the deployed systems.

At the scale of very large systems, we showed in [30] first results that illustrate the fact that the FraSCAti platform [18] can be used to achieve interoperability between applications deployed on heterogeneous cloud platforms. The experiment is currently deployed on 13 public IaaS and PaaS cloud infrastructures. The very same concepts of service and software architecture that are used at smaller scales are put into practice here. Furthermore, we benefit from the same adaptability properties to address the heterogeneity of concepts needed to fit these very large scale infrastructures.

6.2. Context-awareness and Ambient Intelligence Software

Participants: Laurence Duchien, Sébastien Mosser, Clément Quinton.

Context-aware applications are applications that can react to changes on their environment. To achieve such reacting behavior, several challenges have to be faced in terms of: context management, support for dynamic reconfiguration, automation of development, and a consistent development process. One possible way to face those challenges is to use the principles of Software Product Line (SPL) and specifically dynamic SPL (DSPL). DSPLs focus on variability management and aim at deriving different products from a same product family. Additionally, DSPLs allow for products to be derived both at design and at runtime. This enables applications to be adapted during execution and dynamically fit new requirements or resource changes. In [16] we have proposed an approach to unify adaptation at design and at runtime based on Aspect Oriented Modeling. Our approach proposes a unified aspect metamodel and a platform that realizes two different weaving processes to achieve design and runtime adaptations. This approach is used in a Dynamic Software Product Line which derives products that can be configured at design time and adapted at runtime in order to dynamically fit new requirements or resource changes. Such products are implemented using the Service Component Architecture and Java. Finally, we have illustrated the use of our approach based on an adaptive e-shopping scenario. This work corresponds to Carlos Parra’s PhD thesis [11] and is partially funded by the CAPPUCINO project. Finally, in [40], we have proposed to develop an application for mobile devices using Software Product Lines (SPL). Considering variation factors, SPL allows the conception and the development of a software products family minimizing realization cost and time. The result is the APPLIDE framework, which provides SPL for smartphones, and we show how it works with a short demonstration.
6.3. SCeSAME: Formal Definition of Software Architecture Adaptation

Participants: Rubby Casallas, Laurence Duchien, Nohra Villegas, Gabriel Tamura.

In order to define properties on adaptation process, we need to formally model the architecture reconfiguration of a component-based (CB) system as an action performed by itself. These actions are performed in response to the disruption of Quality of Service (QoS) contracts, in the spirit of the Effeil’s rescue clause in object-oriented programming. By doing this, we aim to develop on the vision of the CBSE as a sound base to produce software systems enabled to automatically and safely reconfigure themselves by reconfiguring their abstract (reflection) architectures at runtime. For such structural reconfigurations, a system architect may reuse design patterns from other disciplines with the purpose of restoring QoS contracts, thus preserving them.

Our approach, named SCeSAME for “A Safe Contract-based Self-Adaptive Framework to Preserve QoS Properties on Mobile Devices” is built on the theory of extended graph (e-graph) rewriting proposed in e-graph [60], as a formalism to represent QoS contracts on component. We have given a formal definition of component-based structure systems, QoS contracts, and architecture reconfiguration rules. Based on these definitions, we built a framework that enables a component-based system to preserve its QoS contracts through architecture self-reconfiguration as a responding action to QoS contract violations. Our approach extends a theory of graph rewriting and defines a process calculus as formalisms to model the structure and reconfiguration process of architecture reconfiguration. The reconfiguration process, once parameterized with reconfiguration rules, can be verified as safe, i.e., component structural-compliant, terminating and confluent. This result is a part of Gabriel Tamura’s PhD and the results have been published in [36], [44].
ATEAMS Project-Team

6. New Results

6.1. Ambiguity Detection in Context-free Grammars

The work on static detection of ambiguity in context-free grammars continued in 2011. Bas Basten has worked on scaling previous results to so-called character level grammars. This includes the application of declarative disambiguation filters that increase the efficiency as well as the accuracy of the analysis [14].

6.2. Automated Diagnostics for Ambiguity in Context-free Grammars

When an ambiguity is found this is reported by a complex trace (usually a set of parse trees). It is difficult for a human to spot the cause of the ambiguity and devise a fitting solution. The Dr Ambiguity algorithm is an expert tool, by Bas Basten and Jurgen Vinju, that compares different parse trees for the same sentence on essential attributes that can be distinguished by declarative disambiguation methods [15].

6.3. A general library for software visualization

The Rascal standard library was extended with a very flexible component for the rapid construction of new/experimental (inter-active) visualizations. The current library is fully working and forms the inspiration for a possible domain-specific extension of the Rascal meta programming language to be integrated at a later stage [23]. This is work by Paul Klint and Atze van der Ploeg.

6.4. Comparing Design Patterns - the case of Visitor versus Interpreter

In this research application of Rascal, Mark Hills, Tijs van der Storm, Paul Klint and Jurgen Vinju focused on analyzing the emergent differences in quality when choosing between two different source code design patterns. We constructed a refactoring tool that translates instances of the Visitor design pattern to the Interpreter design pattern in a semi-automated fashion. This then allowed us to study two versions of an otherwise equivalent system in terms of efficiency and maintainability [24].

6.5. Entry in the language workbench competition

Tijs van der Storm and Jurgen Vinju participated on the Language Workbench Competition 2011 (LWC’11), showcasing the DSL construction and capabilities of Rascal. The objective was the development of a number of DSLs for entity-relation modeling. The modular implementation of these languages was documented in a technical report [35]. The DSL implementation featured modular context-free grammars for parsing, modular type checkers, modular code generators and full-fledged IDEs (syntax highlighting, outlining, error marking, etc.). The complete implementation only takes around 700 lines of Rascal code.

6.6. A compiler for OBERON-0

Tijs van der Storm led the participation of ATEAMS in the LDTA Tool Challenge 2011. This was a collaborative effort together with Atze van der Ploeg, Mark Hills, Bas Basten, Paul Klint, Bert Lisser, Jeroen van den Bos, Jurgen Vinju and Arnold Lankamp. The objective of the challenge was to implement all aspects of a simple, imperative language called Oberon-0. The components that had to be implemented included: parsing, pretty printing, name analysis, type checking, and compilation to C. Additionally, the components should be developed in a modular fashion according to four language levels: each language level added more language features and required the modular extension of the components. Although not required for the challenge, we also developed a compiler targeting Java, a compiler targeting JVM byte code, a control-flow graph visualizer, and IDE support. The implementation required only around 4200 lines of Rascal code. The result was presented at the international workshop on Language Descriptions Tools and Applications.
6.7. Generalized Grammar Recovery

Vadim Zaytsev managed to generalize the algorithm for recovering context-free grammars from legacy language documentation. This facilitates the recovery of a lot more grammars to be used in the study of grammarware and software language engineering.

6.8. Comparing Context-free Grammars through test data

Equivalence of the languages generated by two different context-free grammars is undecidable, yet language equivalence is one of the most important quality aspects of context-free grammars for programming languages. Vadim Zaytsev introduced and experimentally validated a method based on differential analysis: generating sentences from both grammars and cross-testing them.
6. New Results

6.1. High-throughput sequence processing

- We published a book chapter on bioinformatics algorithms for GPU/manycore processors [16].
- Within the PhD of T. T. Tran, we proposed a new bit-parallel algorithm, extension of [39], as well as a new indexing structure adapted to GPUs [13].
- We proposed a new index structure specifically designed for reads produced by high throughput sequencers. It can deal both with variable or fixed length reads and can index reads in usually less memory than other classical solutions. This index has been implemented and is available online [10].
- We characterised the number of elements to be reordered when updating a full-text index such as a suffix array. We finally concluded that this number tends to be poly-logarithmic in the input length for DNA sequences [5].

6.2. Noncoding RNAs

- A. Saffarian defended her thesis on November 16. Within her thesis, we obtained two results:
  - We designed a new algorithm to produce all locally optimal secondary structures of an RNA Sequence. Locally optimal secondary structures are thermodynamically stable RNA structures that are maximal for inclusion: they cannot be extended without producing a conflict between base pairs in the secondary structure, or increasing the free energy. A journal article is in revision to Journal of Computational Biology.
  - We also proposed an algorithm to match a multi-structure of RNA against a sequence. A multi-structure gather several RNA structures, as real or putative structures on a same sequence, or as similar structures in a family of RNAs. A journal article was submitted to Algorithms for Molecular Biology.
- We published an algorithm for the comparison RNA secondary structures represented as nested arc-annotated sequences [7].
- The non-coding RNA collaborative annotation platform RNAspace is made available to the community, and published in RNA [3].

6.3. Genome rearrangements

- A. Thomas has started his PhD on September 2011. We already obtained two results:
  - We designed an algorithm for finding the minimal number of block interchanges required to transform a duplicated linear genome into a tandem duplicated linear genome. We provide a formula for the distance as well as a polynomial time algorithm for the sorting problem. This work has been accepted in Bioinformatics 2012.
  - We also introduced and study a new combinatorial problem, a biological phenomenon that apparently associates a significant proportion of segmental duplications in mammalians, drosophilas and bacteria to breakpoints in rearrangement events. called the Genome Dedoubling Problem. It consists in finding a minimum length rearrangement scenario required to transform a genome with duplicated segments into a non-duplicated genome such that duplications are caused by rearrangement breakpoints. We introduced new graph data structures to solve these problems. This work was presented at RECOMB’CG 2011 [11].
• We designed and applied new algorithms for inferring ultra-perfect evolution scenarios for Drosophila and mammals species [6].
• We implemented and applied the algorithm of [32] for the reconstruction of species tree from gene trees of Fungal and eukaryotes species [8].
• We proposed a new reconstruction of the architecture of the ancestral amniote genome based on the detection and assembly of ancestral genomic features conserved in extant species [9].

6.4. Non-ribosomal peptides

• A new database, called Doris (for Database Of non-Ribosomal Synthetases), has been created to extend the information we provide about non-ribosomal peptides to their producing enzymes, the non-ribosomal peptide synthetases. For the moment, a first version of the web interface has been developed by Louise Ott, an engineer from Lille1 University. More than 400 enzymes have been automatically extracted from general databases.
• A collaboration started with members of Orpailleur EPI to design a semi-automatic process to collect non-ribosomal synthetases (NRPSs). We already start adapting MODIM, a generic tool developed by Orpailleur EPI to collect and integrate data extracted from various web sources, to the specific needs of NRPSs.
• As mentioned in the software section, the source code has been reorganised by Laurie Tonon, a SED engineer, to use model view controller software architecture, implemented with Struts2.
5. New Results

5.1. Co-Modeling for HP-SoC with MARTE

5.1.1. Diagonal mesh modeling with MARTE

As a continuation of this work on modeling at system level, a methodology for modeling concepts of NoC-based architectures is proposed especially the modeling of all kinds of topologies (regular, irregular or hierarchical) and routing algorithms. This contribution includes a VHDL code generation. On the other side we proposed a VLSI implementation of a new NoC topology called diagonal mesh that it designed to offer a good tradeoff between hardware cost and theoretical quality of service (QoS). This NoC is based on a new router architecture called FeRoNoC (Flexible, extensible Router NoC).

5.1.2. MARTE extension for reconfigurable hardware models

Reconfigurable System-on-Chip (RSoC), mainly FPGAs, offer several advantages such as flexibility, adaptivity and especially their capability to allow switching several implementations at run-time, i.e., PDR.

PDR feature requires multiple run-time changes in RSoC such as:
- QoS factors: changes in executing functionalities due to designer requirements, or changes due to resource constraints of targeted hardware/platforms.
- The changes can also take place due to other environmental criteria such as communication quality, time and area consumed for reconfiguration and energy consumption.

In previous work [86], we provided an initial contribution to the modeling of these systems by extending UML MARTE profile to incorporate significant design criteria such as power consumption. Furthermore, high flexibility of RSoC implies high design complexity of the control of such system. This makes designing a robust control for managing reconfiguration a studious task. In [25], we present a high level design approach using UML MARTE for modeling dynamic reconfiguration controllers. Our proposed controller is based on distributed monitoring of runtime changes and distributed decision making. Our approach allows to increase flexibility and design reusability compared to centralized solution.

Indeed, in its current version, UML MARTE profile lacks dynamic reconfiguration concepts and requirements for the reconfiguration control mechanism. Even these later are necessary to model and implement rapid prototypes for complex systems. We can only model a state machine at high abstraction levels which is responsible for switching between the available configurations.

So we define a new design methodology using the proposed version of RecoMARTE (extended MARTE) to model PDR concepts at different abstraction levels, mainly architecture (structural and physical models) and allocation (software to Hardware allocation (Sw/Hw Allocate) and Hardware to Hardware allocation (Hw/Hw Allocate)). We also define necessary requirements for the reconfiguration control mechanism in order to manage reconfiguration at every design level. In addition, our solution allows to describe global contracts and constraints for combining automata. As future works, we plan to carry out model transformations to enable automatic code generation of configuration files. The code can then be used as input for commercial tools for final FPGA synthesis.

5.1.3. Comparison of SAC and ArrayOL for parallelism expression

In this joint work with the University of Hertfordshire, we compare and analyse two such schemes. One of them is a domain-specific language, ArrayOL, to OpenCL. The other one is a transformation mechanism for mapping a image/signal processing transformation route for mapping a high-level general purpose array processing language, Single Assignment C (SaC) to CUDA. Using a real-world image processing application as a running example, we demonstrate that albeit the fact of being general purpose, the array processing language be used to specify complex array access patterns generically. Performance of the generated CUDA code is comparable to the OpenCL code created from domain-specific language.
5.1.4. Gaspard Modeling Improvements

Gaspard2 is the IDE proposed by the DaRT team. Its usage can be painful for beginners as well as for experts. We try to improve the usage of Gaspard in different ways:

- By allowing modifications at any model level, and let propagate the modifications to the higher and lower models (Amen Souissi).
- By providing missing diagrams in Papyrus (Amine El Kouen) By customizing the Gaspard User Interface (UI). Modeling in Gaspard is done with the Papyrus Modeler. We participate to the Papyrus development, which allow us to propose some customization tools. These later, are used to provide a modeling UI more adapted to embedded system co-modeling. This work is done by Rahma Yangui (INRIA engineer).
- By allowing to adapt dynamically the UML modeler environment according to the steps of the modeling process (Amine El Kouen’s thesis). This allows to guide the user in its development process, and to propose a simplified UI, oriented to the current development step.

Also, we have migrated from Papyrus I to Papyrus Eclipse.

5.2. Formal Methods for general-purpose and domain-specific languages

5.2.1. Formal Semantics for Domain Specific Modeling Languages

Domain-Specific Modelling Languages (DSMLs) are languages dedicated to modelling in specific application areas. Recently, the design of DSMLs has become widely accessible to engineers trained in the basics of Model-Driven Engineering (MDE): one designs a metamodel for the language’s abstract syntax; then, the language’s operational semantics is expressed using model transformations over the metamodel.

The democratisation of DSM design catalysed by MDE is likely to give birth to numerous languages. One can also reasonably expect that there shall be numerous errors in those languages. Indeed, getting a language right (especially its operational semantics) is hard, regardless of whether the language is defined in the modern MDE framework or in more traditional ones.

Formal approaches can benefit language designers by helping them avoid or detect errors. But, in order to be accepted by nonexpert users, formal approaches have to operate in the background of a familiar language design process, such as the MDE-based one mentioned above.

In 2011 we have migrated from [21], which uses the general Maude semantic framework, towards using the more language-definition specific the K-semantic framework to formalise the basic MDE ingredients used in DSML definition: models, metamodels, and model transformations. We have implemented a prototype tool that takes as input any DSML described in using MDE, and generates formal K definitions for the language’s syntax, static semantics, and operational semantics. Since the definitions are executable, we get execution and formal verification engines for free [44]. A subproject of this work has been a formal definition for a substantial fragment of the OCL language [45].

5.2.2. A new abstraction for signal programs, and improvement of the compilation process

In this work we propose a sound abstraction for an efficient static analysis of synchronous programs describing multi-clock embedded systems in Signal. This abstraction combines the Boolean theory and numeric interval approximation to adequately address clock relations defined as combinations of logical and numerical expressions. Through a few examples, we show how the proposed solution is used to determine absence of reaction captured by empty clocks; mutual exclusion captured by two or more clocks whose associated signals never occur at the same time; or hierarchical control of component activations via clock inclusion. We also show this analysis improves the quality of the code generated automatically by the Signal compiler, e.g., a code with smaller footprint, or a code executed more efficiently thanks to optimizations enabled by the new abstraction [38].
5.2.3. Using bounded model checking to focus fixpoint iterations

Two classical sources of imprecision in static analysis by abstract interpretation are widening and merge operations. Merge operations can be done away by distinguishing paths, as in trace partitioning, at the expense of enumerating an exponential number of paths. In this article, we describe how to avoid such systematic exploration by focusing on a single path at a time, designated by SMT-solving. Our method combines well with acceleration techniques, thus doing away with widenings as well in some cases. We illustrate it over the well-known domain of convex polyhedra [40].

5.2.4. A formal definition of a compiler for the Kermeta metamodeling language in K

Kermeta [109] is a DSL designed as a kernel for metamodel engineering. It unifies metamodeling, constraints, semantics and transformation features into a statically typed language. It is object-oriented and allows for metamodeling features such as attributes, associations, and multiplicities. It also includes design-by-contract, aspect-oriented features, and genericity. This makes Kermeta a large and complex language: indeed, combining all these features into one language may easily lead to inconsistencies.

Christophe’s postdoctoral work, starting in September 2010, has been to formally specify Kermeta. He did so via a specification of compiler for Kermeta in K [117]. K formal specifications are executable, hence, Christophe’s compiler can be used to actually compile Kermeta programs. The compiler it completely self-contained and generates bytecode for an abstract machine also formally specified in K.

This work led to the discovery of several errors and inconsistencies in Kermeta’s manual and existing interpreter. The errors are reported to the Kermeta designers (Triskell project-team at Inria Rennes-Bretagne Atlantique), who, as it turns out, are also writing a compiler of Kermeta in the traditional, informal way. We are planning to make them benefit from the experience we gained in formal compilation.

5.2.5. A generic approach and tool for tracing executions back to a DSML’s operational semantics

Model-driven engineering allows users to define abstract syntaxes for their own DSMLs in terms of metamodels. Several approaches for defining operational semantics for DSMLs have also been proposed. These approaches allow, in principle, for model execution and for formal analyses of the DSMLs. However, most of the time, the executions/analyses are performed via transformations to other languages: code generation, resp. translation to the input language of a model checker. The consequence is that the results (e.g., a program crash log, or a counterexample returned by a model checker) may not be straightforward to interpret by the users of a DSML. We propose a formal and operational framework for tracing such results back to the original DSML’s syntax and operational semantics. We implement the approach in a generic tool written in Kermeta, and illustrated in on the xSPEM language, a timed language for expressing the execution of activities constrained by time, resources, and precedences [31].

5.3. Optimization and compilation techniques

5.3.1. Generated Code Optimization

Performing a model-to-source transformation, whereby a high-level language is mapped to CUDA or OpenCL, is an attractive option. In particular, it enables to harness the power of GPUs without any expertise on the GPGPU programming. In this work, we add a new compilation option for the Gaspard2 transformation chain: UM2OpenCL to detect shareable data zone. The tilers from ArrayOL, which allow express the data parallelism from repetitive tasks, are analyzed in time compilation to create areas of shared data. The identification of these areas is crucial to allow us loading data on shared areas of memory that have high throughput. Consequently, programs automatically generated shall have performances comparable to manually well written programs.
5.3.2. Methodology to generate OpenCL code from MARTE models

In order to reduce design complexity, we propose an approach to generate code for OpenCL API, an open standard for parallel programming of heterogeneous systems. This approach is based on Model Driven Engineering (MDE) and Modeling and Analysis of Real-Time and Embedded Systems (MARTE) standard proposed by Object Management Group (OMG). The aim is to provide resources to non-specialist in parallel programming to implement their applications. Moreover, concepts like reuse and platform independence are present. Since we have designed an application and execution platform architecture, we can reuse the same project to add more functionalities and/or change the target architecture. Consequently, this approach helps industries to achieve their time-to-market constraints. The resulting code, for the host and compute devices, are compilable source files that satisfy the specifications defined on design time.

5.3.3. Profiling into Models

Regarding the models fine tuning, we propose integrating software-profiling results to higher-level specification models [56]. The aim is to optimize the models and, consequently, the generated code. The model optimization approach relies on the Gaspard2 branch dedicated to code generation for OpenCL and GPUs [58]. We offer software execution feedback, based on models transformation traceability [75], to model designers. These feedbacks enable the designers to tune their models in order to improve the software performances even if they do not have in-depth knowledge on the running platform (GPU). First, the code is generated from a first designed model using Gaspard2. The resulting code is then executed within an existing profiling environment. Afterwards, profiling results are delivered directly to designer as annotations in the model. Basically, we move up two types of information, using traceability. The first type directly results from the profiler, e.g. processor occupancy, onto specific regions in the model, enlightening the regions that requires tuning. The second type correspond to results of an expert system analysis that we provide. Information of this second type is delivered to designers as advices in the model annotations. The expert system generates these advices from platform features and running results. For example, it can suggest changing the shape of a task in order to optimize the processor occupancy. The more we feed the knowledge base and engine of the expert system, the more it is able to give better advices.

