Activity Report 2017

Team CARTE

Theoretical adverse computations, and safety

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

RESEARCH CENTER
Nancy - Grand Est

THEME
Security and Confidentiality

Table of contents

Team CARTE

Creation of the Project-Team: 2009 January 01, updated into Team: 2016 January 01, end of the Team: 2017 December 31

Keywords:

Computer Science and Digital Science:

A1.1.11. - Quantum architectures
A2.4.1. - Analysis
A4.5. - Formal methods for security
A7.2. - Logic in Computer Science
A8.6. - Information theory
A8.7. - Graph theory

Other Research Topics and Application Domains:

B9.4.1. - Computer science
B9.4.2. - Mathematics

1. Personnel

Research Scientists

Frédéric Dupuis [CNRS, Researcher, from Oct. 2017]
Nazim Fatès [Inria, Researcher]
Isabelle Gnaedig [Inria, Researcher]
Mathieu Hoyrup [Inria, Researcher]
Simon Perdrix [CNRS, Researcher]

Faculty Members

Emmanuel Jeandel [Team leader, Univ. de Lorraine, Professor, HDR]
Emmanuel Hainry [Univ. de Lorraine, Associate Professor]
Irène Marcovici [Univ. de Lorraine, Associate Professor (délégation Inria), from Sep 2017]
Romain Péchoux [Univ. de Lorraine, Associate Professor]

PhD Students

Pierre Mercuriali [Univ. de Lorraine]
Renaud Vilmart [Univ. de Lorraine]

Interns

Jordina Francès de Mas [Univ. de Lorraine, from Mar 2017 until Jul 2017]
Quentin Ladeveze [Univ. de Lorraine, from Apr 2017 until Jun 2017]
Denis Rochette [Univ. de Lorraine, from May 2017 until Jul 2017]
David Ahmad Zonneveld Michel [Univ. de Lorraine, from Mar 2017 until Jul 2017]

Administrative Assistants

Sophie Drouot [Inria]
Delphine Hubert [Univ. de Lorraine]
Martine Kuhlmann [CNRS]
Christelle Leveque [Univ. de Lorraine]

Visiting Scientist

Ross Duncan [University of Strathclyde, Glasgow, Jun. 2017]

2. Overall Objectives

2.1. Overall Objectives

The aim of the CARTE research team is to take into account adversity in computations, which is implied by actors whose behaviors are unknown or unclear. We call this notion adversary computation.

The project combines two approaches. The first one is the analysis of the behavior of systems, using tools coming from Continuous Computation Theory. The second approach is to build defenses with tools coming from logic, rewriting and, more generally, from Programming Theory.

The research activities of the CARTE team are now focused on the theme of Computation over Continuous Structures.

3. Research Program

3.1. Computer Virology

Historically, computer virology was one of the two main research directions of the team. This axis of research is no longer included the priorities of team as the members who were working on this topic have founded their own team.

3.2. Computation over continuous structures

Classical recursion theory deals with computability over discrete structures (natural numbers, finite symbolic words). There is a growing community of researchers working on the extension of this theory to continuous structures arising in mathematics. One goal is to give foundations of numerical analysis, by studying the limitations of machines in terms of computability or complexity, when computing with real numbers. Classical questions are : if a function $f:\mathbb{R}\to\mathbb{R}$ is computable in some sense, are its roots computable? in which time? Another goal is to investigate the possibility of designing new computation paradigms, transcending the usual discrete-time, discrete-space computer model initiated by the Turing machine that is at the base of modern computers.

While the notion of a computable function over discrete data is captured by the model of Turing machines, the situation is more delicate when the data are continuous, and several non-equivalent models exist. In this case, let us mention computable analysis, which relates computability to topology [53], [79]; the Blum-Shub-Smale model (BSS), where the real numbers are treated as elementary entities [45]; the General Purpose Analog Computer (GPAC) introduced by Shannon [75]with continuous time.

3.3. Rewriting

The rewriting paradigm is widely used for specifying, modeling, programming and proving. It allows one to easily express deduction systems in a declarative way, and to express complex relations on infinite sets of states in a finite way, provided they are countable. Programming languages and environments with a rewriting based semantics have been developed ; see ASF+SDF [46], MAUDE [49], and TOM [71].

For basic rewriting, many techniques have been developed to prove properties of rewrite systems like confluence, completeness, consistency or various notions of termination. Proof methods have also been proposed for extensions of rewriting such as equational extensions, consisting of rewriting modulo a set of axioms, conditional extensions where rules are applied under certain conditions only, typed extensions, where rules are applied only if there is a type correspondence between the rule and the term to be rewritten, and constrained extensions, where rules are enriched by formulas to be satisfied [40], [52], [76].

An interesting aspect of the rewriting paradigm is that it allows automatable or semi-automatable correctness proofs for systems or programs: the properties of rewriting systems as those cited above are translatable to the deduction systems or programs they formalize and the proof techniques may directly apply to them.

Another interesting aspect is that it allows characteristics or properties of the modeled systems to be expressed as equational theorems, often automatically provable using the rewriting mechanism itself or induction techniques based on completion [50]. Note that the rewriting and the completion mechanisms also enable transformation and simplification of formal systems or programs.

Applications of rewriting-based proofs to computer security are various. Approaches using rule-based specifications have recently been proposed for detection of computer viruses [77], [78]. For several years, in our team, we have also been working in this direction. We already proposed an approach using rewriting techniques to abstract program behaviors for detecting suspicious or malicious programs [41], [42].

4. Application Domains

4.1. Continuous computation theories

Understanding computation theories for continuous systems leads to studying hardness of verification and control of these systems. This has been used to discuss problems in fields as diverse as verification (see e.g., [39]), control theory (see e.g., [47]), neural networks (see e.g., [72]), and so on. We are interested in the formal decidability of properties of dynamical systems, such as reachability [63], the Skolem-Pisot problem [44], the computability of the ω-limit set [62]. Those problems are analogous to verification of safety properties.

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

In contrast with the discrete setting, it is of utmost importance to compare the various models of computation over the reals, as well as their associated complexity theories. In particular, we