The model optimization relies on the hypothesis that the high level models are error free. Since these models are complex, it is difficult for the designers to conceive them correctly the first time. We propose a new approach, enabling the model designer to debug its models. For this purpose, we offer a quick and automatic code instrumentation to the model designer. As for the model optimisation, we take advantage of the model transformation traceability to keep the link between models and software execution and to provide execution information feedback. Hence, the information produced in the running environment during the software execution is moved up directly onto the models, allowing the model designers verifying the behavior of their software, directly on the high level models.

5.3.4. Static Analysis of Polychronous Specifications with SMT Theory

As opposed to single clocked synchronous programming paradigms, polychronous formalism allows specification of concurrent data flow computation on signals such that various data flows can evolve asynchronous with respect to each other. We formulated the clock analysis in Signal compilation [38] and the detection of false loops in MRICDF as a decision problem in Satisfiability Modulo Theory (SMT) [30][59]. Due to recent interests in SMT solvers, a number of efficient solvers are available which offer a greater expressiveness in dealing with non Boolean constraints and allow us to discern false loops from realizable causalities in reasonable computation time. We demonstrated that several polychronous specifications rejected by current compilers due to their inability to identify only true causal loops, can be synthesized as correct sequential embedded software.

5.3.5. Programming functional and real-time aspects simultaneously

An embedded system is usually required to respect real-time constraints related to physical constraints, either those of its environment or those of the physical devices it controls. First, it is often multi-periodic since its devices have different physical characteristics and must therefore be controlled at different rates. Second,
the system must respect deadline constraints, which may correspond for instance to a maximum end-to-end latency requirement between observations (inputs) and the corresponding reactions (outputs). A correct implementation must respect all the real-time constraints and must also be functionally deterministic, meaning that the outputs of the system are always the same for a given sequence of inputs. Current practice often deals with this two aspects separately, while our objective is to deal with them simultaneously.

To this intent, we must first introduce real-time primitives at the programming language level. We carried on previous work on the PRELUDE language [19], which provides such primitives in a synchronous data-flow language. We produced a complete end-to-end framework for the design and the implementation of embedded systems on a symmetric multicore: the PRELUDE-SCHEDCORE toolset [32]. We recently started a Master research project to study how real-time aspects could be introduced in more traditional programming paradigms with the SCALA a language.

The PRELUDE compiler translates a program into a set of dependent periodic tasks. We proposed a new dynamic priority-based scheduling policy capable of dealing with the extended precedence constraints (constraints between tasks of different periods) of such systems in [36], [48].

Finally, as PRELUDE\textsc{x} semantics defines formally both the functional and the temporal behaviour of a system, we studied temporal formal verification in [46].

5.3.6. Chaining Localized Model Transformation

Usually, two transformations can only be chained if the output metamodel of the first one is included into the input metamodel of the second one. This compliance issue forces to design either tailored fine-grain model transformations for a dedicated chain or large and complex transformations. In both cases, transformations are not reusable and hardly maintainable.

In order to solve this problem, we have introduced localized transformations which apply to a (typically very small) subset of an input metamodel of a transformation. Each localized transformation is designed and implemented to accomplish a specific transformation task, and involves and is applicable to a few concepts. The input and output metamodels of these transformations are not disjoint contrarily to traditional transformations; new chaining constraints have to be defined. We have thus defined new chaining constraints based on a type analysis to specify when two transformations can be chained in one, both or any order [96]. In some cases, this analysis concludes that the transformations can be chained in both order but with some input models, the two output models resulting of the two chaining, are not the same. We have introduce an intermediary abstraction level independent of any transformation language that focuses on read, modified, created and deleted metaelements. We are pursuing our investigations with this new abstraction level.

5.4. Green computing on SoC

5.4.1. Correct and Energy-Efficient Design of a Multimedia Application on SoC

We studied the design and analysis of multimedia applications such as the JPEG encoder on multiprocessor architectures [55] [24] [13]. A model-based approach was adopted by using the UML Marte specifications [54]. An abstract clock analysis has been proposed to deal with the correctness of system behaviors and to find the most suitable execution platform configurations regarding performance and energy consumption. Our approach offers a rapid and reliable design space analysis, which is crucial when implementing complex systems [37].

5.4.2. Design Space Exploration for Efficient Data Intensive Computing on SoCs

Finding efficient implementations of data intensive applications, such as radar/sonar signal and image processing, on a system-on-chip is a very challenging problem due to increasing complexity and performance requirements of such applications. One major issue is the optimization of data transfer and storage micro-architecture, which is crucial in this context. We proposed a comprehensive method to explore the mapping of high-level representations of applications into a customizable hardware accelerator [52]. The high-level representation is given in a language named Array-OL. The customizable architecture uses FIFO queues and
a double buffering mechanism to mask the latency of data transfers and external memory access. The mapping of a high-level representation onto a given architecture is achieved by applying loop transformations in Array-OL. A method based on integer partition is used to reduce the space of explored solutions. Our proposition aims at facilitating the inference of adequate hardware realizations for data intensive applications. It is illustrated on a case study consisting in implementing a hydrophone monitoring application.

5.4.3. Power Estimation

Within the context of the OPEN-PEOPLE project, we aim at addressing the power estimation challenges of embedded system design with a new approach, combining Functional Level Power Analysis with advanced SystemC – Transaction Level Modeling (TLM) simulation techniques, in order to formally prove qualitative and quantitative properties of the final system power estimation. This approach requires the construction of a power models from FLPA for different embedded boards (FPGA and ASIC) and building up system level simulation environment for the analysis of power model and proofs of properties of the simulated system [42].

As a main contribution, we propose a new hybrid system-level power consumption estimation methodology for complex embedded systems [41]. A key word in our contribution is hybridization between abstraction levels. Almost all the previous studies focus on power estimation for a given abstraction level without overcoming the wall of speed/accuracy trade-off. The idea here is to build up a hybrid power estimation tool that combines Functional Level Power Analysis (FLPA) for hardware power modeling and Transactional Level Modeling (TLM) simulation technique for rapid system prototyping and fast power estimation. Basically, the FLPA is used for processor power modeling. In the frame of this work, it will be extended to cover the other hardware components used in the MultiProcessor System-on-Chip (MPSoC) such as the memory and the reconfigurable logic. After that, we go further in terms of scalability to target heterogeneous multiprocessor architectures. The functional power estimation part is coupled with a fast SystemC simulator in order to obtain the needed micro-architectural activities for power models, which allows us to reach a superior bargain between accuracy and speed [43].

5.5. Dynamic reconfiguration for HP-SoC

5.5.1. Context switching for volatile IP

Dynamic reconfigurations require configuration decisions from smart controllers. Such a decision implies context saving of an existing IP or switching from an IP to another (loading a new bitstream). The store/restore operations can be managed by the operating system or by using a dedicated hardware component. In this work, a new model for hardware IP context storage and management is proposed. The approach is based on a flexible hardware wrapper which can make IP reconfigurable. In fact, these wrappers contain a naming system supporting efficient runtime context switching.

5.5.2. A generic broadcast network for HP-SoC architecture

The hNoC model proposes a specific network on chip dedicated to the massively parallel architecture SCAC. This model is composed of huge number of complex routers, called node elements (the NEs), communicating and working in perfect synchronizations. Each NE is potentially connected to its neighbors via a regular connection. Furthermore, each NE is connected to a heterogeneous set of computing groups (clusters) allow asynchronous processing. Each group includes a combination of processors programmable, the PEs (software processing units) and specialized hardware accelerators (hardware processing units) to perform critical tasks demanding the more performance. All the system is controlled by a Network Controller Unit, the NCU. The NCU and The PEs are implemented with the Forth processor.

The aim of our works is to design a new kind of communication network model for SCAC architecture to overcome firstly the overlapping communications with computations and secondly to increase significantly the external performances in terms of throughput. The difficulty of designing hNoC is a compromise between an optimal quality of broadcasting, high bandwidth and important flexibility of use, while reducing power consumption and silicon area.
Our first contributions defined a broadcast with mask model integrated in the communication network hNoC of SCAC architecture. This model is based on subnetting the network of processing nodes which separate the control of communication and processing. Our model was implemented in synthetizable VHDL code that is simulated and targeted Xilinx Virtex6 (XC6VLX240T) board.

5.5.3. Distributed control for dynamic reconfiguration

The aim of our current work is to propose a distributed approach for reconfiguration control on FPGAs. The main reason for choosing a distributed control approach is that, with the ever growing complexity and size of the modern reconfigurable systems, the traditional centralized approach is no more efficient. Instead, a distributed control has many advantages in terms of performance and design efficiency. Indeed, the distributed control allows to avoid communication bottlenecks and to increase the parallelism compared to the centralized one, allowing a better performance which is a critical issue especially for high-performance applications. At the design level, the distributed control has many advantages. It allows to decrease the design complexity of the control by dividing the intelligence between the controllers, which allows a shorter design time and an easier verification. It also facilitates the reuse of the controllers instead of redesigning a centralized controller for different systems, which allows also a higher scalability in order to adapt to the growing size of the modern SoC. Our approach for reconfiguration control is an event-driven control, where events come from a variety of sources in order to ensure a high adaptivity of the reconfigurable systems. Reconfiguration can be triggered by a user input, a change in the environment condition (e.g., changes in lightening condition) or a change in performance or power consumption requirements, etc. Therefore, we propose a modular structure of each controller allowing three major tasks: monitoring, decision making and reconfiguration realization. In order to respect the global constraints of the system, the controllers communicate their decisions to each other in order to handle cooperation and conflicts. In [25], we proposed a high-level design of our approach using Model Driven Engineering aiming to combine the advantages of the distributed control with the high-level design in order to decrease design complexity and automate code generation increasing thus design productivity.

At the physical level, the distributed control has been implemented for simple applications in order to test the different modules of the controllers (monitoring, decision making, communication between controllers). As a future work, we plan to implement the distributed control for more complex applications in order to highlight the advantages of our approach and study its limits.

5.5.4. Avionic test bench on heterogenous reconfigurable platform

The aim goal of this thesis is to design the next Eurocopter avionic test bench generation. For the past 20 years, Test Systems have always been considered as a must do in the avionic development cycle. In early 2008, the Eurocopter research department has undertaken a profound reflection on the vocation Pro-Active Test Systems [15]. Hitherto, the test systems were based on real time specific CPU boards that run proprietary real time operating systems and plugged with Input/Output (I/O) boards to communicate with the equipments under test. In current industrial practice, the well-spread VME CPU boards are widely used. Due to the present test system performance requirement, an increase in the computation rates is needed, but it cannot be delivered by the VME CPU boards any-more. Furthermore, this solution is considered as an expensive maintainable technology. To overcome these drawbacks, the usage of multicore hosts (PC or workstation) allows an immediate increase in the capacity of computation. An important outcome of this transition is the refusal of the obsolete CPU boards. However, this solution cannot guarantee the real-time criteria while the execution of concurrent tasks due to the lack of an appropriate Operating System (OS) environment. In addition, this solution brings new communication latencies between the CPUs and I/O boards plugged in the VME backplane. In this work, our proposal is to make profit from the new available hardware computing resource (FPGA) and to make up hybrid avionic test systems [27]. Indeed, FPGA technology could offer a higher computation rates comparing to CPUs up to 10x. It could implement heavy models in a hardware fashion with the management of the parallelism degree to answer the real-time constraints of the application. The main challenge of hybrid (CPU/FPGA) architectures concerns the programming model and the design methodology. We need to deal with the heterogeneity of both hardware and software parts in order to obtain a fast system prototyping. In current industrial practice, manual coding is still widely adopted in the development of hybrid architectures, which is clearly not suited to manage the complexity intrinsic in these systems. For designers,
this approach is very tedious, error-prone and expensive. In the first part of our work we emphasized the usage of Model Driven Engineering (MDE) for heterogeneous systems in order to reduce the design complexity of CPU-FPGA architectures [72]. In ReCoSoC paper, we focused on the prototyping environment and the related development tools in order to map existing software into CPU-FPGA architectures by detecting all data dependencies and get the parallelism degree. Moreover, we presented communication solutions comparing fast links such as Ethernet and PCIe. Secondly Multi-Core optimizations in different environments such as Linux with Open Source real-time patches (Xenomai) and processor affinities capabilities. Then, we presented in [28] a new generation of adaptive and generic avionic test benches using FPGA reconfigurability capabilities. Indeed, nowadays, each Eurocopter test bench is related to a specific embedded part and a specific aircraft. Proposing such generic architecture will reduce the helicopter design cycle significantly by testing different embedded systems at the same time.

5.6. Application case-studies

5.6.1. Experimentations for electromagnetism simulations
The electrical and electronic engineering has used parallel programming to solve its large scale complex problems for performance reasons. However, as parallel programming requires a non-trivial distribution of tasks and data, developers find it hard to implement their applications effectively. Thus, we used our approach, based on Model Driven Engineering (MDE) and the MARTE profile, to generate code for a sparse solver and achieve a good speed-up. Moreover, thanks to model reuse capacity, we can add/change functionalities or the target architecture and still keep a good scalability.

5.6.2. H.264 modeling on NoC, implementation and synthesis
In addition, the H.264 coder is modeled using MARTE profile and a hardware description for all components is proposed, particularly the Motion Estimation (ME), adopts many new features to increase the coding performance such as block matching algorithm, motion vector prediction, variable block size motion estimation, etc. However, VBSME is utilized in the MPEG4-AVC/H.264 standard which leads to a higher computational complexity and a higher data dependence that makes the hardware implementation very complex. The aim of our work is to propose a VLSI architecture for full-search VBSME (FSVBSME). This contribution allows the reusing smaller sub-blocks for the computation results, sharing sub-blocks comparator and offering low power consumption.

5.7. Axellience
Based on the good results of the localized transformations coupled with MDFactory in Gaspard in term of reusability, modifiability and understandability, Alexis Muller (Expert Engineer) decided to study the opportunity to create a start-up company from these works. Due to his past experiment in the domain of information system and the maturity of the model usage by the enterprises, the idea was to target the automatic generation of information system from UML model and no more to address embedded systems. Joined by Thomas Legrand (Software Engineer), they developed new localized transformations and new chains. The results and the first feed-backs from enterprises in the domain of information systems are very encouraging. Furthermore, the Axellience project has win the national competitive examination of helping to the creation of innovating enterprises (Oseo). A technological transfer concerning MDFactory is foreseen between the DaRT team and the Axellience project in order to create the start-up company in the early beginning of the 2012 year. Straight collaborations between the company and the DaRT team should continue via the works around localized transformations.
6. New Results

6.1. Generalizing dual-feasible functions to the multi-dimensional case

Participant: F. Clautiaux.

Dual-feasible functions have been used in the past to compute lower bounds and valid inequalities for different combinatorial optimization and integer programming problems. Until now, all the dual-feasible functions proposed in the literature were 1-dimensional functions. We extended the principles of dual-feasible functions to the m-dimensional case by introducing the concept of vector packing dual-feasible function. We explored the theoretical properties of these functions in depth, and we proposed general schemes for generating some instances of these functions. Additionally, we proposed and analyzed different new families of vector packing dual-feasible functions. All the proposed approaches were tested extensively using benchmark instances of the 2-dimensional vector packing problem. Our computational results show that these functions can approximate very efficiently the best known lower bounds for this problem and improve significantly the convergence of branch-and-bound algorithms.

6.2. Aggregation algorithms for network flow mathematical models

Participant: F. Clautiaux.

We designed a general framework for solving very large network flow mathematical models that use a pseudo-polynomial number of variables. It is based on an initial aggregation of the vertices of the model and its iterative refinement using different optimization techniques. This led to large improvements for a special case of vehicle routing problem. Several theoretical questions regarding convergence, worst-case analysis and approximation algorithms are raised by our work and are now under study.

6.3. New Price Setting models in the Energy Field

Participant: L. Brotcorne.

The electricity supply industry is facing in many countries a restructuring process towards deregulation and competition. In that context classical marginal cost based approaches based on estimation of cost production function and demand functions are not well-suited anymore. Indeed, the energy prices have to be defined not only to retrieve the production costs but also in order to take into account the consumer behavior. Consumers make their choice of service, or of energy provider in order to minimize their disutility values. Failing to recognize that may lead to tremendous lack on revenues. In order to capture this hierarchical decision process where a leader (the energy provider) takes explicitly into account the reaction of a follower (the consumers) in his decision process (see for example [1]) the energy pricing problems addressed in this subject have been modeled as bilevel programs.

6.4. Bi-level formulation for a Long-Distance Freight Transportation Problem

Participants: M. Dialby, L. Brotcorne, E.-G. Talbi.

A company wants to convey different types of products from origin i to points of destination j. It can deliver the goods itself or hire a transport company, and subcontract part of the application. The transport company must offer attractive prices while aiming to maximize its profit. The aim of this problem is to determine rates that allow the carrier to maximize its revenues and remain affordable for the customer. The problem is modeled as a bilevel program at the first level, the carrier (leader) wants to maximize its revenues; at the second level, the client (follower) aims to minimize its expenses. A primal dual heuristic has been proposed to solve the problem.
6.5. Advances in Parallel Metaheuristics on GPU

Participants: Thé Van Luong, Nouredine Melab, El-Ghazali Talbi.

Nowadays, GPU computing has recently been revealed effective to deal with time-intensive problems. This new emerging technology is believed to be extremely useful to speed up many complex algorithms. One of the major issues for metaheuristics is to rethink existing parallel models and programming paradigms to allow their deployment on GPU accelerators. Generally speaking, the major issues we have to deal with are: the distribution of data processing between CPU and GPU, the thread synchronization, the optimization of data transfer between the different memories, the memory capacity constraints, etc. The contribution of our work is to deal with such issues for the redesign of parallel models of metaheuristics to allow solving of large scale optimization problems on GPU architectures. Our objective is to rethink the existing parallel models and to enable their deployment on GPUs.

Thereby, the new results involve a new generic guideline for building efficient parallel metaheuristics on GPU (e.g. tabu search, iterated local search, island model for evolutionary algorithms, pareto local search or multi-start algorithms). Our challenge is to come out with the GPU-based design of the whole hierarchy of parallel models. In this purpose, very efficient approaches are proposed for CPU-GPU data transfer optimization, thread control, mapping of solutions to GPU threads or memory management. These approaches have been exhaustively experimented using eleven optimization problems and six GPU configurations. Compared to a CPU-based execution, experiments report up to 80-fold acceleration for large combinatorial problems and up to 2000-fold speed-up for a continuous problem. The different works related to our work have been accepted in a dozen of publications, including the IEEE Transactions on Computers journal.

6.6. Parallel Evolutionary Algorithms for Energy-Aware Scheduling


In the last decades, energy becomes an increasingly important issue in computing and embedded systems. In computing systems, minimizing energy consumption can significantly reduce the amount of energy bills. The demand for computing systems steadily increases and the cost of energy continues to rise. In embedded systems, reducing the use of energy allows to extend the autonomy of these systems. In addition, the reduction of energy decreases greenhouse gas emissions. Therefore, many researches are carried out to develop new methods in order to consume less energy. In this work, we propose an overview of the main methods used to reduce the energy consumption in computing and embedded systems.

As a use case and to give an example of a method, this work describes our new parallel bi-objective hybrid genetic algorithm that takes into account the completion time and the energy consumption. In terms of energy consumption, the obtained results show that our approach outperforms previous scheduling methods by a significant margin. In terms of completion time, the obtained schedules are also shorter than those of other algorithms.

6.7. A Parallel Bi-objective Hybrid Metaheuristic for Energy-Aware Scheduling for Cloud Computing Systems


In this work, we investigate the problem of scheduling precedence-constrained parallel applications on heterogeneous computing systems (HCSs) like cloud computing infrastructures. This kind of applications was studied and used in many research works. Most of these works propose algorithms to minimize the completion time (makespan) without paying much attention to energy consumption. We propose a new parallel bi-objective hybrid genetic algorithm that takes into account, not only makespan, but also energy consumption. We particularly focus on the island parallel model and the multi-start parallel model. Our new method is based on dynamic voltage scaling (DVS) to minimize energy consumption. In terms of energy consumption, the obtained results show that our approach outperforms previous scheduling methods by a significant margin. In terms of completion time, the obtained schedules are also shorter than those of other algorithms. Furthermore, our study demonstrates the potential of DVS.
6.8. A Pareto-based GA for Scheduling HPC Applications on Distributed Cloud Infrastructures  

**Participants:** N. Melab, E.-G. Talbi.

Reducing energy consumption is an increasingly important issue in cloud computing, more specifically when dealing with High Performance Computing (HPC). Minimizing energy consumption can significantly reduce the amount of energy bills and then increase the provider’s profit. In addition, the reduction of energy decreases greenhouse gas emissions. Therefore, many researches are carried out to develop new methods in order to consume less energy. In this work, we present a multi-objective genetic algorithm (MO-GA) that optimizes the energy consumption, CO$_2$ emissions and the generated profit of a geographically distributed cloud computing infrastructure. We also propose a greedy heuristic that aims to maximize the number of scheduled applications in order to compare it with the MO-GA. The two approaches have been experimented using realistic workload traces from Feitelson’s PWA Parallel Workload Archive. The results show that MO-GA outperforms the greedy heuristic by a significant margin in terms of energy consumption and CO$_2$ emissions. In addition, MO-GA is also proved to be slightly better in terms of profit while scheduling more applications.

6.9. An Hybrid Multiobjective Method to solve Biclustering of Microarray Data  

**Participants:** L. Jourdan, K. Seridia, E.-G. Talbi.

In this work, we propose an a multi-objective genetic algorithm (NSGA-II) with a heuristic to solve the biclustering problem of micro-array data. Due to the huge size of the datasets, we propose a new representation based on a string of integers and the associated operators. Experimental results on real data set show that our approach can find significant biclusters of high quality.

6.10. Flexibility and dynamic optimization  

**Participants:** L. Jourdan, M. Khouadjia, E.-G. Talbi.

In this work we propose a new method that explicitly searches for routes that are flexible enough to allow easy adaptation after a new order has arrived. For that we propose a measure of flexibility, and show that better solutions can be obtained when the "planning horizon" for all subproblems is modified to take the flexibility of solutions into account.

6.11. Indicator-based Multi-objective Local Search  

**Participant:** A. Liefooghe.

In the last few years, a significant number of multi-objective metaheuristics have been proposed in the litterature in order to address real-world problems. Local search methods play a major role in many of these metaheuristic procedures. We adapt a recent and popular indicator-based selection method in order to define a population-based multi-objective local search. The proposed algorithm is designed in order to be easily adaptable, parameter independent and to have a high convergence rate. The capacity of our algorithm to reach these goals is evaluated on a large bunch of experiments. Three combinatorial optimization problems are investigated: a flow-shop scheduling problem, a ring star problem and a nurse scheduling problem. The experiments show that our algorithm can be applied with success to different types of multi-objective optimization problems and that it outperforms some classical metaheuristics. Furthermore, the parameter sensitivity analysis enables us to provide some useful guidelines about how to set the main parameters.

6.12. Connectedness and Local Search for Bi-objective Knapsack Problems  

**Participant:** A. Liefooghe.
In [33], we report an experimental study on a given structural property of connectedness of the set of Pareto-optimal solutions for two variants of the bi-objective knapsack problem. A local search algorithm that explores this property is then proposed and its performance is compared against exact algorithms in terms of running time and number of optimal solutions found. The experimental results indicate that this simple local search algorithm is able to find a representative set of Pareto-optimal solutions in most of the cases, and in much less time than exact approaches.

6.13. Set-based Multiobjective Fitness Landscapes

**Participants:** S. Verel, A. Liefooghe, C. Dhaenens.

Fitness landscape analysis aims to understand the geometry of a given optimization problem in order to design more efficient search algorithms. However, there is a very little knowledge on the landscape of multiobjective problems. In [43], we consider multiobjective optimization as a set problem. Then, we give a general definition of set-based multiobjective fitness landscapes. An experimental set-based fitness landscape analysis is conducted on the multiobjective NK-landscapes with objective correlation. The aim is to adapt and to enhance the comprehensive design of set-based multi-objective search approaches, motivated by an a priori analysis of the corresponding set problem properties. Our experimental study shows that tools from single-objective fitness landscapes can directly be extended for analyzing set-based multiobjective search approaches. The relevant features of multimodality and ruggedness has been highlighted for this particular class of problems.


**Participants:** S. Verel, A. Liefooghe, L. Jourdan, C. Dhaenens.

The structure of the search space explains the behavior of multiobjective search algorithms, and helps to design well-performing approaches. In this work, we analyze the properties of multiobjective combinatorial search spaces, and we pay a particular attention to the correlation between the objective functions. To do so, we extend the multiobjective NK-landscapes in order to take the objective correlation into account. We study the co-influence of the problem dimension, the degree of non-linearity, the number of objectives, and the objective correlation on the structure of the Pareto optimal set, in terms of cardinality and number of supported solutions [45], as well as on the number of Pareto local optima [46]. This work concludes with guidelines for the design of multiobjective local search algorithms, based on the main fitness landscape features. All our results show that no expectation on the performance of multiobjective local search algorithms can be drawn without taking the problem properties into account very precisely. Indeed, it has now become clear that the number of objectives is one of the key issue to explain a problem complexity, but we also pointed out that the objective correlation is at least as important. Multiobjective fitness landscape analysis plays a central role to explain the performance of local search algorithms, and to design more efficient methods, that suit better the problem features.

6.15. On the Neutrality of Combinatorial Optimization Problem to Design an Efficient Neutrality-based Local Search

**Participants:** M.-E. Marmion, C. Dhaenens, L. Jourdan, A. Liefooghe, S. Verel.

In the context of the permutation flowshop scheduling problem, a deep landscape analysis focused on the neutrality property has been driven [hal-00550356]. This analysis characterizes the neutral networks of the local optima in order to make propositions about the way to exploit it in algorithms. Hence, NILS has been designed in order to exploit the neutrality of local optima [hal-00563459]. As soon as a local optimum is found, the search is allowed to move to equivalent neighbors. Moreover, NILS gets only one parameter that controls the number of solutions allowed to be visited with the same fitness value. NILS has been tested on flowshop and has shown promising results.
6.16. **Guiding the Search over Neutral Networks**  
**Participants:** M.-E. Marmion, C. Dhaenens, L. Jourdan, A. Liefooghe, S. Verel.

In a context of neutrality, VEGAS was designed to escape from neutral networks based on the evolvability of solutions, and on a multi-armed bandit by selecting the more promising solution from the neutral network [hal-00579990]. Its main feature is to consider the whole evaluated solutions of a neutral network rather than the last accepted solution as classical methods. VEGAS was tested on NKq-landscapes (problems built to present neutral properties) and results show the importance of considering the whole identified solutions from the neutral network and of guiding the search explicitly.

6.17. **DAMS: Distributed Adaptive Metaheuristic Selection**  
**Participants:** B. Derbel, S. Verel.

In this work, we design a new Distributed Adaptive Metaheuristic Selection (DAMS) scheme. DAMS is dedicated to adaptive optimization in distributed environments. Given a set of metaheuristics, the goal of DAMS is to coordinate their local execution on distributed nodes in order to optimize the global performance of the distributed system. DAMS is based on three-layer architecture allowing nodes to decide distributively what local information to communicate, and what metaheuristic to apply while the optimization process is in progress. Within this context, we specialize DAMS by describing a particular instantiation called Select Best and Mutate (SBM). Its is a simple, yet efficient, adaptive distributed algorithm using an exploitation component allowing nodes to select the metaheuristic with the best locally observed performance, and an exploration component allowing nodes to detect the metaheuristic with the actual best performance. SBM features are analyzed from both a parallel and an adaptive point of view, and its efficiency is demonstrated through experimentations and comparisons with other adaptive strategies (sequential and distributed).

6.18. **A Method to Combine Combinatorial Optimization and Statistics to Mine High-Throughput Genotyping Data**  
**Participants:** J. Hamon, C. Dhaenens, J. Jacques.

In collaboration with Gènes Diffusion, we are interested in high-throughput genotyping data in order to select a subset of genes explaining a trait of interest. We suggest to study these high-throughput data combining combinatorial optimization and statistical methods. A first method based on an ILS (Iterated Local Search) and using a statistical criterion to calculate the fitness was suggested and compared with classical statistical approaches.

**Participants:** J. Jacques, L. Jourdan, C. Dhaenens.

This work focuses on helping clinical trials investigators to screen more patients. First, we performed an analysis of clinical trial business and medical data available in French hospitals. We carried on several expert interviews. Then we developed a model to this problem as an association rules mining problem. After a statistical study of rule interestingness measures, we proposed an improvement of this model as a multi-objective combinatorial optimization problem.

6.20. **Reducing Thread Divergence in GPU-based B&B Applied to the Flow-shop Problem**  
**Participants:** I. Chakroun, A. Bendjoudi, N. Melab.
Branch-and-Bound (B&B) algorithms are attractive methods for solving to optimality combinatorial optimization problems. Nevertheless, they are time-intensive when dealing with large problem instances. Therefore, several parallel B&B strategies based on large computer clusters and grids have been proposed in the literature. However, to the best of our knowledge no contribution has been proposed for designing B&B algorithms on GPUs (Graphic Processing Units). Because of their tremendous computing power and remarkable cost efficiency, GPUs have been recently revealed as a powerful way to achieve high performance on long-running scientific applications. In this research work, we propose to revisit the design and implementation of B&B algorithms on GPU. We focus on the parallel evaluation of the bounds since preliminary experiments performed on the Flow-Shop scheduling problem (FSP) have shown that the bounding operation consumes over 98% of the execution time of the B&B algorithm. To deal with thread divergence reduction issue caused by the bounding operation a code refactoring approach have been proposed.

6.21. Fitness Landscapes: Local Optima Network

Participant: S. Vérel.

A new methodology to study the structure of the configuration spaces of hard combinatorial problems. It consists in building the network that has as nodes the locally optimal configurations and as edges the weighted oriented transitions between their basins of attraction. We apply the approach to the detection of communities in the optima networks produced by two different classes of instances of a hard combinatorial optimization problem: the quadratic assignment problem (QAP). We provide evidence indicating that the two problem instance classes give rise to very different configuration spaces. For the so-called real-like class, the networks possess a clear modular structure, while the optima networks belonging to the class of random uniform instances are less well partitionable into clusters.
MINT Team

6. New Results

6.1. Improvement of the force-feedback in a 1-ddl device

Participants: Michel Amberg, Frédéric Giraud, Betty Lemaire-Semail.

Traveling Wave Ultrasonic Motor have many advantages compared to the classical electromagnetic motors: they are lightweight, they don’t need any speed reducer and they make no noise. In a 1-ddl force feedback device, they can help to reduce the bulk size of the mechanism by simplifying the kinematic chain. However, their control has to be very precise because the torque produced is not a straightforward function of the electrical parameters. Previously, we proposed several control algorithms and we obtained good results. But at low speed, problems still remains, like a stick-slip phenomena which makes the motor producing a cogging torque.

To cope with this problem, we first proposed an accurate modeling of the motor and its torque production [24]. We introduced a friction torque \( T_f \) which holds the non linearity of the torque production. The evolution of this friction torque has been identified through an experimental study. Then we obtained by inversion a control scheme [13]. The basic idea is to compensate the virtual friction torque. In order to achieve a more accurate control of the torque, we proposed to identify on-line the parameters of the equation of \( T_f \).

A one-degree-of-freedom force feedback lever was built to verify the control laws. The experiment involves use of the lever of the digitracker which is free to rotate about the horizontal axis, and is presented in figure 1. In the same figure, we plotted the output torque of the motor, compared to its reference. Both are consistent, showing a good accuracy of the torque controller. To achieve that, the estimator’s parameters are time-varying.

Figure 1. (a) The 1-ddl haptic device; (b) experimental run of the torque controller with its parameter estimator; in H, results are plotted in the Torque-position plane, reference is in green and measurements is in blue while C, D and G show the estimator’s parameters

6.2. Haptic Perception of Curvature through active touch

Participants: Michel Amberg, Frédéric Giraud, Betty Lemaire-Semail.
Haptic perception of curvature can be achieved by passive or active finger touch. In this study we proposed a new haptic device that could independently orient, elevate and translate a flat plate. User is free to move his finger on the plate; by controlling plate’s orientation and position accordingly to the position of the finger, we can render a curved shape. The device is composed of two 6-dof haptic devices (Novint Falcon) on which we attached the plate (Figure 2). A force sensor is used to compute the position of the finger on the plate. Several modelings have been proposed to calculate the orientation and position of the plate. We then measured how accurate simulations of curved shapes are. To achieve that work, we simulated several curved surfaces with different curvature. As the perception performance of curvature is dependent on local surface orientation, the plate was always kept tangent to a virtual shape at the contact point. We then asked people to compare simulated curvature to the real ones. We found that users are able to find the real shape (among five) corresponding to the simulated one [21].

6.3. Tactile input with programmable friction

**Participants:** Michel Amberg, Géry Casiez, Frédéric Giraud, Betty Lemaire-Semail, Paolo Olivo, Nicolas Roussel.

Our work on programmable friction relies on a particular technology we have been developing for several years. The STIMTAC is a touchpad device that supports friction reduction by means of a *squeeze film effect* [29]. It uses a controlled vibration at an ultrasonic frequency with a few micrometers amplitude to create an air bearing between a user’s finger and the device’s surface. As the frequency is outside skin mechanoreceptors’ bandwidth, one does not feel this vibration but its effect on tribological contact mechanisms: the touchpad feels more slippery as the amplitude is raised.

We have used this touchpad to create *Surfpad*, a pointing facilitation technique that operates in the tactile domain. Experiments comparing this technique to *semantic pointing* [30] and constant control-display gain with and without distractor targets clearly show the limits of traditional target-aware control-display gain...
adaptation in the latter case, and the benefits of the tactile approach in both cases [17]. Surfpad leads to a performance improvement close to 9% compared to unassisted pointing at small targets with no distractor. It is also robust to high distractor densities, keeping an average performance improvement of nearly 10% while semantic pointing can degrade up to 100%. Our results also suggest the performance improvement is caused by tactile information feedback rather than mechanical causes, and that the feedback is more effective when friction is increased on targets using a simple step function.

This year’s work on the hardware aspects of the STIMTAC resulted in a compact and quiet prototype powered by the USB cable used for data communication and supporting precise and reliable finger tracking based on multiple force sensors (Figure 3, left). Within the context of the 3DTOUCH project, efforts have also been targeted at the adaptation of the STIMTAC operating principles to off-the-shelf transparent touch sensors. Our latest prototypes demonstrate the compatibility of our approach with resistive (Figure 3, right) and capacitive technologies. In order to facilitate the design and evaluation of novel interaction techniques taking advantage of these prototypes, we have started developing a specific library, tIO, that supports all of them in a unified way.

Figure 3. Compact opaque STIMTAC and transparent resistive prototype

6.4. Methods and tools to characterize, replicate and compare pointing transfer functions

Participants: Géry Casiez, Damien Marchal, Nicolas Roussel.

Transfer functions are the only pointing facilitation technique actually used in modern graphical interfaces involving the indirect control of an on-screen cursor. But despite their general use, very little is known about them. We developed EchoMouse, a device we created to characterize the transfer functions of any system, and libpointing, a toolkit that we developed to replicate and compare the ones used by Windows, OS X and Xorg [16]. We described these functions and reported on an experiment that compared the default one of the three systems. Our results show that these default functions improve performance up to 24% compared to a unitless constant CD gain. We also found significant differences between them, with the one from OS X improving performance for small target widths but reducing its performance up to 9% for larger ones compared to Windows and Xorg. These results notably suggest replacing the constant CD gain function commonly used by HCI researchers by the default function of the considered systems.

6.5. Multimodal pen input for interactive multitouch surfaces

Participant: Géry Casiez.
Touch interaction is arguably more immediate and natural in many situations, but fingers are imprecise and difficult to write with. Alternatively, using a pen (or stylus) makes writing more natural and pointing more precise. Luckily, this does not need to be a unilateral choice: pen and touch can be used simultaneously. However, without non-dominant hand coordination or graphical buttons, the pen itself supports few modes. This makes single-handed mobile usage difficult and reduces the number of combined touch and pen modes. When frequently switching between pen-oriented modes, such as drawing, handwriting, gestures, and lasso selection, this can hurt performance. Inferring modes is difficult, and most users prefer explicit control. Schemes for squeezing multiple explicit modes from a pen include adding barrel buttons and classifying pressure, tilt, barrel rotation, or grip. But these can be error-prone and ambiguous. A simple way to add a second mode is by adding an “eraser,” a second contact point. The pencil analogy lends intuition and users have explicit control.

Conté is a small input device inspired by the way artists manipulate a real Conté crayon. By changing which corner, edge, end, or side is contacting the display, the operator can switch interaction modes using a single hand. Conté’s rectangular prism shape enables both precise pen-like input and tangible handle interaction. Conté also has a natural compatibility with multi-touch input: it can be tucked in the palm to interleave same-hand touch input, or used to expand the vocabulary of bimanual touch. Inspired by informal interviews with artists, we catalogue Conté’s characteristics, and use these to outline a design space. We describe a prototype device using common materials and simple electronics. With this device, we demonstrate interaction techniques in a test-bed drawing application [19].

6.6. Perceived difficulty of pen gestures

Participants: Géry Casiez, Laurent Grisoni.

There are three primary factors which contribute to a successful gesture-based interface: the acquisition technology, the recognizer, and the design of the gesture set. Technologies to acquire gestures, and gesture recognition algorithms, are now quite robust and widely available. However, developing techniques and criteria to help designers create an intuitive and easy-to-perform gesture set remain an active area of research. The challenge is that in order to successfully integrate into an application, a gesture has to satisfy multiple criteria: it must be unambiguously recognized; fit well with its associated function; be easy to learn and recall; and be efficient to perform.
Our empirical results show that users perceive the execution difficulty of single stroke gestures consistently, and execution difficulty is highly correlated with gesture production time. We use these results to design two simple rules for estimating execution difficulty: establishing the relative ranking of difficulty among multiple gestures; and classifying a single gesture into five levels of difficulty. We confirm that the CLC model does not provide an accurate prediction of production time magnitude, and instead show that a reasonably accurate estimate can be calculated using only a few gesture execution samples from a few people. Using this estimated production time, our rules, on average, rank gesture difficulty with 90% accuracy and rate gesture difficulty with 75% accuracy. Designers can use our results to choose application gestures, and researchers can build on our analysis in other gesture domains and for modeling gesture performance [18].
6. New Results

6.1. Intermediate dependency generative models

Participants: Christophe Biernacki, Matthieu Marbac-Lourdelle, Vincent Vandewalle.

Defining generative models for dealing with possibly correlated categorical variables is at the core of the MODAL activity. We start by noticing that it is straightforward to build a full independent distribution $\hat{p}$ and also a full dependent one $\hat{\hat{p}}$ in the categorical situation. However, both are usually too crude for modeling most of real situations.

Our idea is to combine both extreme distributions $\hat{p}$ and $\hat{\hat{p}}$ in order to obtain a new distribution called $\tilde{p}(i)$ which is an intermediate dependent situation between full independence and full dependence and (ii) which is not degenerate. As a consequence, $\tilde{p}$ is a meaningful distribution because its particular "positioning" between $\hat{p}$ and $\hat{\hat{p}}$ directly models and reveals strength of dependency between variables.

In addition, since both $\hat{p}$ and $\hat{\hat{p}}$ are easily available for most variables types, we expect to be able to design a distribution $\tilde{p}$ for most variables types, and not also the categorical ones.

A PhD thesis started on October’11 on this topic in continuation of the Master’s thesis of Matthieu Marbac-Lourdelle [37].

6.2. Transfer learning in model-based clustering

Participants: Christophe Biernacki, Alexandre Lourme.

In many situations one needs to cluster several datasets, possibly arising from different populations, instead of a single one, into partitions with identical meaning and described by similar features. Such situations involve commonly two kinds of standard clustering processes. The samples are clustered traditionally either as if all units arose from the same distribution, or on the contrary as if the samples came from distinct and unrelated populations. But a third situation should be considered: As the datasets share statistical units of same nature and as they are described by features of same meaning, there may exist some link between the samples.

We propose a linear stochastic link between the samples, what can be justified from some simple but realistic assumptions, both in the Gaussian and in the t mixture model-based clustering context ([15] and a paper in revision). In the general context (categorical or heterogeneous variables), we propose to use alternatively an entropic link between populations [17]. All these works are related to the Lourme’s PhD thesis [11].

A chapter of book about transfer learning (including clustering, classification and regression) is currently submitted for publication (joint work with Julien Jacques and Alexandre Lourme).

6.3. Block regression for variable clustering: Application to genetic data

Participants: Christophe Biernacki, Julien Jacques, Loïc Yengo.

Genome Wide Association (GWA) studies have proved the implication of numerous single nucleotides polymorphisms (SNP) in the etiology of common diseases. Nevertheless, only a small part of the expected heritability of those diseases is explained by the most significantly associated SNPs. Many researches that have been lately investigating this missing heritability have considered interactions between genes and/or environmental factors as a plausible and promising explanation. Considering all if not a large number (hundreds of thousands) of variants altogether stresses the problem of the high dimensionality that most regression-based methods cannot afford. To solve this issue one either reduces the number of variants to be analyzed (shrinkage approaches) or groups them according to a certain similarity. We introduce here a regression model that simultaneously clusterizes the variants sharing close effect size while selecting the most informative clusters. The estimation of the model parameters is proposed by maximizing the likelihood.

The challenges of this research rely on finding efficient algorithms for the clustering part while studying the consistency of our estimators for which the classical asymptotic theory does not apply [33], [40].
6.4. Label switching in mixtures

**Participants:** Christophe Biernacki, Vincent Vandewalle.

During the last fifteen years there has been an increasing interest for using Bayesian methods in mixtures models. However, one of the principal issues of these methods is the non-identifiability of components caused by symmetric prior (whatever be the kind of variables), which makes the Gibbs outputs useless for inference; this problem is known as label switching. We propose to condition the posterior distribution by a particular numbering, not on the parameter as it is usually done, but rather on a latent partition, for which the posterior distributions are not any more strictly invariant up to a renumbering of the partition [26], [19], [32]. The importance of this asymmetry depends on the choice of partition space cutting. The challenge we address is to choose a particular cutting which is justified and also easy to compute. The idea is to use some properties of the (unavailable) completed posterior distribution.

6.5. Degeneracy in Gaussian mixtures

**Participant:** Christophe Biernacki.

In the case of Gaussian mixtures, unbounded likelihood is an important theoretical and practical problem. Using the weak information that the latent sample size of each component has to be greater than the space dimension, we derive a simple non-asymptotic stochastic lower bound on variances. We prove also that maximizing the likelihood under this data-driven constraint leads to consistent estimates. Currently, such results are proved in the univariate case [34]. The challenge is now not only to extend them in the multivariate situation but also to complete these theoretical results with some practical strategies for properly avoiding degeneracy in softwares devoted to such mixture estimations.

This is a joined work with Gwénaëlle Castellan.

6.6. Wavelet based clustering using mixed effects functional models

**Participant:** Guillemette Marot.

Curve clustering in the presence of inter-individual variability has longly been studied, especially using splines to account for functional random effects. However splines are not appropriate when dealing with high-dimensional data and can not be used to model irregular curves such as peak-like data. We propose a wavelet based clustering procedure [23] and apply it to high dimensional data. We suggest a dimension reduction step based on wavelet thresholding adapted to multiple curves and using an appropriate structure for the random effect variance, we ensure that both fixed and random effects lie in the same functional space even when dealing with irregular functions that belong to Besov spaces. In the wavelet domain our model resumes to a linear mixed-effects model that can be used for a model-based clustering algorithm and for which we develop an EM algorithm for maximum likelihood estimation. An R package curvclust implementing this procedure is under building and should be posted to the CRAN, the official website of the R software, before Dec. 2011. An article has been submitted once to Biometrics and received good reports. This paper should also be submitted again to Biometrics once curvclust is on the CRAN.

6.7. Comparison of normalisation procedures in RNA-sequencing before differential analysis

**Participant:** Guillemette Marot.

The continuing technical improvements and decreasing cost of next-generation sequencing technologies have made RNA sequencing (RNA-seq) a popular choice for gene expression studies in recent years. Because the data collected from such studies differ considerably from those measured using microarray technology, the statistical tools used for analysis must be adapted accordingly. In particular, several methods for the normalization of RNAseq data (removal of errors due to the small number of samples, corrections for sequence composition) have been proposed in recent years. With the Statomique Consortium, we have compared seven normalisation methods. First results are given in [28].
6.8. Comparison of peak finding methods applied to tiling array experiments

**Participant:** Guillemette Marot.

Scan statistics are widely used to detect peaks in tiling array experiments. An extensive analysis study of real biological data is being performed with Florent Sebbane and David Hot teams (Institut Pasteur, Lille) for the study of the Yersinia Pestis bacteria in order to find new small RNAs. First results have been presented in [31]. Given a signal composed of intensities ordered along the genome, the statistical problem is to detect peaks, taking into account the irregular design of the chips, which the biologists had chosen a few years ago. A master student (D. Thuillier) has compared different normalisation methods during a 6 months internship and improved the first analysis results presented in [31]. We also propose a local score procedure, which seems promising according to first biological results obtained. The next step is to work with Alain Célisse in order to choose a generative model on the normalised data which would enable to give appropriate initial values to the local score procedure and associate p-values to local scores.

6.9. Model-based clustering for functional data

**Participants:** Julien Jacques, Cristian Preda.

Two procedures for clustering functional data have been developed.

The first one, published in [14], is based on a functional latent mixture model which fits the functional data in group-specific functional subspaces. By constraining model parameters within and between groups, a family of parsimonious models is exhibited which allows to fit onto various situations. An estimation procedure based on the EM algorithm is proposed for estimating both the model parameters and the group-specific functional subspaces. Experiments on real-world datasets show that the proposed approach performs better or similarly than classical clustering methods while providing useful interpretations of the groups.

The second procedure, currently submitted, is a model-based clustering procedure, defined on the basis of an approximation of the density of functional random variables [36]. As previously, the EM algorithm is used for parameter estimation and the maximum a posteriori rule provides the clusters. Simulation study and real data application illustrate the interest of this methodology.

6.10. Generative models and random graphs

**Participant:** Alain Célisse.

The aim is to study consistency of variational and maximum likelihood estimates built from a particular generative model of random graph where independence between the ridges of the graph is not assumed. These results are established from concentration inequalities. They have a great practical interest since they justify a posteriori intensive use of variational methods in this context.

It is a joint collaboration with Jean-Jacques Daudin and a paper is submitted [35].

6.11. Resampling and learning

**Participant:** Alain Célisse.

This aim is to study the \( k \) nearest neighbors algorithm in binary classification in two different cases: Passive and active learning. The choice of \( k \) is addressed by cross-validation (resampling). In particular, we try to discover the influence of the cutting parameter on which depends the cross-validation with the retained \( k \) value.

It is a joined work with Tristan Mary-Huard [16].
6. New Results

6.1. Modeling XML document transformations

Participants: Joachim Niehren, Sophie Tison, Sławek Staworko, Aurélien Lemay, Anne-Cécile Caron, Yves Roos, Shunichi Amano, Camille Vacher, Benoît Groz, Antoine Ndione, Tom Sebastian.

Query answering on XML streams. In [16], Gauwin and Niehren introduce the notion of finite streamability for query languages, and classify fragments of XPath that are finitely streamable or not. They show that if a query language is finitely streamable, then its satisfiability problem can be solved in polynomial time, which in turn is known to fail for mostly all fragments of XPath. They also show that FXP, the fragment of ForwardXPath with child and descendant axis, conjunction, and negation becomes finitely streamable if bounding the number of conjunctions. Since 3 conjunctions are enough in many practical applications, FXP is most relevant in practice. Without any bound, FXP is not finitely streamable, since its satisfiablity problem is DEXPTIME hard. The positive result for FXP with a bounded number of conjunctions is obtained by compilation of FXP to deterministic nested word automata. The compiler is in exponential time in the number of conjunctions, and thus polynomial if this parameter is bounded.

Answer enumeration for n-ary queries. Bagan, Filiot, Gauwin, and Niehren investigated answer enumeration algorithms for dialects of XPath with variables. The problem with n-ary queries is that answer sets may grow exponentially in |t|n, so that algorithms depending polynomially on the size of the answer set might still be unfeasible. In such case, it might still be possible to enumerate elements of answer sets on need. The questions is then whether enumeration can be done efficiently without duplicates and failures, that is with constant delay between subsequent answers and polynomial time preprocessing in the size of the query and the tree. We obtained positive results on answer enumeration with constant delay enumeration for acyclic conjunctive queries over so called X-doublebar structures that we introduce [24]. These subsume tree structures with child, next-sibling and next-sibling* axis, but not the descendant axis. Our result can be lifted to a dialect of ConditionalXPath with variables, that is FO-complete on trees of bounded depth, so that the descendant axis is not needed.

Tree automata global constraints. TAGEDs are a new class of tree automata with constraints that currently receive much interest from top conferences on theoretical computer science. During its postdoc in Lille, Vacher improved complexity bounds for some fragments of decidability results [12].

Sequential tree-to-word transducers. Laurence, Lemay, Niehren, Staworko, Tommasi considered deterministic sequential top-down tree-to-word transducers (STWα), that capture the class of deterministic top-down nested-word to word transducers. While reordering and copying are not allowed, STWα are nevertheless very expressive because they allow concatenation of outputs, deletion of inner nodes and they can produce context free languages as output. Their expressiveness is incomparable with DTOPα (plus concatenation, but minus copying). While objecting for learning algorithms, they study normalization of STWα in a first step and then develop unique minimalization algorithms for normalized STWα in a second step in [19]. The idea of normalization is to produce the output in an earliest manner, when reading the input in document order. This works only on binary trees, but can be lifted to unranked trees modulo the binary top-down encoding. The normalization algorithm is by far nontrivial. The natural continuation of this approach will be toward learning algorithms for earliest STWα.

Access control for XML views. The PhD project of Groz, supervised by Staworko and Tison, is centered on access control for XML databases, and in particular on security of user views over XML documents. He obtained results on query rewriting for read-only queries, and translation for update queries. More precisely, given an XML view definition and a user defined query (resp. update program) q, the problem is to find a source query (resp. update program) that is equivalent to q on the view. Caron, Groz, Roos, Staworko and Tison study update programs and views represented by recognizable tree languages in [15], and devise algorithms for update translation in different settings, namely without or with constraints on the authorised source updates.

**Participants:** Jérôme Champavère, Jean Decoster, Jean-Baptiste Faddoul, Antonino Freno, Gemma Garriga, Rémi Gilleron, Mikaela Keller, Grégoire Laurence, Aurélien Lemay, Joachim Niehren, Sławek Staworko, Marc Tommasi, Fabien Torre.

**Induction of tree automata.** Champavère, Gilleron, Lemay and Niehren proposed to use schemas for improving induction algorithms for monadic queries represented by tree automata [26]. The idea is to use pruning strategies to eliminate useless parts of trees when learning from partially annotated trees such that only the structure of relevant fragments is learned. This allows to avoid generalization errors and to learn from fewer annotations. They define schema-guided pruning strategies. They define stable queries w.r.t. a pruning strategy and show that stable queries are learnable.

**Further Results.** In [21], Staworko proposed learning twig and path queries. Prioritized repairing and consistent query answering in relational databases was tackled in [13] and Bounded repairability for regular tree languages in [20].

Torre and Terlutte explored the combination of automata and words balls for sequences classification in [14].

Tommasi participated in the writing of a chapter of a book on conditional Markov fields for information extraction [23].

Garriga and collaborators from the Fraunhofer Institute in Bonn, studied fixed parameter tractable algorithms for the discovery of maximal order preserving submatrices in bioinformatic applications in [17].

We begun a new activity on *learning for social network and information network* supported by the arrivals of Gemma GARRIGA, Mikaela KELLER and Antonino FRENO. Freno, Garriga and Keller [22] proposed a model for predicting new links in a network which exploit both the current structure of the network and the content of its node.
NON-A Team

5. New Results

5.1. Model-free control

Participants: Cédric Join, Riachy Samer, Lotfi Belkoura.

After the successful implementation of model-free control \cite{75, 81} for several concrete situations:

- Throttle control for IC engines (with APPEDGE and PSA) \cite{94};
- Stop-and-go automotive control strategy (in collaboration with the École des Mines de Paris and PSA) \cite{72, 114, 115};
- Hydroelectrical dams modeling and control (in collaboration with EDF) \cite{92, 93};
- Shape memory actuators (collaboration with the team directed by Prof. E. Delaleau at the École Nationale des Ingénieurs de Brest \cite{88, 89});
- Model-free control involves the design of the so-called "intelligent" PID controllers \cite{75, 82}, and a mathematical explanation via "intelligent" PID controllers of the strange ubiquity of PIDs has been developed in \cite{74}, and the simulations confirm the superiority of the new intelligent feedback design;
- Application of model-free control method to set Delta hedging \cite{76};
- Model-free control of "Planar Vertical Take-Off and Landing" (PVTOL) aircraft \cite{108};
- Model-free control for power converters \cite{103};
- The longitudinal control of the electrical vehicle by using model-free control technique \cite{73};
- Model-free control for automatic water level regularization \cite{93} and \cite{92};
- \cite{49} simplifies several aspects of the practical implementation of the newly introduced model-free control and of the corresponding intelligent PID controllers. Four examples with their computer simulations permit to test our techniques.

More achievements have been made in 2011, listed as follows:

- Shape Memory Alloys (SMA) are more and more integrated in engineering applications. These materials with their shape memory effect permit to simplify mechanisms and to reduce the size of actuators. Most of successful control strategies applied to SMA actuator are not often suitable for industrial applications. In \cite{17}, an application of the new framework of model-free control to a SMA spring based actuator was proposed. This control strategy is based on new results on fast derivatives estimation of noisy signals, its main advantages are: its simplicity and its robustness. Experimental results and comparisons with PI control are exposed that demonstrate the efficiency of this new control strategy.
- The regulation of freeway traffic flow, which is a complex nonlinear system, is achieved via the newly introduced model-free control in \cite{39} and \cite{64}. Several computer simulations are validating our control strategy, which is easy to implement and shows good robustness properties with respect to perturbations;
- After numerous successful applications, \cite{36} has revisited some points of model-free control. The numerical differentiation of noisy signals may be replaced by a real time parameter identification which is much simpler. The strange ubiquity of classic PIDs is explained as well as the almost universal utilization of ultra-local models of order 1. We show that even with a partially known model the utilization of an intelligent PI controller remains profitable.
- The Ph.D. work of Y. El Afou allowed for experimental results on climate control in greenhouse.
5.2. Algebraic technique for estimation, differentiation and its applications

Participants: Cédric Join, Mamadou Mboup, Wilfrid Perruquetti, Lotfi Belkoura, Olivier Gibaru, Zoran Tiganj, Dayan Liu.

Elementary techniques from operational calculus, differential algebra, and noncommutative algebra lead to a new algebraic approach for estimation and detection. It is investigated in various areas of applied sciences and engineering. The following lists only some applications:

- [28] presents a partial derivatives estimation method for multidimensional signals. On a small interval the signal is represented by a truncated Taylor expansion. Then the application of multivariate Laplace transform together with adequate algebraic manipulations enabled us to express the desired partial derivative of any order as a function of iterated integrals of the noisy signal. Several recurrence relations and structural properties were provided. An interpretation of the estimators as least square minimization is also done by expressing the estimators in an orthogonal basis constituted by Jacobi polynomials. This projection enabled us not only to show a spatial shifting inherent to a specific class of estimators but also to synthesize a new class of estimators minimizing the truncation remainder of the Taylor local model. We provided also another class of estimators minimizing the noise influence. Finally we provided a numerical implementation scheme in the form of a finite impulse digital filters.

- A fast identification algorithm is proposed in [20] for systems with delayed inputs. It is based on a non-asymptotic distributional estimation technique initiated in the framework of systems without delay. Such a technique leads to simple realization schemes, involving integrators, multipliers and piecewise polynomial or exponential time functions. Thus, it allows for a real time implementation.

- A new approach to estimate vehicle tire forces and road maximum adherence is presented in [30]. Contrarily to most of previous works on this subject, it is not an asymptotic observer based estimation, but a combination of elementary diagnosis tools and new algebraic techniques for filtering and estimating derivatives of noisy signals. In a first step, instantaneous friction and lateral forces will be computed within this framework. Then, extended braking stiffness concept is exploited to detect which braking efforts allow to distinguish a road type from another. A weighted Dugoff model is used during these “distinguishable” intervals to estimate the maximum friction coefficient. Very promising results have been obtained in noisy simulations and real experimentations for most of driving situations.

- [27] proposes a diagnosis approach of sensor and actuator modeled as structured signals acting on a particular class of uncertain linear dynamical systems. The main advantage of this approach is that it is possible under certain assumptions, to detect, isolate and identify faults using only input and output measurements without having to identify model parameters. The method is based on the generation and analysis of analytical redundancy relations and exploits the fact that a structured signal satisfies a differential equation. The decision rule is based entirely on the temporal behaviour of the estimates of some fault characteristics.

- Numerical causal derivative estimators from noisy data are essential for real time applications especially for control applications or fluid simulation so as to address the new paradigms in solid modeling and video compression. By using an analytical point of view, [23] revisited the $n$th order algebraic derivative estimators. Thanks to a given noise level and a well-suitable integration length window, we analyzed the derivative estimator error;

- Recent algebraic parametric estimation techniques provide an estimate of the derivatives by using iterated integrals of a noisy observation signal. These algebraic parametric differentiation techniques give derivative estimations which contain two sources of errors: the bias term error and the noise error contribution. In order to reduce these errors, [25] extends the parameter domains used in the estimators, and studies some error bounds which depend on these parameters. This allows us to minimize these errors. It is shown that a compromise choice of these parameters implies an “optimized” error among the noise error contribution, the bias term error and the time delay.
• The numerical differentiation by integration method based on Jacobi polynomials originally intro-
duced by Mboup, Fliess and Join is revisited in [24] for the central case where the used integration
window is centered.

• [59] proposed new algebraic techniques to estimate the amplitude, frequency and phase of a biased
and noisy sinusoidal signal. The methods which are popular today seem unable to obtain a robust
estimation of those parameters within a fraction of the signal’s period. The efficiency of our approach
is illustrated by several computer simulations;

• A “practical” comparison between high-order sliding modes and the recently introduced model-free
control is made in [56]. The perfect knowledge of the relative degree of the output variable, which
is a standard assumption for sliding modes, is assumed. The comparisons are based on two concrete
case-studies and on numerous computer simulations. The smoothness of the input variables, the
robustness with respect to noises and the straightforward extendibility of the model-free controllers
to MIMO systems are highlighted.

• [43] and [66] present a parameter estimation algorithm for a magnetic bearing. Such process are
inherently unstable systems with strongly nonlinear dynamics. A simplified model of the magnetic
bearing is developed, which enables to obtain a linear expression with respect to the unknown
parameters. These parameters are measurable with difficulties, and may slightly vary over time.
The expression of the estimates is written as a function of integrals of the inputs and outputs of the
system. The simulations and the experiments show a fast and robust on-line identification

• Estimators of the frequency, amplitude and phase of a noisy sinusoidal signal with time-varying
amplitude by using the algebraic parametric techniques is studied in [52], in which a similar strategy
to estimate these parameters by using modulating functions method is applied. The convergence of
the noise error part due to a large class of noises is studied to show the robustness and the stability
of these methods. We also show that the estimators obtained by modulating functions method are
robust to “large” sampling period and to non zero-mean noises.

• In the framework of the SYSIASS project, a single landmark based localization algorithm for non-
holonomic mobile robots is studied in [58]. In the case of a unicycle robot model, the localization
problem is equivalent to the system observability. Based on this observation, the proposed localiza-
tion method consists in finding a vector function which depends on the measurement vector and its
derivatives, for which a numerical differentiation method is used in [58].

5.3. Observability and observer design for nonlinear systems

Participants: Jean-Pierre Barbot, Wilfrid Perruquetti, Lotfi Belkoura, Thierry Floquet, Gang Zheng.

Observability analysis and observer design are important issues in the field of control theory. Some recent
results are listed below:

• [32] investigates the observability and observer design for a class of single output switched systems
with high frequency switching, where classical observers cannot be applied directly since the high
frequency switching signals are not derivable. By assuming that these signals are integrable in the
less restrictive way, and defining a new output, this study shows that algebraic observer can be
adopted to estimate the states of the studied switched systems. Although the main idea is explained
via normal forms, it can be easily extended to treat generic switched systems with high frequency
switching.

• Observability of a class of switched systems with Zeno phenomenon or high switching frequency is
treated in [31]. Particularly, three observability forms are proposed and the observability for each
form with knowledge of filtered switching signal is analyzed. Meanwhile, sufficient and necessary
conditions for the existence of a diffeomorphism to transform a class of switched systems into one
of such forms are presented.
A triangular canonical form for a class of 0-flat nonlinear systems is studied in [13]. Necessary and sufficient geometrical conditions are given in order to guarantee the existence of a local diffeomorphism to transform the studied nonlinear systems into the proposed 0-flat canonical form, which enables us to compute the flat output as well.

A fault tolerant control for induction motors based on backstepping strategy is designed in [44]. The proposed approach permits to compensate both the rotor resistance variations and the load torque disturbance. Moreover, to avoid the use of speed and flux sensors, a second order sliding mode observer is used to estimate the flux and the speed. The designed observer converges in a finite time and gives a good estimate of flux and speed even in the presence of rotor resistance variations and load torque disturbance.

[42] studies the observability problem of a general class of singular linear systems with unknown inputs. It is shown that, under some assumptions, the problem is equivalent to study the observability of a standard linear system with unknown inputs satisfying algebraic constraints. We obtain necessary and sufficient conditions for observability in terms of the zeros of the system matrix.

[53] is concerned with the study of observability properties of systems without inputs via homogeneous approximations. This approximation is induced by a filtration on the space of observation. A corresponding filtration on a Lie algebra of vector fields is defined and allows to construct the approximation that preserve observability properties. An explicit construction is given in [53].

5.4. Time-delay systems

Participants: Jean-Pierre Richard, Jean-Pierre Barbot, Thierry Floquet, Gang Zheng, Denis Efimov, Wilfrid Perruquetti.

[22] considers a networked control loop, where the plant is a “slave” part, and the remote controller and observer constitute the “master”. Since the performance of Networked Control Systems (NCS) depends on the Quality of Service (QoS) available from the network, it is worth to design a controller that takes into account qualitative information on the QoS in realtime. The goal of the design is to provide a controller that guarantees two things: 1) high performances (here expressed by exponential decay rates) when the QoS remains globally the same; 2) global stability when the QoS changes. In order to guarantee the global stability, the controller will switch by respecting a dwell time constraint. The dwell time parameters are obtained by using the switched system theories and the obtained conditions are Linear Matrix Inequalities (LMI).

Causal and non-causal observabilities are discussed in [33] for nonlinear time-delay systems with unknown inputs. Using the theory of non-commutative rings and the algebraic framework, the nonlinear time-delay system is transformed into a suitable canonical form to solve the problem. A necessary and sufficient condition is given to guarantee the existence of a change of coordinates leading to such a form.

The notion of homogeneity is extended to the time-delay nonlinear systems in [45]. It is shown that under some conditions the stability of homogeneous functional systems on a sphere implies the global stability of the system. The notion of local homogeneity is introduced, the relations between stability of the locally approximating dynamics and the original time-delay system are established.

[38] addresses the problem of the position/force tracking in tele-operation system and proposes a haptic proxy control scheme, in which communication delays are assumed to be both time-varying and asymmetric, and the response of the synchronization and the transparency are improved. The control design is performed using Linear Matrix Inequality (LMI) optimization based on Lyapunov-Krasovskii functionals (LKF) and $H_1$ control theory.

Stability and synchronization of systems with time-varying delays is studied in [37], in which a novel control scheme with position/velocity information channel on the basis of Lyapunov-Krasovskii functional (LKF) and $H_1$ control theory by using Linear Matrix Inequality (LMI) is proposed. The proposed solution is efficient for different working conditions, such as abrupt motion and wall contact illustrated by various simulations.
• Embedded systems can benefit from all results on variable sampling for delayed systems [18], [19] and [47].
5. New Results

5.1. RFID and Internet of Things

Participants: Roudy Dagher, Nathalie Mitton, Roberto Quilez, Loic Schmidt, David Simplot-Ryl, Lei Zhang.

5.1.1. Reader anti-collision protocol

In a Radio-Frequency IDentification network, while several readers are placed close together to improve coverage and consequently read rate, reader-reader collision problems happen frequently and inevitably. High probability of collision not only impairs the benefit of multi-reader deployment, but also results in misreadings in moving RFID tags. In order to eliminate or reduce reader collisions, we propose in [28] an Adaptive Color based Reader Anti-collision Scheduling algorithm (ACoRAS) for 13.56 MHz RFID technology where every reader is assigned a set of colors that allows it to read tags during a specific time slot within a time frame. Only the reader holding a color (token) can read at a time. Due to application constraints, the number of available colors should be limited, a perfect coloring scheme is not always feasible. ACoRAS tries to assign colors in such a way that overlapping areas at a given time are reduced. To the best of our knowledge ACoRAS is the first reader anti-collision algorithm which considers, within its design, both application and hardware requirements in reading tags. We show, through extensive simulations, that ACoRAS outperforms several anticollision methods and detects more than 99% of mobile tags while fitting application requirements.

5.1.2. Distributed ALE

Following the Internet of Things concept [14], each object is associated with a unique identifier which will allow to retrieve information about it in large databases. In the process of managing a large amount of objects, and consequently a large amount of events from readers, without overloading the network, these events have to be filtered and aggregated. This is the aim of the Application Level Events (ALE) standard from EPCGlobal, which receives events from readers and sends a useful and well constructed report to the business application. The ALE may be connected to several hundreds of readers. As the number of readers may increase with the increase of the company, a bottleneck may appear with all readers events sent to the ALE. A solution for scalability is to distribute the ALE. In [37], we propose an efficient way to solve this problem based on a Distributed Hash table (DHT). One role of the ALE is to insulate business application from technical concern so in our solution, we present a mechanism to distribute the ALE using Chord, a well-known peer-to-peer lookup system, and being transparent for business applications. This solution is compliant with the EPCglobal existing standard, scalable, robust and transparent for other layers of the middleware. We show that our solution generates only 10% overhead than in a nominal case while offering a better robustness and scalability when numbers of tags and readers increase significantly.

5.1.3. Advance Internet of Things

The Internet of Things (IoT) is a network of Internet-enabled objects, whose original purpose would be to interconnect all things in our daily life to build an always connected world. However, most of studies in the current IoT scientific community only focus on the radio-frequency identification (RFID) and wireless sensor network (WSN) based objects and lose the generality features endowed by the original definition of IoT. Furthermore, the emergence and proliferation of smart objects have been significantly changing our daily lives. It has been becoming evident that the objects should far beyond only "be identified and interconnected", but can also be controlled in an intelligent and transparent way independent of third party object (user) profiles and space and time span. In [39], we proposes a standardization scheme for a new paradigm: Advanced Internet of Things (AIoT), which is based on our proposed Unified Object Description Language (UODL) and allows to identify and interconnect every object and event with a standard format, and makes it easier and flexible for the third party control and management by integrating multiple services issued from cloud computing.
The purpose of our proposed AIoT scheme is to build a smart world of always on, always-awareness, always-connected, always-controllable, and establish an “intelligent networking” based relationship among the objects, service suppliers and the third party users. In the scope of AIoT, all the objects are transparent across the networks and can be identified and controlled (with security guarantees) via a standard prototype anytime and anywhere.

5.2. Topology control and neighbor discovery

Participants: Xu Li, Nathalie Mitton, Jovan Radak, David Simplot-Ryl, Isabelle Simplot-Ryl.

5.2.1. Topology control

Topology control is a tool for self-organizing wireless networks locally. It allows a node to consider only a subset of links/neighbors in order to later reduce computing and memory complexity. Topology control in wireless sensor networks is an important issue for scalability and energy efficiency. It is often based on graph reduction performed through the use of Gabriel Graph or Relative Neighborhood Graph. This graph reduction is usually based on geometric values.

In [35] we tackle the problem of possible connectivity loss in the reduced graph by applying a battery level based reduction graph. Experiments are conducted to evaluate our proposition. Results are compared with RNG [52] reduction which takes into account only the strength of the received signal (RSSI). Results show that our algorithm maintains network connectivity longer than solutions from the literature and balances the energy consumption over nodes.

In [31], we propose a radically new family of geometric graphs, i.e., Hypocomb, Reduced Hypocomb and Local Hypocomb for topology control. The first two are extracted from a complete graph; the last is extracted from a Unit Disk Graph (UDG). We analytically study their properties including connectivity, planarity and degree bound. All these graphs are connected (provided the original graph is connected) planar. Hypocomb has unbounded degree while Reduced Hypocomb and Local Hypocomb have maximum degree 6 and 8, respectively. To our knowledge, Local Hypocomb is the first strictly-localized, degree-bounded planar graph computed using merely 1-hop neighbor position information. We present a construction algorithm for these graphs and analyze its time complexity. Hypocomb family graphs are promising for wireless ad hoc networking. We report our numerical results on their average degree and their impact on FACE [49] routing. We discuss their potential applications and some open problems.

5.2.2. Neighbor discovery

To perform topology control, a node needs to discover its neighbors. Hello protocol is the basic technique for neighborhood discovery in wireless ad hoc networks. It requires nodes to claim their existence/aliveness by periodic "hello" messages. Central to a hello protocol is the determination of hello message transmission rate. No fixed optimal rate exists in the presence of node mobility. The rate should in fact adapt to it, high for high mobility and low for low mobility. In [30], we propose a novel mobility prediction based hello protocol, named ARH (Autoregressive Hello protocol). Each node predicts its own position by an ever-updated autoregression-based mobility model, and neighboring nodes predict its position by the same model. The node transmits "hello" message (for location update) only when the predicted location is too different from the true location (causing topology distortion), triggering mobility model correction on both itself and each of its neighbors. ARH evolves along with network dynamics, and seamlessly tunes itself to the optimal configuration on the fly using local knowledge only. Through simulation, we demonstrate the effectiveness and efficiency of ARH, in comparison with the only competitive protocol TAP (Turnover based Adaptive hello Protocol). With a small model order, ARH achieves the same high neighborhood discovery performance as TAP, with dramatically reduced message overhead (about 50% lower hello rate).
5.2.3. Address allocation

In [9], we propose a localized address autoconfiguration (LaConf) scheme for wireless ad hoc networks. Address allocation information is maintained on the network border nodes, called addressing agents (AAs), which are locally identified by a geographic routing protocol GFG (Greedy-FACE-Greedy). When a node joins the network, it acquires an address from a neighboring AA (if any exists) by local communication or from the head AA (a geographic extreme AA) by GFG-based multi-hop communication. A Geographic Hash Table (GHT) is adopted for duplicate address detection. Each address is hashed to a unique location in the network field, and the associated assignment information is stored along the face perimeter enclosing that location (in the planar graph). When a node receives an address assignment, it consults with the perimeter nodes around the hash location of the assigned address about any conflicts. AAs detects network partitions and mergers locally according to neighborhood change and triggers AA re-selection and network re-configuration (if necessary). We propose to apply a Connected Dominating Set (CDS) to improve the performance. We also evaluate LaConf through simulation using different planar graphs.

5.3. Routing

Participants: Nicolas Gouvy, Xu Li, Nathalie Mitton, David Simplot-Ryl.

In mobile wireless sensor networks, flows sent from data collecting sensors to a sink could traverse inefficient resource expensive paths. Such paths may have several negative effects such as devices battery depletion that may cause the network to be disconnected and packets to experience arbitrary delays. This is particularly problematic in event-based sensor networks (deployed in disaster recovery missions) where flows are of great importance. In [27], we use node mobility to improve energy consumption of computed paths. Mobility is a two-sword edge, however. Moving a node may render the network disconnected and useless. We propose CoMNet (Connectivity preservation Mobile routing protocol for actuator and sensor NETworks), a localized mechanism that modifies the network topology to support resource efficient transmissions. To the best of our knowledge, CoMNet is the first georouting algorithm which considers controlled mobility to improve routing energy consumption while ensuring network connectivity. CoMNet is based on (i) a cost to progress metric which optimizes both sending and moving costs, (ii) the use of a connected dominating set to maintain network connectivity. CoMNet is general enough to be applied to various networks (actuator, sensor). Our simulations show that CoMNet guarantees network connectivity and is effective in achieving high delivery rates and substantial energy savings compared to traditional approaches. CoMNET has then been extended in [26] to multi-hop movement.

In [12] we propose a novel localized Integrated Location Service and Routing (ILSR) scheme, based on the geographic routing protocol GFG, for data communications from sensors to a mobile sink in wireless sensor networks. The objective is to enable each sensor to maintain a slow-varying routing next hop to the sink rather than the precise knowledge of quick-varying sink position. In ILSR, sink updates location to neighboring sensors after or before a link breaks and whenever a link creation is observed. Location update relies on flooding, restricted within necessary area, where sensors experience (next hop) change in GFG routing to the sink. Dedicated location update message is additionally routed to selected nodes for prevention of routing failure. Considering both unpredictable and predictable (controllable) sink mobility, we present two versions. We prove that both of them guarantee delivery in a connected network modeled as unit disk graph. ILSR is the first localized protocol that has this property. We further propose to reduce message cost, without jeopardizing this property, by dynamically controlling the level of location update. A few add-on techniques are as well suggested to enhance the algorithm performance. We compare ILSR with an existing competing algorithm through simulation. It is observed that ILSR generates routes close to shortest paths at dramatically lower (90% lower) message cost.

In [29], we propose a novel trust management scheme for improving routing reliability in wireless ad hoc networks. It is grounded on two classic autoregression models, namely Autoregressive (AR) model and Autoregressive with exogenous inputs (ARX) model. According to this scheme, a node periodically measures the packet forwarding ratio of its every neighbor as the trust observation about that neighbor. These measurements constitute a time series of data. The node has such a time series for each neighbor. By applying
an autoregression model to these time series, it predicts the neighbors future packet forwarding ratios as their trust estimates, which in turn facilitate it to make intelligent routing decisions. With an AR model being applied, the node only uses its own observations for prediction; with an ARX model, it will also take into account recommendations from other neighbors. We evaluate the performance of the scheme when AR, ARX or a previously proposed Bayesian model is used. Simulation results indicate that the ARX model is the best choice in terms of accuracy.

5.4. Self-deployment, localization and area coverage

Participants: Milan Erdelj, Xu Li, Enrico Natalizio, Nathalie Mitton, Tahiry Razafindralambo, David Simplot-Ryl, Isabelle Simplot-Ryl.

5.4.1. Deployment

First steps in order to perform any task, a network needs to be deployed and nodes need to discover each others. To the best of our knowledge, very few scenarios when robots self-deploy to afterwards themselves constitute the network nodes or drop off sensor nodes have been investigated so far and none of them ensure the network connectivity at every step. In [15], we consider the self-deployment of wireless sensor networks. We present a mechanism which allows to preserve network connectivity during the deployment of mobile wireless sensors. Our algorithm is localized and is based on a subset of neighbors for motion decision. Our algorithm maintains a connected topology regardless of the direction chosen by each sensor. To preserve connectivity, the distance covered by the mobile nodes is constrained by the connectivity of the node to its neighbors in a connected subgraph like the relative neighborhood graph. We show the connectivity preservation property of our algorithm through analysis and present some simulation results on different deployment schemes such as full coverage, point of interest coverage or barrier coverage.

Another approach is the one proposed in [34] in which node placement is performed off-line with objective to optimize a criterion. Based on the specific application, different objectives can be taken into account such as energy consumption, throughput, delay, coverage, etc. Also many schemes have been proposed in order to optimize a specific quality of service (QoS) parameter. Power consumption is an essential issue in wireless multimedia sensor networks (WMSNs) due to the elevated processing capabilities requested by the video acquisition hardware installed on the generic sensor node. Hence, node placement scheme in WMSNs greatly impacts the overall network lifetime. [34] first proposes a suitable hardware architecture to implement a feasible WMS node based on off-the-shelf technology, then it evaluates the energy consumption obtained throughout a wise "energy-spaced" placement of the wireless nodes without affecting the video quality of multimedia traffic. In [4], we propose to use a neural network as a controller for nodes mobility and a genetic algorithm for the training of the neural network through reinforcement learning. This kind of scheme is extremely adaptive, since it can be easily modified in order to consider different objectives and QoS parameters. In fact, it is sufficient to consider a different kind of input for the neural network to aim for a different objective. All things considered, we propose a new method for programming a WSRN and we show practically how the technique works, when the coverage of the network is the QoS parameter to optimize. Simulation results show the flexibility and effectiveness of this approach even when the application scenario changes (e.g., by introducing physical obstacles).

5.4.2. Coverage

The coverage of Points of Interest (PoI) is a classical requirement in mobile wireless sensor applications. Optimizing the sensors self-deployment over a PoI while maintaining the connectivity between the sensors and the sink is thus a fundamental issue. [22] addresses the problem of autonomous deployment of mobile sensors that need to cover a predefined PoI with a connectivity constraints and provides the solution to it using Relative Neighborhood Graphs (RNG) [52]. Our deployment scheme minimizes the number of sensors used for connectivity thus increasing the number of monitoring sensors. Analytical results, simulation results and real implementation are provided to show the efficiency of our algorithm. To the best of our knowledge, only [21] both preserves the network connectivity and validates its proposition through experimentations with real wireless robots. This work has been extended to discovery and coverage of multi-point of interested in [52].
Indeed, the problems of multiple PoI coverage, environment exploration and data report are still solved separately and there are no works that combine the aforementioned problems into a single deployment scheme. In [21], we present a novel approach for mobile sensor deployment, where we combine multiple PoI coverage with network connectivity preservation and environment exploration in order to capture the dynamics of the monitored area. We examine the performance of our scheme through extensive simulation campaigns.

As sensors are energy constrained devices, one challenge in wireless sensor networks (WSNs) is to guarantee coverage and meanwhile maximize network lifetime. In [7], we leverage prediction to solve this challenging problem, by exploiting temporal-spatial correlations among sensory data. The basic idea lies in that a sensor node can be turned off safely when its sensory information can be inferred through some prediction methods, like Bayesian inference. We adopt the concept of entropy in information theory to evaluate the information uncertainty about the region of interest (RoI). We formulate the problem as a minimum weight submodular set cover problem, which is known to be NP hard. To address this problem, an efficient centralized truncated greedy algorithm (TGA) is proposed. We prove the performance guarantee of TGA in terms of the ratio of aggregate weight obtained by TGA to that by the optimal algorithm. Considering the decentralization nature of WSNs, we further present a distributed version of TGA, denoted as DTGA, which can obtain the same solution as TGA. The implementation issues such as network connectivity and communication cost are extensively discussed. We perform real data experiments as well as simulations to demonstrate the advantage of DTGA over the only existing competing algorithm and the impacts of different parameters associated with data correlations on the network lifetime.

5.4.3. Localization

In mobile-beacon assisted sensor localization, beacon mobility scheduling aims to determine the best beacon trajectory so that each sensor receives sufficient beacon signals with minimum delay. We propose a novel DeteRministic bEAcon Mobility Scheduling (DREAMS) algorithm [32, 10], without requiring any prior knowledge of the sensory field. In this algorithm, beacon trajectory is defined as the track of depth-first traversal (DFT) of the network graph, thus deterministic. The mobile beacon performs DFT under the instruction of nearby sensors on the fly. It moves from sensor to sensor in an intelligent heuristic manner according to RSS (Received Signal Strength)-based distance measurements. We prove that DREAMS guarantees full localization (every sensor is localized) when the measurements are noise-free. Then we suggest to apply node elimination and topology control (Local Minimum Spanning Tree) to shorten beacon tour and reduce delay. Through simulation we show that DREAMS guarantees full localization even with noisy distance measurements. We evaluate its performance on localization delay and communication overhead in comparison with a previously proposed static path based scheduling method.

5.5. Platforms and Substitution Networks


5.5.1. Platforms

In the framework of the ANR SensLAB project, a wireless sensor testbed has been set up in Lille in order to allow the evaluation through experiments of scalable wireless sensor network protocols and applications. All functionalities offered by the platform have then been presented in [17, 16, 42]. SensLAB’s main and most important goal is to offer an accurate open access multiusers scientific tool to support the design, the development tuning, and the experimentation of real large-scale sensor network applications. The SensLAB testbed is composed of 1024 nodes over 4 sites. Each site hosts 256 sensor nodes with specific characteristics in order to offer a wide spectrum of possibilities and heterogeneity. Within a given site, each one of the 256 nodes is able both to communicate via its radio interface to its neighbors and to be configured as a sink node to exchange data with any other “sink node”. The hardware and software architectures that allow to reserve, configure, deploy firmwares and gather experimental data and monitoring information are described. We also present demonstration examples to illustrate the use of the SensLAB testbed and encourage researchers to test
and benchmark their applications/protocols on a large scale WSN testbed. A survey of platforms similar to SensLAB can be found in [6].

5.5.2. Emulation

Although some platforms like SensLAB are very convenient, they do not always fit the application requirements and setting up experimental testbed of large scale wireless sensor networks requires huge cost, space and human resources. A more affordable approach is needed to provide preliminary insights on network protocols performance. To overcome the need for significant number of sensors required to perform a realistic experiment, and/or to experiments with high density networks, we introduce in [43] a novel approach: emulation by using all available sensors as candidate forwarding neighbors of the node S currently holding the packet. Destination position is virtual. After successfully sending message to forwarding node B over realistic wireless channel, the position of virtual destination is adjusted by translating it for vector BS and possibly rotating it to change the neighborhood configuration. The same node S then again selects new forwarding neighbor. Such selection of best forwarding neighbor continues until virtual destination appears close to a real node, and the later then becomes final destination node. Compared to real testbeds, our emulation has advantages of testing networks with very large densities (which may not be possible in small scale implementations), and in unlimited scalability of our physical implementations (e.g. we can emulate network with a million nodes).

5.5.3. Substitution network

A substitution network is a rapidly deployable backup wireless solution to quickly react to network topology changes due to failures or to flash crowd effects on the base network. Unlike other ad hoc and mesh solutions, a substitution network does not attempt to provide new services to customers but rather to restore and maintain at least some of the services available before the failure. Furthermore, a substitution network is not deployed directly for customers but to help the base network to provide services to customers. Therefore, a substitution network is not, by definition, a stand-alone network. [36] describes the quality of service architecture for substitution networks and discuss provisioning, maintenance, and adaptation of QoS inside and between the base network and the substitution network. In the same context, [33] shows the impact of the router mobility on the QoS of such networks.

5.6. Data collection and management

Participants: Thierry Delot, Geoffroy Cogniaux, Arnaud Fontaine, Alia Ghaddar, Michael Hauspie, Samuel Hym, Xu Li, Nathalie Mitton, Tahiry Razafindralambo, David Simplot-Ryl, Isabelle Simplot-Ryl.

5.6.1. Data collection

Wireless sensors networks (WSNs) are deployed to collect huge amounts of data from the environment. This produced data has to be delivered through sensor’s wireless interface using multi-hop communications toward a sink. The position of the sink impacts the performance of the wireless sensor network regarding delay and energy consumption especially for relaying sensors. Optimizing the data gathering process in multi-hop wireless sensor networks is, therefore, a key issue. [19] and [18] address the problem of data collection using mobile sinks in a WSN. We provide a framework that studies the trade-off between energy consumption and delay of data collection. This framework provides solutions that allow decision makers to optimally design the data collection plan in wireless sensor networks with mobile sinks.

In [20], [5], we focus on information gathering in vehicular ad hoc networks. Until now, only a few research works have addressed this problem. They have lead to solutions relying on push models, where potentially useful data are pushed towards vehicles. To the best of our knowledge, no work has tackled the use of pull models in VANETs. Such models would allow users to send queries to a set of cars in order to find the desired information. In order to propose such a query processing scheme, the main challenge to address is to route the different results towards their recipient in a highly dynamic network where the nodes move very quickly. To solve this issue, we propose GeoVanet, a DHT-based geographic routing protocol which ensures that the sender of a query can get a consistent answer. Our goal is not to compute the query result "instantaneously" but to ensure that the user will be able to retrieve it within a bounded time. To prove the effectiveness of GeoVanet,
an experimental evaluation is provided in the paper. It shows that up to 80% of the available query results are delivered to the user.

Another way to optimize data collection is to send data only when necessary. Knowledge discovery and data analysis in resource constrained wireless sensor networks faces different challenges. One of the main challenges is to identify misbehaviors or anomalies with high accuracy while minimizing energy consumption in the network. In [25], we extend a previous work of us and we present an algorithm for temporal anomalies detection in wireless sensor networks. Our experiments results show that our algorithm can efficiently and accurately detect anomalies in sensor measurements. It also produces low false alarm rate for slow variation time series measurements without harvesting the source of energy.

In data aggregation, sensor measurements from the whole sensory field or a sub-field are collected as a single report at an actor using aggregate functions such as sum, average, maximum, minimum, count, deviation, etc. We propose a localized Delay-bounded and Energy-efficient Data Aggregation (DEDA) protocol [11], [38] for request-driven wireless sensor networks with IEEE 802.11 CSMA/CA MAC layer. This protocol uses a novel two-stage delay model, which measures end-to-end delay using either hop count or degree sum along a routing path depending on traffic intensity. It models the network as a unit disk graph (UDG) and constructs a localized minimal spanning tree (LMST) sub-graph. Using only edges from LMST, it builds a shortest path (thus energy-efficient) tree rooted at the actor for data aggregation. The tree is used without modification if it generates acceptable delay, compared with a given delay bound. Otherwise, it is adjusted by replacing LMST sub-paths with UDG edges. The adjustment is done locally on the fly, according to the DEsired Progress (DEP) value computed at each node. We further propose to integrate DEDA with a localized sensor activity scheduling algorithm and a localized connected dominating set algorithm, yielding two DEDA variants, to improve its energy efficiency and delay reliability. Through an extensive set of simulation, we evaluate the performance of DEDA with various network parameters. Our simulation results indicate that DEDA far outperforms the only existing competing protocol.

5.6.2. Data management

The use of reliable high-level languages based on virtual machines, such as java, is now possible on systems as small as smart cards or sensors. However, the potential of these languages is widely limited by hardware constraints as memory storage capacity etc. We claim that is lock may be leveraged by coupling cache mechanisms with external memory storages. [40] is a preliminary study of the set up of such an approach. Thanks to simulation based results, we identify three main factors which tend to decrease the performances of cache setting code in Java.

5.6.3. Data security

[41], [24] presents the enforcement of control flow policies for Java bytecode devoted to open and constrained devices. On-device enforcement of security policies mostly relies on run-time monitoring or inline checking code, which is not appropriate for strongly constrained devices such as mobile phones and smart-cards. We present a proof-carrying code approach with on-device lightweight verification of control flow policies statically at loading time. Policies are expressed by finite automata, the technique is in-between security automata and control flow security policies of Jensen et al. Our approach is suitable for evolving, open and constrained Java-based systems as it is compositional, to avoid re-verification of already verified bytecode upon loading of new bytecode, and it is regressive, to cleanly support bytecode unloading.

While mobile devices have become ubiquitous and generally multi-application capable, their operating systems provide few high level mechanisms to protect services offered by application vendors against potentially hostile applications coexisting on the device. In [23], we tackle the issue of controlling application interactions including collusion in Java-based systems running on open, constrained devices such as smart cards or mobile phones. We present a model specially designed to be embedded in constrained devices to verify at install-time that interactions between applications abide by the security policies of each involved application without resulting in run-time computation overheads; this models deals with application (un)installations and policy changes in an incremental fashion. We show the feasibility of our approach and its security
enhancements on a multi-application use case for GlobalPlatform/Java Card smart cards. This approach is developed in EVe - TCF.

Telecommunication software systems, containing security vulnerabilities, continue to be created and released to consumers. We need to adopt improved software engineering practices to reduce the security vulnerabilities in modern systems. Contracts can provide a useful mechanism for the identification, tracking, and validation of security vulnerabilities. In [8], we propose a new contract-based security assertion monitoring framework (CB SAMF) that is intended to reduce the number of security vulnerabilities that are exploitable across multiple software layers, and to be used in an enhanced systems development life cycle (SDLC). We show how contract-based security assertion monitoring can be achieved in a live environment on Linux. Through security activities integrated into the SDLC we can identify potential security vulnerabilities in telecommunication systems, which in turn are used for the creation of contracts defining security assertions. Our contract model is then exercised, as runtime probes, against two common security related vulnerabilities in the form of a buffer overflow and a denial of service.
5. New Results

5.1. Package understanding and Assessing

**Participants:** Stéphane Ducasse, Nicolas Anquetil, Usman Bhatti, Jannik Laval.

To support the understanding of large systems is to offer ways to understand and fix dependencies between software elements. We worked on how to semi-automatically reorganize packages to minimize coupling.

**Efficient Retrieval and Ranking of Undesired Package Cycles in Large Software Systems.** Many design guidelines state that a software system architecture should avoid cycles between its packages. Yet such cycles appear again and again in many programs. We believe that the existing approaches for cycle detection are too coarse to assist the developers to remove cycles from their programs. We describe an efficient algorithm that performs a fine-grained analysis of the cycles among the packages of an application. In addition, we define a metric to rank cycles by their level of undesirability, prioritizing the cycles that seem the least desirable to the developers. Our approach is validated on two large and mature software systems in Java and Smalltalk. [19]

**Legacy Software Restructuring: Analyzing a Concrete Case.** Software re-modularization is an old preoccupation of reverse engineering research. The advantages of a well structured or modularized system are well known. Yet after so much time and efforts, the field seems unable to come up with solutions that make a clear difference in practice. Recently, some researchers started to question whether some basic assumptions of the field were not overrated. The main one consists in evaluating the high-cohesion/low-coupling dogma with metrics of unknown relevance. In this paper, we study a real restructuring case (on the Eclipse platform) to try to better understand if (some) existing metrics would have helped the software engineers in the task. Results show that the cohesion and coupling metrics used in the experiment did not behave as expected and would probably not have helped the maintainers reach there goal. We also measured another possible restructuring which is to decrease the number of cyclic dependencies between modules. Again, the results did not meet expectations. [14]

**An empirical model for continuous and weighted metric aggregation.** It is now understood that software metrics alone are not enough to characterize software quality. To cope with this problem, most of advanced and/or industrially validated quality models aggregate software metrics: for example, cyclomatic complexity is combined with test coverage to stress the fact that it is more important to cover complex methods than accessors. Yet, aggregating and weighting metrics to produce quality indexes is a difficult task. Indeed certain weighting approaches may lead to abnormal situations where a developer increasing the quality of a software component sees the overall quality degrade. Finally, mapping combinations of metric values to quality indexes may be a problem when using thresholds. In this paper [20], we present the problems we faced when designing the Squale quality model, then we present an empirical solution based on weighted aggregations and on continuous functions. The solution has been termed the Squale quality model and validated over 4 years with two large multinational companies: Air France-KLM and PSA Peugeot-Citroen.

**Modularization Metrics: Assessing Package Organization in Legacy Large Object-Oriented Software.** In systems consisting of several thousands of classes, classes cannot be considered as units for software modularization. In such context, packages are not simply classes containers, but they also play the role of modules: a package should focus on providing well identified services to the rest of the software system. Therefore, understanding and assessing package organization is primordial for software maintenance tasks. Although there exist a lot of works proposing metrics for the quality of a single class and/or the quality of inter-class relationships, there exist few works dealing with some aspects for the quality of package organization and relationship. We believe that additional investigations are required for assessing package modularity aspects. The goal of these papers [13], [28] is to provide a complementary set of metrics that assess some modularity principles for packages in large legacy object-oriented software: Information-Hiding, Changeability and Reusability principles. Our metrics are defined with respect to object-oriented dependencies.
that are caused by inheritance and method call. We validate our metrics theoretically through a careful study of the mathematical properties of each metric.

5.2. Tools and Tool Infrastructure

Participants: Stéphane Ducasse, Veronica Uquillas-Gomez, Jannik Laval.

Reengineering large applications implies an underlying tool infrastructure that can scale and also be extended.

Ring: a Unifying Meta-Model and Infrastructure for Smalltalk Source Code Analysis Tools. Source code management systems record different versions of code. Tool support can then compute deltas between versions. To ease version history analysis we need adequate models to represent source code entities. As a first step to provide an infrastructure to support history analysis, this article [12] presents Ring, a unifying source code meta-model that can be used to support several activities and proposes a unified and layered approach to be the foundation for building an infrastructure for version and stream of change analyses. We re-implemented three tools based on Ring to show that it can be used as the underlying meta-model for remote and off-image browsing, scoping refactoring, and visualizing and analyzing changes. As a future work and based on Ring we will build a new generation of history analysis tools.

AspectMaps: A Scalable Visualization of Join Point Shadows. When using Aspect-Oriented Programming, it is sometimes difficult to determine at which join point an aspect executes. Similarly, when considering one join point, knowing which aspects will execute there and in what order is non-trivial. This makes it difficult to understand how the application will behave. A number of visualizations have been proposed that attempt to provide support for such program understanding. However, they neither scale up to large code bases nor scale down to understanding what happens at a single join point. In this paper [18], we present AspectMaps - a visualization that scales in both directions, thanks to a multi-level selective structural zoom. We show how the use of AspectMaps allows for program understanding of code with aspects, revealing both a wealth of information of what can happen at one particular join point as well as allowing to see the “big picture” on a larger code base. We demonstrate the usefulness of AspectMaps on an example and present the results of a small user study that shows that AspectMaps outperforms other aspect visualization tools.

Challenges to support automated random testing for dynamically typed languages. Automated random testing is a proved way to identify bugs and precondition violations, and this even in well tested libraries. In the context of statically typed languages, current automated random testing tools heavily take advantage of static method declaration (argument types, thrown exceptions) to constrain input domains while testing and to identify errors. For such reason, automated random testing has not been investigated in the context of dynamically typed languages. We present the key challenges that have to be addressed to support automated testing in dynamic languages. [17]

SmartGroups, Focusing on Task-Relevant Source Artifacts in IDEs. Navigating large software systems, even when using a modern IDE (Integrated Development Environment) is difficult, since conceptually related software artifacts are distributed in a huge software space. For most software maintenance tasks, only a small fraction of the entire software space is actually relevant. The IDE, however, does not reveal the task relevancy of source artifacts, thus developers cannot easily focus on the artifacts required to accomplish their tasks. Smart Groups help developers to perform software maintenance tasks by representing groups of source artifacts that are relevant for the current task. Relevancy is determined by analyzing historical navigation and modification activities, evolutionary information, and runtime information. The prediction quality of Smart Groups is validated with a benchmark evaluation using recorded development activities and evolutionary information from versioning systems. [24]

5.3. Constructs for Dynamic Languages

Participants: Stéphane Ducasse, Marcus Denker, Veronica Uquillas-Gomez, Gwenael Casaccio, Camillo Bruni, Jean-Baptiste Arnaud, Damien Pollet.

To support our research on secure dynamic languages, we focused on improving language infrastructure.
Efficient Proxies in Smalltalk. A proxy object is a surrogate or placeholder that controls access to another target object. Proxy objects are a widely used solution for different scenarios such as remote method invocation, future objects, behavioral reflection, object databases, inter-languages communications and bindings, access control, lazy or parallel evaluation, security, among others. Most proxy implementations support proxies for regular objects but they are unable to create proxies for classes or methods. Proxies can be complex to install, have a significant overhead, be limited to certain type of classes, etc. Moreover, most proxy implementations are not stratified at all and there is no separation between proxies and handlers. We present Ghost, a uniform, light-weight and stratified general purpose proxy model and its Smalltalk implementation. Ghost supports proxies for classes or methods. When a proxy takes the place of a class it intercepts both, messages received by the class and lookup of methods for messages received by instances. Similarly, if a proxy takes the place of a method, then the method execution is intercepted too. [22]

Bootstrapping a Smalltalk. Smalltalk is a reflective system. It means that it is defined in itself in a causally connected way. Traditionally, Smalltalk systems evolved by modifying and cloning what is called an image (a chunk of memory containing all the objects at a given point in time). During the evolution of the system, objects representing it are modified. However, such an image modification and cloning poses several problems: (1) There is no operational machine-executable algorithm that allows one to build a system from scratch. A system object may be modified but it may be difficult to reproduce its exact state before the changes. Therefore it is difficult to get a reproducible process. (2) As a consequence, certain classes may not have been initialized since years. (3) Finally, since the system acts as a living system, it is not simple to evolve the kernel for introducing new abstractions without performing some kind of brain surgery on oneself. There is a need to have a step by step process to build Smalltalk kernels from scratch. After an analysis of past and current practices to mutate or generate kernels, we describe a kernel bootstrap process step-by-step. First the illusion of the existence of a kernel is created via stubs objects. Second the classes and meta-classes hierarchy are generated. Code is compiled and finally information needed by the virtual machine and execution are generated and installed. [15]

Flexible Object Layouts: Enabling Lightweight Language Extensions by Intercepting Slot Access. Programming idioms, design patterns and application libraries often introduce cumbersome and repetitive boilerplate code to a software system. Language extensions and external DSLs (domain specific languages) are sometimes introduced to reduce the need for boilerplate code, but they also complicate the system by introducing the need for language dialects and inter-language mediation. To address this, we propose to extend the structural reflective model of the language with object layouts, layout scopes and slots. Based on the new reflective language model we can 1) provide behavioral hooks to object layouts that are triggered when the fields of an object are accessed and 2) simplify the implementation of state-related language extensions such as stateful traits. By doing this we show how many idiomatic use cases that normally require boilerplate code can be more effectively supported. We present an implementation in Smalltalk, and illustrate its usage through a series of extended examples. [25]

5.4. Resources

Participants: Stéphane Ducasse, Marcus Denker, Mariano Martinez-Peck, Nick Papoylias.

Resource management is important in the context of resource constrained devices as well as situations were a large amount of data is modeled but not accessed often. One example for resource constrained devices are autonomous robots. An example for large models that are accessed infrequently are typical models of systems for software re-engineering.

With Ecole des Mines de Douai we explore how to analyze and improve memory in the case of unused data.

Problems and Challenges when Building a Manager for Unused Objects. Large object-oriented applications may occupy hundreds of megabytes or even gigabytes of memory. During program execution, a large graph of objects is created and constantly changed. Most object runtimes support some kind of automatic memory management based on garbage collectors (GC) whose idea is the automatic destruction of unreferenced objects. However, there are referenced objects which are not used for a long period of time or that are
used just once. These are not garbage-collected because they are still reachable and might be used in the future. Due to these unused objects, applications use much more resources than they actually need. We present the challenges and possible approaches towards an unused object manager for Pharo. The goal is to use less memory by swapping out the unused objects to secondary memory and leaving in primary memory only those objects that are needed and used. When one of the unused objects is needed, it is brought back into primary memory. [23]

Clustered Serialization with Fuel. Serializing object graphs is an important activity since objects should be stored and reloaded on different environments. There is a plethora of frameworks to serialize objects based on recursive parsing of the object graphs. However such approaches are often too slow. Most approaches are limited in their provided features. For example, several serializers do not support class shape changes, global references, transient references or hooks to execute something before or after being stored or loaded. Moreover, to be faster, some serializers are not written taking into account the object-oriented paradigm and they are sometimes even implemented in the Virtual Machine hampering code portability. VM-based serializers such as ImageSegment are difficult to understand, maintain, and fix. For the final user, it means a serializer which is difficult to customize, adapt or extend to his own needs. We present a general purpose object graph serializer based on a pickling format and algorithm. We implement and validate this approach in the Pharo Smalltalk environment. We demonstrate that we can build a really fast serializer without specific VM support, with a clean object-oriented design, and providing most possible required features for a serializer. We show that our approach is faster that traditional serializers and compare favorably with ImageSegment as soon as serialized objects are not in isolation. [16]

Towards Structural Decomposition of Reflection with Mirrors Mirrors are meta-level entities introduced to decouple reflection from the base-level system. Current mirror-based systems focus on functional decomposition of reflection. We advocate that mirrors should also address structural decomposition. Mirrors should not only be the entry points of reflective behavior but also be the storage entities of meta-information. This decomposition can help resolve issues in terms of resource constraints (e.g. embedded systems and robotics) or security. Indeed, structural decomposition enables discarding meta-information. [21]

5.5. Empirical Studies in Software Product Line Engineering

Participant: Nicolas Anquetil.

Software Product Line Engineering (SPL) is a new development paradigm that promises to offer faster development, with better quality. The idea is to develop a generic application (the Software Product Line) with pre-defined variation points. From this, new applications are derived from the generic application and the options are chosen for the possible variation points. Because it is still a new paradigm, Software Product Line development is still an active research domain where empirical research is useful to check the validity of the results.

These publications are the results of an earlier research project to which N. Anquetil participated.

Managing information flow in the SPL development processes. Traceability is a quality attribute in software engineering that establishes the ability to describe and follow the life of a requirement in both the forward and backward directions (i.e. from its origins throughout its specification, implementation, deployment, use and maintenance, and vice-versa). The IEEE Standard Glossary of Software Engineering Terminology defines traceability as “the degree to which a relationship can be established between two or more products of the development process, especially products having a predecessor-successor or master-subordinate relationship to one another”. According to (Palmer, 1997) “traceability gives essential assistance in understanding the relationships that exist within and across software requirements, design, and implementation”. Thus, trace relationships help in identifying the origin and rationale for artefacts generated during development lifecycle and the links between these artefacts. Identification of sources helps understanding requirements evolution and validating implementation of stakeholders’ requirements. The main advantages of traceability are: (i) to relate software artefacts and design decisions taken during the software development cycle; (ii) to give feedback to architects and designers about the current state of the development, allowing them to reconsider alternative
design decisions, and to track and understand bugs; and (iii) to ease communication between stakeholders. [26]

Empirical research in software product line engineering. Empirical evaluation has for many years been utilized to validate theories in other science disciplines. One of the first well-known reported examples of empirical evaluation occurred when Galileo wanted to prove that the rate of descent of objects was independent of their mass. This would disprove a theory put forward by Aristotle that the rate of descent is directly proportional to their weight. To prove his theory Galileo dropped two balls made from the same material but different masses from the top of the Tower of Pisa. When the experiment was performed Galileo’s theory was proved correct through the empirical evidence collected. What this story demonstrates is the importance of empirical validation to verify or disprove theories and hypotheses. The purpose of this publication [27] is to emphasize the importance and difficulties of empirical evaluation in the domain of SPLE.
6. New Results

6.1. Interactive Simulation of Liver Resection PASSPORT demonstration at SIGGRAPH

The 3-year EU PASSPORT project is being finalized. In this context, we created a GPU-based interactive simulation of laparoscopic liver resection that was selected for SIGGRAPH Real Time Live! [21]. While similar medical simulators have been developed in the past, this demonstration relies on advanced methods and the computational power of today’s GPUs to simulate multiple organs with high-resolution deformations and collisions in real-time. We use detailed meshes generated from segmented CT scans, facilitating the reproduction of patient-specific scenarios, as is necessary for the pre-operative rehearsal of complex or risky medical cases. In the presented application, the user can examine the mechanical and collision models, and the generated contacts while the simulated patient is breathing. He can manipulate a laparoscopic instrument to navigate through the abdominal cavity, push on organs and perform a thermal ablation.

![Figure 5. Left: mechanical FEM models (4k tetrahedra), Middle: Collision surfaces (15k triangles), Right: Visual Models. Bottom: the user view during liver resection. The resulting simulation runs at 25 FPS.](image)

While similar medical simulators have been developed in the past 10 years, this demonstration is based on recently proposed methods: high-resolution Finite Element Model (FEM) with implicit time-integration implemented on GPU [1], volume contact constraints [2], an efficient numerical solver based on asynchronous preconditioning [17], as well as improvements in visual and haptic rendering. These methods allow to simulate in real-time all organs in the abdominal cavity using a improved level of precision compared to previous works. The FEM formulation enables to reproduce specific material properties. Contacts are handled by precise constraints with frictions on detailed surface meshes. Both methods support topological changes efficiently, as demonstrated by performing a resection of a portion of a liver, an important step in
surgical procedures performed to remove cancerous tumors. This work was presented at SIGGRAPH 2011 [21].

6.2. Biomechanical simulation of electrode migration for deep brain stimulation

Deep Brain Stimulation is a modern surgical technique for treating patients who suffer from affective or motion disorders such as Parkinson’s disease. The efficiency of the procedure relies heavily on the accuracy of the placement of a micro-electrode which sends electrical pulses to a specific part of the brain that controls motion and affective symptoms. However, targeting this small anatomical structure is rendered difficult due to a series of brain shifts that take place during and after the procedure. We introduce a biomechanical simulation of the intra and postoperative stages of the procedure in order to determine lead deformation and electrode migration due to brain shift. To achieve this goal, we propose a global approach, which accounts for brain deformation but also for the numerous interactions that take place during the procedure (contacts between the brain and the inner part of the skull and falx cerebri, effect of the cerebrospinal fluid, and biomechanical interactions between the brain and the electrodes and cannula used during the procedure). Preliminary results show a good correlation between our simulations and various results reported in the literature. This work was presented at MICCAI 2011 [16].

![Figure 6. Screenshot showing the simulated deflection of the right electrode immediately after operation (left) and several weeks after the operation (right).](image)

6.3. Preconditioner-Based Contact Response and Application to Cataract Surgery

We introduced a new method to compute, in real-time, the physical behavior of several colliding soft-tissues in a surgical simulation. The numerical approach is based on finite element modeling and allows for a fast update of a large number of tetrahedral elements. The speed-up is obtained by the use of a specific preconditioner that is updated at low frequency. The preconditioning enables an optimized computation of both large deformations and precise contact response. Moreover, homogeneous and inhomogeneous tissues are simulated with the same accuracy. This method was used in a simulation of one step in a cataract surgery procedure, which require to handle contacts with non homogeneous objects precisely. This work was presented at MICCAI 2011 [17].
6.4. Interactive Blood-Coil Simulation in Real-time during Aneurysm Embolization

We introduced a complete process for patient-specific simulations of coil embolization, from mesh generation with medical datasets to computation of coil-flow bilateral influence. We propose a new method for simulating the complex blood flow patterns that take place within the aneurysm, and for simulating the interaction of coils with this flow. Porous media was introduced to model the impact of the coil onto the flow (as a change of flow pattern and a decrease of velocity) from a statistical point of view, while the reverse effect on the coil (as a shift in the blood flow) was described by the local drag force. By solving the Navier-Stokes Equations with extra porous terms using the DEC method, the velocity field of blood flow was obtained, and then used to compute the drag force applied on the coil during aneurysm embolization. This work was published in the Computers & Graphics journal [13].

6.5. Constraint-based Haptic Rendering of Multirate Compliant Mechanisms
The research, that is published in IEEE transaction of Haptics [12], is dedicated to haptic rendering of complex physics-based environment in the context of surgical simulation. A new unified formalism for modeling the mechanical interactions between medical devices and anatomical structures and for computing accurately the haptic force feedback is presented. The approach deals with the mechanical interactions using appropriate force and/or motion transmission models named compliant mechanisms. These mechanisms are formulated as a constraint-based problem that is solved in two separate threads running at different frequencies. The first thread processes the whole simulation including the soft-tissue deformations, whereas the second one only deals with computer haptics. This method builds a bridge between the so called virtual mechanisms (that were proposed for haptic rendering of rigid bodies) and intermediate representations (used for rendering of complex simulations). With this approach, it is possible to describe the specific behavior of various medical devices while relying on a unified method for solving the mechanical interactions between deformable objects and haptic rendering. The technique is demonstrated in interactive simulation of flexible needle insertion through soft anatomical structures with force feedback.

![Figure 9. Constraint-based Haptic Rendering of Multirate Compliant Mechanisms](image)

6.6. Asynchronous Haptic Simulation of Contacting Deformable Objects with Variable Stiffness
This research, published in IROS proceedings [18], presents a new asynchronous approach for haptic rendering of deformable objects. When stiff non-linear deformations take place, they introduce important and rapid variations of the force sent to the user. This problem is similar to the stiff virtual wall for which a high refresh rate is required to obtain a stable haptic feedback. However, when dealing with several interacting deformable objects, it is usually impossible to simulate all objects at high rates. To address this problem we propose a quasi-static framework that allows for stable interactions of asynchronously computed deformable objects. In the proposed approach, a deformable object can be computed at high refresh rates, while the remaining deformable virtual objects remain computed at low refresh rates. Moreover, contacts and other constraints between the different objects of the virtual environment are accurately solved using a shared Linear Complementarity Problem (LCP). Finally, we demonstrate our method on two test cases: a snap-in example involving non-linear deformations and a virtual thread interacting with a deformable object.

![Figure 10. Schematic visualization of the computational model](image-url)
6. New Results

6.1. Introduction

The new results are organized in the following sections:

1. decision under uncertainty,
2. foundations of machine learning,
3. supervised learning,
4. signal processing (sensor networks),
5. other results.

6.2. Decision Under Uncertainty


6.2.1. Reinforcement learning and approximate dynamic programming

In the domain of reinforcement learning and approximate dynamic programming, we identify two main lines of research.

6.2.1.1. Links between Approximate Dynamic Programming and Statistical Learning Theory

The main objective here is to use tools from statistical learning theory to derive finite-sample performance bounds for RL and ADP algorithms. The goal is to derive bounds on the performance of the policies induced by these algorithms in terms of the number of simulation data and the capacity and approximation power of the considered function and policy spaces. The results of this study allow us to have a better understanding of the functionality of these algorithms and help us to design them more efficiently. The main contributions to this research line in 2011 are:

- **Classification-based Policy Iteration with a Critic** [25], [51]. In collaboration with Bruno Scherrer (INRIA Nancy - Grand Est, Team MAIA) we extended last year work on classification-based policy iteration by adding a value function approximation component (critic) to rollout classification-based policy iteration (RCPI) algorithms. The idea is to use a critic to approximate the return after we truncate the rollout trajectories. This allows us to control the bias and variance of the rollout estimates of the action-value function. Therefore, the introduction of a critic can improve the accuracy of the rollout estimates, and as a result, enhance the performance of the RCPI algorithm. We presented a new RCPI algorithm, called direct policy iteration with critic (DPI-Critic), and provided its finite-sample analysis when the critic is based on the LSTD method. We also empirically evaluated the performance of DPI-Critic and compared it with DPI and LSPI in two benchmark reinforcement learning problems.

- **Finite-Sample Analysis of Least-Squares Policy Iteration** [10], [45]. We extended last year work on the finite-sample analysis of least-squares temporal-difference (LSTD) to the least-squares policy iteration (LSPI) algorithm. In particular, we analyzed how the error at each policy evaluation step is propagated through the iterations of a policy iteration method, and derive a performance bound for the LSPI algorithm.
• **Speedy Q-Learning** [16], [48]. We introduce a new convergent variant of Q-learning, called speedy Q-learning, to address the problem of slow convergence in the standard form of the Q-learning algorithm. We prove a PAC bound on the performance of SQL, which shows that for an MDP with \( n \) state-action pairs and the discount factor \( \gamma \) only \( T = O(\log(n)/(\epsilon^2(1 - \gamma)^4)) \) steps are required for the SQL algorithm to converge to an \( \epsilon \)-optimal action-value function with high probability. This bound has a better dependency on \( 1/\epsilon \) and \( 1/(1 - \gamma) \), and thus, is tighter than the best available result for Q-learning. Our bound is also superior to the existing results for both model-free and model-based instances of batch Q-value iteration that are considered to be more efficient than the incremental methods like Q-learning.

• **Selecting the State-Representation in Reinforcement Learning** [34]. The problem of selecting the right state-representation in a reinforcement learning problem is considered. Several models (functions mapping past observations to a finite set) of the observations are given, and it is known that for at least one of these models the resulting state dynamics are indeed Markovian. Without knowing neither which of the models is the correct one, nor what are the probabilistic characteristics of the resulting MDP, it is required to obtain as much reward as the optimal policy for the correct model (or for the best of the correct models, if there are several). We propose an algorithm that achieves that, with a regret of order \( T^{2/3} \) where \( T \) is the horizon time.

• **Transfer from Multiple MDPs** [32]. Transfer reinforcement learning (RL) methods leverage on the experience collected on a set of source tasks to speed-up RL algorithms. A simple and effective approach is to transfer samples from source tasks and include them in the training set used to solve a target task. In this paper, we investigate the theoretical properties of this transfer method and we introduce novel algorithms adapting the transfer process on the basis of the similarity between source and target tasks. Finally, we report illustrative experimental results in a continuous chain problem.

6.2.1.2. RL in High-dimensional Spaces

The main objective here is to devise, analyze, implement, and experiment with RL algorithms whose sample and computational complexities do not grow rapidly with the dimension of the state space. We have tackled this problem from two different angles:

• **Exploiting the Regularities of the Problem** [57], [8], [27]. In order to solve RL in high dimensions, we should exploit all the regularities of the problem in hand. **Smoothness** is the most common regularity. We continued our collaboration with Amir massoud Farahmand and Csaba Szepesvári at the university of Alberta, Canada, and Shie Mannor at Technion, Israel, on using regularization methods for automatic model selection for value function approximation in RL. We have devised and analyzed the first \( \ell_2 \)-regularized RL algorithms by adding \( \ell_2 \)-regularization to three well-known ADP algorithms: fitted Q-iteration, modified Bellman residual minimization, and least-squares temporal-difference learning [57], [8]. The designed algorithms work in both linear and reproducing kernel Hilbert spaces. **Sparsity** is another form of regularity that clearly plays a central role in the emerging theory of learning in high dimensions. We have worked on using \( \ell_1 \)-regularization in approximate dynamic programming and RL, which may also serve as a method for feature selection in value function approximation. We have derived finite-sample performance bounds for an algorithm resulting from adding \( \ell_1 \)-penalty to the widely-used least-squares temporal-difference learning (LSTD) algorithm [27].

• **Random Projections** [28], [52]. We have looked into recent directions popularized in compressive sensing concerning the preservation of properties, such as norm or inner-product, of high dimensional objects when projected on possibly much lower dimensional random subspaces. We have studied the popular LSTD algorithm when a space of low dimension is generated with a random projection from the high-dimensional space, and derived performance bounds for the resulting algorithm [28], [52].

6.2.2. Planning and exploration vs. exploitation trade-off

In the domain of planning and exploration-exploitation algorithms, we identify two main lines of research.
6.2.2.1. Multi-arm Bandit, Online Learning and Optimization

- **Active Learning in Multi-Armed Bandit Problems** [18], [49], [24], [50]. This can be seen as an online allocation problem with several options and is closely related to the problem of *optimal experimental design* in statistics. The objective here is to allocate a fixed budget to a finite (or possibly infinite) number of options (arms) in order to achieve the best accuracy in estimating the quality of each option. In addition to having application in a number of different fields such as *online advertisement* and *personalizing treatment*, this problem is of specific importance in RL in which generating training data is usually expensive. In this framework, we have studied the following two problems: 1) estimating the mean values of all the arms uniformly well in a multi-armed bandit setting [18], [49], and 2) identifying the best arm in each of the bandits in a multi-bandit multi-armed setting [24], [50]. For each problem, we have developed algorithms with theoretical guarantees.

- **Finite Time Analysis of Stratified Sampling for Monte Carlo** [20]. We consider the problem of stratified sampling for Monte-Carlo integration. We model this problem in a multi-armed bandit setting, where the arms represent the strata (an interval in the input domain), and the goal is to estimate a weighted average of the mean values of the arms. We propose a strategy that samples the arms according to an upper bound on their standard deviations and compare its estimation quality to an ideal allocation that would know the standard deviations of the strata. We provide two regret analyses: a distribution-dependent bound $O(n^{-3/2})$ that depends on a measure of the disparity of the strata, and a distribution-free bound $O(n^{-4/3})$ that does not.

- **Optimistic Optimization of a Deterministic Function without the Knowledge of its Smoothness** [36]. We consider a global optimization problem of a deterministic function $f$ in a semi-metric space, given a finite budget of $n$ evaluations. The function $f$ is assumed to be locally smooth (around one of its global maxima) with respect to a semi-metric. We describe two algorithms based on optimistic exploration that use a hierarchical partitioning of the space at all scales. A first contribution is an algorithm, DOO, that requires the knowledge of $\Theta$. We report a finite-sample performance bound in terms of a measure of the quantity of near-optimal states. We then define a second algorithm, SOO, which does not require the knowledge of the semi-metric under which $f$ is smooth, and whose performance is almost as good as DOO optimally-fitted.

- **Finite-Time Analysis of Multi-armed Bandits Problems with Kullback-Leibler Divergences** [35]. We consider a Kullback-Leibler-based algorithm for the stochastic multi-armed bandit problem in the case of distributions with finite supports (not necessarily known beforehand), whose asymptotic regret matches the lower bound of Burnetas and Katehakis (1996). Our contribution is to provide a finite-time analysis of this algorithm; we get bounds whose main terms are smaller than the ones of previously known algorithms with finite-time analyses (like UCB-type algorithms).

- **Adaptive bandits: Towards the best history-dependent strategy** [33]. We consider multi-armed bandit games with possibly adaptive opponents. We introduce models $\Theta$ of constraints based on equivalence classes on the common history (information shared by the player and the opponent) which define two learning scenarios: (1) The opponent is constrained, i.e. he provides rewards that are stochastic functions of equivalence classes defined by some model. The regret is measured with respect to (w.r.t.) the best history-dependent strategy. (2) The opponent is arbitrary and we measure the regret w.r.t. the best strategy among all mappings from classes to actions (i.e. the best history-class-based strategy) for the best model. This allows to model opponents (case 1) or strategies (case 2) which handle finite memory, periodicity, standard stochastic bandits and other situations. When only one model is considered, we derive tractable algorithms achieving a tight regret (at time $T$) bounded by $O(\sqrt{TAC})$, where $C$ is the number of classes. Now, when many models are available, all known algorithms achieving a nice regret $O(\sqrt{T})$ are unfortunately not tractable and scale poorly with the number of models. Our contribution here is to provide tractable algorithms with regret bounded by $T^{2/3}C^{1/3} \log(|\Theta|)^{1/2}$. 

• **Pure Exploration in Finitely-Armed and Continuous-Armed Bandits** [5]. We consider the framework of stochastic multi-armed bandit problems and study the possibilities and limitations of forecasters that perform an on-line exploration of the arms. These forecasters are assessed in terms of their simple regret, a regret notion that captures the fact that exploration is only constrained by the number of available rounds (not necessarily known in advance), in contrast to the case when the cumulative regret is considered and when exploitation needs to be performed at the same time. We believe that this performance criterion is suited to situations when the cost of pulling an arm is expressed in terms of resources rather than rewards. We discuss the links between the simple and the cumulative regret. One of the main results in the case of a finite number of arms is a general lower bound on the simple regret of a forecaster in terms of its cumulative regret: the smaller the latter, the larger the former. Keeping this result in mind, we then exhibit upper bounds on the simple regret of some forecasters. The paper ends with a study devoted to continuous-armed bandit problems; we show that the simple regret can be minimized with respect to a family of probability distributions if and only if the cumulative regret can be minimized for it. Based on this equivalence, we are able to prove that the separable metric spaces are exactly the metric spaces on which these regrets can be minimized with respect to the family of all probability distributions with continuous mean-payoff functions.

• **X-Armed Bandits** [6]. We consider a generalization of stochastic bandits where the set of arms, $X$, is allowed to be a generic measurable space and the mean-payoff function is locally Lipschitz with respect to a dissimilarity function that is known to the decision maker. Under this condition we construct an arm selection policy, called HOO (hierarchical optimistic optimization), with improved regret bounds compared to previous results for a large class of problems. In particular, our results imply that if $X$ is the unit hypercube in a Euclidean space and the mean-payoff function has a finite number of global maxima around which the behavior of the function is locally continuous with a known smoothness degree, then the expected regret of HOO is bounded up to a logarithmic factor by $\sqrt{n}$, that is, the rate of growth of the regret is independent of the dimension of the space. We also prove the minimax optimality of our algorithm when the dissimilarity is a metric. Our basic strategy has quadratic computational complexity as a function of the number of time steps and does not rely on the doubling trick. We also introduce a modified strategy, which relies on the doubling trick but runs in linearithmic time. Both results are improvements with respect to previous approaches.

• **Learning with Stochastic Inputs and Adversarial Outputs** [11]. Most of the research in online learning is focused either on the problem of adversarial classification (i.e., both inputs and labels are arbitrarily chosen by an adversary) or on the traditional supervised learning problem in which samples are independent and identically distributed according to a stationary probability distribution. Nonetheless, in a number of domains the relationship between inputs and outputs may be adversarial, whereas input instances are i.i.d. from a stationary distribution (e.g., user preferences). This scenario can be formalized as a learning problem with stochastic inputs and adversarial outputs. In this paper, we introduce this novel stochastic-adversarial learning setting and we analyze its learnability. In particular, we show that in binary classification, given a hypothesis space $H$ with finite VC-dimension, it is possible to design an algorithm which incrementally builds a suitable finite set of hypotheses from $H$ used as input for an exponentially weighted forecaster and achieves a cumulative regret of order $\sqrt{n \text{VC}(H) \log n}$ with overwhelming probability. This result shows that whenever inputs are i.i.d., it is possible to solve any binary classification problem using a finite VC-dimension hypothesis space with a sub-linear regret independently from the way labels are generated (either stochastic or adversarial). We also discuss extensions to multi-label classification, regression, learning from experts and bandit settings with stochastic side information, and application to games.

• **ICML Exploration-Exploitation Challenge** [65], [63]. Olivier Nicol and Jérémie Mary won the ICML challenge on Exploration and Exploitation 2 organized by Cambridge on dataset provided by Adobe. The winning approach is based on ideas close to bayesian networks and Thomson sampling as Ad Predictor from Microsoft. These kind of sucess emphases the need for better theoretical analysis of theses frameworks. The challenge was also a good occasion to think about the best way
to evaluate online politics (this part also attracts interest from Orange Labs). A publication to JMLR is submitted.

6.2.2.2. Planning

- **Optimistic Planning for Sparsely Stochastic Systems** [17]. We propose an online planning algorithm for finite action, sparsely stochastic Markov decision processes, in which the random state transitions can only end up in a small number of possible next states. The algorithm builds a planning tree by iteratively expanding states, where each expansion exploits sparsity to add all possible successor states. Each state to expand is actively chosen to improve the knowledge about action quality, and this allows the algorithm to return a good action after a strictly limited number of expansions. More specifically, the active selection method is optimistic in that it chooses the most promising states first, so the novel algorithm is called optimistic planning for sparsely stochastic systems. We note that the new algorithm can also be seen as model-predictive (receding-horizon) control. The algorithm obtains promising numerical results, including the successful online control of a simulated HIV infection with stochastic drug effectiveness.

- **Optimistic Planning in Markov decision processes** [46]. We review a class of online planning algorithms for deterministic and stochastic optimal control problems, modeled as Markov decision processes. At each discrete time step, these algorithms maximize the predicted value of planning policies from the current state, and apply the first action of the best policy found. An overall receding-horizon algorithm results, which can also be seen as a type of model-predictive control. The space of planning policies is explored optimistically, focusing on areas with largest upper bounds on the value or upper confidence bounds, in the stochastic case. The resulting optimistic planning framework integrates several types of optimism previously used in planning, optimization, and reinforcement learning, in order to obtain several intuitive algorithms with good performance guarantees. We describe in detail three recent such algorithms, outline the theoretical guarantees on their performance, and illustrate their behavior in a numerical example.

6.2.3. Applications

6.2.3.1. Management of ad campaigns on the web

More work has been dedicated to the topic aiming at optimizing ad campaigns on the web under real-time constraints, in a dynamic environment [9].

6.3. Foundations of Machine Learning

**Participants:** Daniil Ryabko, Azadeh Khaleghi, Romaric Gaudel.

6.3.1. Sequence prediction in the most general form

The problem of sequence prediction consists in forecasting, on each step of time $n$, the probabilities of the next outcome of the observed sequence of data $x_1, x_2, \ldots, x_n, \ldots$. In the most general formulation of the problem, we assume that we are given a set $\mathcal{C}$ of probability measures (on the space of infinite sequences). We can then assume that the sequence is generated by an unknown measure $\mu$ that belongs to $\mathcal{C}$, or that the measure $\mu$ is arbitrary, but we compare the performance of our predictor to that of the best predictor in $\mathcal{C}$.

6.3.1.1. Relation between the realizable and non-realizable cases of the sequence prediction problem

The realizable case of the sequence prediction problem is when the measure $\mu$ belongs to an arbitrary but known class $\mathcal{C}$ of process measures. The non-realizable case is when $\mu$ is completely arbitrary, but the prediction performance is measured with respect to a given set $\mathcal{C}$ of process measures. We are interested in the relations between these problems and between their solutions, as well as in characterizing the cases when a solution exists, and finding these solutions. In this work [13] we show that if the quality of prediction is measured by total variation distance, then these problems coincide, while if it is measured by expected average KL-divergence, then they are different. For some of the formalizations we also show that when a solution exists, it can be obtained as a Bayes mixture over a countable subset of $\mathcal{C}$. As an illustration to the
general results obtained, we show that a solution to the non-realizable case of the sequence prediction problem exists for the set of all finite-memory processes, but does not exist for the set of all stationary processes.

6.3.2. Statistical inference

We continue to obtain new results using the theoretical framework developed recently for studying time series generated by stationary ergodic time series. This year, new results obtained include a topological characterizing of composite hypotheses for which consistent tests exist, as well as new results on clustering.

6.3.2.1. A criterion for the existence of consistent tests

The most general result that we have obtained [14] on hypothesis testing provides a complete characterization (necessary and sufficient conditions) for the existence of a consistent test for membership to an arbitrary family $H_0$ of stationary ergodic discrete-valued processes, against $H_1$ which is the complement of $H_0$ to this class of processes. The criterion is that $H_0$ has to be closed in the topology of distributional distance, and closed under taking ergodic decompositions of its elements.

6.3.3. Clustering

6.3.3.1. Online clustering of time series

An asymptotically consistent algorithm has been proposed for the problem of online clustering of time series. There is a growing body of time series samples, each of which grows with time. On each time step, it is required to group these time series into $k$ clusters. It is known that each of the time series is generated by one out of known stationary ergodic distributions. An algorithm is proposed that, for each fixed portion of samples, eventually (with probability 1) puts into the same group those and only those samples that were generated by the same distribution. Empirical performance of the algorithm is evaluated on synthetic and real data.

6.3.3.2. Clustering of ranked data

We introduced [47] a novel approach to clustering rank data on a set of possibly large cardinality $n \in \mathbb{N}^*$, relying upon Fourier representation of functions defined on the symmetric group $\mathfrak{S}_n$. In the proposed setup, covering a wide variety of practical situations, rank data are viewed as distributions on $\mathfrak{S}_n$. Cluster analysis aims at segmenting data into homogeneous subgroups, hopefully very dissimilar in a certain sense. Whereas considering dissimilarity measures/distances between distributions on the non commutative group $\mathfrak{S}_n$, in a coordinate manner by viewing it as embedded in the set $[0, 1]^n$ for instance, hardly yields interpretable results and leads to face obvious computational issues, evaluating the closeness of groups of permutations in the Fourier domain may be much easier in contrast. Indeed, in a wide variety of situations, a few well-chosen Fourier (matrix) coefficients may permit to approximate efficiently two distributions on $\mathfrak{S}_n$ as well as their degree of dissimilarity, while describing global properties in an interpretable fashion. Following in the footsteps of recent advances in automatic feature selection in the context of unsupervised learning, we propose to cast the task of clustering rankings in terms of optimization of a criterion that can be expressed in the Fourier domain in a simple manner.

6.4. Supervised learning


6.4.1. Regression and classification

- Sparse Recovery with Brownian Sensing [19].

We consider the problem of recovering the parameter $\alpha$ of a sparse function $f$ (i.e. the number of non-zero entries of $\alpha$ is small compared to the number $K$ of features) given noisy evaluations of $f$ at a set of well-chosen sampling points. We introduce an additional randomization process, called Brownian sensing, based on the computation of stochastic integrals, which produces a Gaussian sensing matrix, for which good recovery properties are proven, independently on the number of
sampling points $N$, even when the features are arbitrarily non-orthogonal. Under the assumption that $f$ is Hölder continuous with exponent at least $1/2$ we provide an estimate of the parameter with quadratic error $O(||\eta||/N)$, where $\eta$ is the observation noise. The method uses a set of sampling points uniformly distributed along a one-dimensional curve selected according to the features. We report numerical experiments illustrating our method.

- **Operator-valued Kernels for Nonlinear FDA** [31], [38], [30], [53] Following the extension of RKHS to functional setting [74], we further developed this work in [38] for functional supervised classification.

We introduced a set of rigorously defined operator-valued kernels that can be valuably applied to nonparametric operator learning when input and output data are continuous smooth functions, and we have showed their use for solving the problem of minimizing a $L^2$-regularized functional in the case of functional outputs without the need to discretize covariate and target functions [53].

The framework developed can also be applied when the input data are both discrete and continuous [30].

Our fully functional approach has been successfully applied to the problems of speech inversion [31] and sound recognition [38], showing that the proposed framework is particularly relevant for audio signal processing applications where attributes are really functions and dependent of each other.

This work is done in collaboration with Francis Bach (INRIA, Sierra), Alain Rakotomamonjy and Stéphane Canu (LITIS, Rouen).

- **Datum-wise representation** [44], [54]. We consider supervised classification. We introduce the concept of datum-wise representation for supervised classification [44]. While traditional approaches yield a “best” representation at the data space level, that is, the same representation is used for all the data, we proposed the idea, as well as an algorithm, that yields the “best” representation for each data. Among other appealing properties, this leads to sparse representation of each data, and an averaged sparser representation of each data in the data space. Along a classifier, the learning algorithm produces a “representer”, that is a function that yields a representation given a data.

We further improved this approach to encompass various settings which are traditionally kept as different (cost-sensitive classification and different structured sparsity) [54].

- **Iso-regularization descent** [1]. Manuel Loth has defended his PhD dissertation [1] where he has provided a detailed presentation and analysis of his algorithm to solve the LASSO. This algorithm is very efficient. It is an active set algorithm that solves the LASSO by considering it a convex problem with linear constraints.

- **Learning with few examples** [41], [64]. Christophe Salperwyck has studied the performance of various classifiers when few examples are available. This is an important point in incremental learning, and few studies have been devoted to this particular setting. Performance we are accustomed to when the examples are quite numerous are severely disturbed in this setting. For more details, please see [41], [64].

- **Incremental discretization** [40]. In incremental learning, discretization should be adaptive in order to cope with the values of the attributes that are observed. This issue is currently under study by Christophe Salperwyck [40].

### 6.5. Sensors Networks: Tracking, Localization and Communication

**Participants**: Emmanuel Delande, Emmanuel Duflos, Pierre Chainais, Philippe Vanheeghe.
6.5.1. The sensor management problem

The aim of this work is to manage a set of sensors to track vehicles or groups of people in land applications. Our work focuses on sensor management in the frame of the random finite sets where the Probability Hypothesis Density (PHD) is a well-known method for single-sensor multi-target tracking problems in a Bayesian framework, but the extension to the multi-sensor case seems to remain a challenge. We have proposed an extension of Mahler’s work to the multi-sensor case by providing an expression of the true PHD multi-sensor data update equation. Then, based on the configuration of the sensors fields of view (FOVs), a joint partitioning of both the sensors and the state space provides an equivalent yet more practical expression of the data update equation, allowing a more effective implementation in specific FOV configurations ([70]). This work is done in collaboration with Thales Communications. The multi-sensor / multi-target filtering problem by using PHD filtering methods are topics developed in the PhD thesis of Emmanuel Delande. This PhD thesis entitled "Multi-sensor PHD filtering with application to sensor management" will be defended in December 2011. In addition to the different questions described above, see also [22] and [23]. Then, a new approach using operational objectives, related to the type of application, for sensor manager is proposed.

6.5.2. Statistical signal processing: application to civil engineering

We have obtained a PICS (International Project for Scientific Cooperation) from the CNRS in 2008 for 3 years to work in cooperation with the Department of Civil and Environmental Engineering of the University of Waterloo (Canada). During this cooperation we have developed a belief functions based method to track the building materials on a construction site. ([71]). Based on this cooperation, during 2011 a new common research project with the same department of the University of Waterloo has been built, and is actually submitted for funding. The topic of this project is the using of nonparametric Bayesian models in the area of Non-Destructive Testing.

6.5.3. Accurate Localization using Satellites in Urban Canyons

Today, Global Navigation Satellite Systems (GNSS) have penetrated the transport field through applications such as monitoring of containers. These applications do not necessarily request a high availability, integrity and accuracy of the positioning system. For safety applications (as complete guidance of autonomous vehicles), performances require to be more stringent. For, sensors may deliver very erroneous measurements because of such hard external conditions which reduce significantly the possibilities to receive direct signals. The consequences of environmental obstructions are unavailability of the service and reception of reflected signals that degrades in particular the accuracy of the positioning. Indeed, NLOS (Non Line Of Sight) signals, i.e. signals received after reflections on the surrounding obstacles, frequently occur in dense environments and degrade localization accuracy because of the delays observed on the propagation time measurement creating additional error on pseudorange estimation. In the previous years we have proposed new algorithms to improve the localization precision. This algorithm are based on two principles : a jump multimodel approach and a joint state - noise density estimation. We have focused this year on an approach using Dirichlet Process Mixture to track the noise density in urban canyon while estimating the position of the vehicle. Algorithm have been validated on real data collected in a French town : Belfort. Nicolas Viandier has defended his PhD on this subject on June 2011. ([76], [75], [84], [85], [4]). These results will be presented to the Workshop Non Parametric Bayes at the NIPS Conference en Decembre 2011 ([62]) and to the ICASSP 2011 Conference ([37]).

6.5.4. Internet of Things : Mitigation of Impulsive Noise Effects

The term "Internet of Things" has come to describe a number of technologies and research disciplines that enable the Internet to reach out into the real world of physical objects. Technologies like RFID, short-range wireless communications, real-time localization and sensor networks are now becoming increasingly common, bringing the Internet of Things into commercial use. In such applications the data sent by a thing to another may generate an impulse noise in the reception channel of objects in the neighbourhood. The noise appearing in such applications can be considered as \(\alpha\)-stable. In this context, we’ve tackled the problem of interference mitigation in ad hoc networks. In such context, the multiple access interference (MAI) is known to be of an
impulsive nature. Therefore, the conventional Gaussian assumption can not be considered to model this type of interference. Contrariwise, it can be accurately modeled by stable distributions. Here, this issue is addressed within an Orthogonal Frequency Division Multiplexing (OFDM) transmission link assuming a symmetric $\alpha$-stable model for the signal distortion due to MAI. We have proposed a method for the joint estimation of the transmitted multicarrier signal and the noise parameters. Based on sequential Monte Carlo (SMC) methods, the proposed scheme allows the online estimation using a Rao-blackwellized particle filter. These results have been presented to the International Conference on Acoustics, Speech, and Signal Processing (ICASSP 2011) [29]. We are now focusing on bayesian non linear filtering with non stationnary alpha stable measurement noise. We have shown that a Dirichlet Process Mixture can improve the estimation by modelling the noise by both a infinite Cauchy mixture or a infinite alpha stable mixture. These first results will be presented to the Workshop Non Parametric Bayes at the NIPS Conference en Decembre 2011 [62].

6.5.5. Image processing and statistical image modeling

Pierre Chainais arrived in SequeL in September 2010 with the purpose of a thematic evolution toward non parametric Bayesian approaches. This represents an important investment in very new directions on an emerging topic at the interface between machine learning and signal/image processing. Discussions have begun with Emmanuel Duflos and Philippe Vanheeghe on the use of non parametric Bayesian approaches to blind deconvolution of noisy natural images. The main objective is to use together the typical structure and sparsity of space-scale representations of images.

Pierre Chainais has continued working on several older projects. One of them deals with the segmentation of nanotubes in microscopic imaging [12], [43]. B. Lebental at IFFSTAR works on the conception of new nano-sensors based on the use of carbon nanotubes to build a nano-membrane. P. Chainais has developed an image processing pipeline to analyse images of these nanomembranes so as to characterize their properties in a precise and objective manner. Among other properties, the histograms of orientations of the nanotubes is provided. This tool will be very useful since such nanosensors are becoming more and more common.

In solar astronomy [7], [21], we have proposed a tool for the virtual super-resolution of scale invariant textured images. The aim of this project was to provide astronomers with plausible high-resolution images to calibrate next generation spatial telescopes. In particular, our images can be used to optimize the compression algorithm to be embedded in a spatial telescope. In collaboration with M. Chevaldonné and J-M. Favreau (Université Clermont-Ferrand I), we work a software for texture synthesis on 3D surfaces [42] based on multifractal processes. A first version of the software is under current development. More marginal is our work on the use of stochastic processes for the simulation of turbulent pressure fields in collaboration with M. Pachebat (Laboratoire de Mécanique et d’Acoustique de Marseille) and Nicolas Totaro (LVA, INSA Lyon).
5. New Results

5.1. Statistical Physics

The analysis of multi-scale phenomena and asymptotic problems aiming at identifying the influence of microscopic scales on the macroscopic observations is a hot topic in the team. Results have been obtained concerning the derivation of effective law describing the behavior of a particle interacting with a thermal bath or a set of oscillators. This work, which combines modeling efforts, analysis and large computations, is the object of a longstanding collaboration with P. Parris (Missouri-Rolla) and is the heart of the PhD thesis of B. Aguer [37],[1]. More recently, S. De Bièvre and P. Parris have described the approach to equilibrium in such systems [11]. Transport in a related quantum mechanical model was studied in [6]. Some long time effective behavior of related models has been obtained in [58].

At the same time, M. Rousset is working on the numerical simulation of stochastically perturbed Molecular Dynamics. The main goal is to handle in the same simulation the fastest time scales (the oscillations of molecular bindings), and the slowest time scales (the so-called reaction coordinates). Recently, a monograph [60] has been published which summarized standard and state-of-the-art free energy calculations, that are used to accelerate slow variables in MD simulations. In [61] analysis of constrained dynamics is proposed, with associated numerical schemes. In [62], a new method has been proposed which drastically slows down the fast frequencies with a penalty and accelerates simulations, while conserving the statistical behavior of molecular systems.

Recently, in [64] M. Rousset has initiated some new research on variance reduction in hybrid methods, where a “fine-grained” model, typically a kinetic model, is simulated with particle/Monte-Carlo method, and the variance of the latter is reduced using the information of a “coarse-grained” model, a PDE computed with a grid method.

5.2. Hyperbolic Problems, Conservation laws and Gas Dynamics

The convergence analysis of numerical schemes for conservation laws with unstructured meshes with an original proof based on probabilistic argument is a striking result due to F. Lagoutière with F. Delarue, [56]. More generally, we refer to [59] for an overview of F. Lagoutière’s works.

J.-F. Coulombel has studied the stability of finite difference approximations of hyperbolic systems with boundary conditions. This series of works, part of which is a collaboration with A. Gloria, generalizes and simplifies previous results by Gustafsson, Kreiss, Tadmor, Wu and others. In collaboration with O. Guès and M. Williams, J.-F. Coulombel has also studied the justification of geometric optics for hyperbolic boundary value problems. The results describe the reflection of highly oscillating wave trains on a boundary. Eventually, J.-F. Coulombel has studied with S. Benzoni and N. Tzvetkov well-posedness issues for some nonlocal versions of Burgers equation.

5.3. Control in Fluid Mechanics

Results on active and passive control on the 3D Ahmed body in the 25° rear-window configuration were obtained in [4],[5],[21]. Moreover, results on the pressure wave generated by high-speed trains entering tunnels were published in [20].

5.4. Fluid/Particles Flows

We are interested in two-phase flows involving a dense and a disperse phase. These models lead to interesting mathematical questions, [38]. We develop new asymptotic preserving methods for fluid/particles flows [50]. This approach follows the scheme we developed for radiative transfer equations [51].
5.5. Plasma Physics

We obtained several results of asymptotic analysis concerning either kinetic or macroscopic models for charge transport, see [45], [44] and [52] (and we also refer to the related work [53]). Through the collaboration with Thales we proposed in [3] a method to compute numerically the boundary conditions for the Euler system derived from the BGK equation in the hydrodynamic limit. In particular this method is based on an analysis of boundary layers. In [7] we extend these techniques to the coupled Euler Poisson system.

5.6. Analysis and numerical simulation of the Schrödinger equation

The linear or nonlinear Schrödinger equation with potential is one of the basic equations of quantum mechanics and it arises in many areas of physical and technological interest, e.g. in quantum semiconductors, in electromagnetic wave propagation, and in seismic migration. The Schrödinger equation is the lowest order one-way approximation (paraxial wave equation) to the Helmholtz equation and is called Fresnel equation in optics, or standard parabolic equation in underwater acoustics. The solution of the equation is defined on an unbounded domain. If one wants to solve such a whole space evolution problem numerically, one has to restrict the computational domain by introducing artificial boundary conditions. So, the objective is to approximate the exact solution of the whole-space problem, restricted to a finite computational domain. A review article [39] was written this year to describe and compare the different current approaches of constructing and discretizing the transparent boundary conditions in one and two dimensions. However, these approaches are limited to the linear case (or nonlinear with the classical cubic nonlinearity: an article written was dedicated to this case this year [41]) and constant potentials. Therefore, in collaboration with X. Antoine (IECN Nancy and Inria Lorraine), we proposed to P. Klein to study, in her PhD thesis, the case of the Schrödinger equation with variable potentials. The study of the non-stationary one-dimensional case has already led to one publication [40] and some preliminary results in the stationary case are really promising. These cases are relevant since for example the equations appear in the Bose Einstein condensate with a quadratic potential.

This problem is obviously not limited to the Schrödinger equation and new developments are in progress on the Korteweg de Vries equation with M. Ehrhardt. This equation is more difficult to study due to its third order derivative in space.

Dispersive equations, such as the Schrödinger equation are also considered as boundary-value problems. For example, in [57], G.D. studies the long time asymptotics of the solutions of linear Schrodinger equations considered as initial-boundary value problems on the half-line and on bounded intervals when the boundary data are periodic functions of time. G.D. obtains theoretical results using a transformation method introduced by T. Fokas and provides several numerical experiments to support them.

The Diffusion Monte-Carlo method is a powerful strategy used by chemists to estimate the groundstate energy of a N-body Schrödinger Hamiltonian with high accuracy. However, the method suffers from two major limitations:

- The quantity of physical interest is more the energy variation with respect to a parameter than the energy itself.
- The case of Fermions (as electrons of atoms) relies on constraining the random walkers in some nodal pocket (which imposes skew-symmetry on the distribution of walkers) which is only approximately known (the Fixed Node Approximation).

In the article [63], Mathias Rousset proposed a new strategy for the case of Fermions to compute the energy variation with respect to a variation of the nodal pocket. The ultimate goal is to design a Monte-Carlo strategy able to optimize the Fixed Node Approximation.

5.7. Homogenization

We have three types of results regarding the homogenization theory and its applications.
The first series of results is related to nonlinear elasticity. In [2], A. Gloria has proved the convergence of a discrete model for rubber towards a nonlinear elasticity theory in collaboration with R. Alicandro and M. Cicalese. The numerical simulation of the model has been addressed within the ARC Disco by A. Gloria, P. La Tallec and M. Vidrascu (project team MACS). Comparisons with mechanical experiments are promising, and related inverse problems have been addressed in the post-doc of M. de Buhan. Two publications are in preparation. Related theoretical results in homogenization of nonlinear elasticity models have been obtained by A. Gloria and S. Neukamm (MPI Leipzig) in [15].

A second type of results concerns a quantitative theory of stochastic homogenization of discrete linear elliptic equations. A breakthrough has been obtained by A. Gloria and F. Otto (MPI Leipzig) in [16] and [17], who gave the first optimal variance estimate of the energy density of the corrector field for stochastic discrete elliptic equations. The proof makes extensive use of a spectral gap estimate and of deep elliptic regularity theory, bringing in fact the probabilistic arguments to a minimum. This analysis has enabled A. Gloria to propose efficient numerical homogenization methods, both in the discrete and continuous settings [13], [12]. In [14], A. Gloria and J. C. Mourrat has pushed the approach forward and introduced new approximation formulas for the homogenized coefficient. In [26] they have considered a more probabilistic approach and given a complete error analysis of a Monte-Carlo approximation of the homogenized coefficients in the discrete case. Work in progress concerns the generalization of the results on discrete elliptic equations to the continuous case.

The third direction of research concerns the periodic homogenization of a coupled elliptic/parabolic system arising in the modeling of nuclear waste storage. This work is in collaboration with the French agency ANDRA. A. Gloria, T. Goudon, and S. Krell have made a complete theoretical analysis of the problem, derived effective equations, and devised an efficient method to solve the effective problem numerically, based on the reduced basis approach. A publication is in preparation. This subject will be continued with the arrival of Z. Habibi.

5.8. Radiative Transfert

The interest of the team in developing efficient numerical methods preserving the asymptotic behavior of kinetic equations modelling the radiative transfer phenomena in the diffusive regime has recently brought two new innovative schemes. On the one hand, the moment closure equations proposed in [43] involve non local terms that lead to the introduction of specific numerical approximations. On the other hand, a new scheme [19] based on the projective integration procedure due to Gear and Kevrekidis was proved very efficient theoretically and numerically.

The team has also obtained a rigorous justification of the formation of so-called Zeldovich spikes in radiative shock profiles [32]. As long as the amplitude of the wave is sufficiently large, the temperature profile displays an overshoot. Such phenomenon does not occur for small amplitude waves, nor for viscous shock profiles.

5.9. Complex fluid flows

A numerical treatment [18] of phase transitions arising in the modelling of the behavior of polymers near glass transition by a non linear diffusion equation was conducted in the continuation of the theoretical results by Evans and Portilheiro and Mascia, Terracina and Tesei.

5.10. A posteriori error estimators for finite element methods

First, the generalization of [55] in the case of the full convection-reaction-diffusion case lead to robust estimators, for which the dependance of the constant in the data are explicitly given [8]. Then, we succeeded in obtaining some “asymptotic exact estimators” for the Reissner-Mindlin system in order to provide an accurate bound of the error, while keeping a reasonable computational cost [10], [24]. Finally, we obtained some residual-based a posteriori error estimators for the Maxwell system in its vectorial and scalar potential formulation [9], [23].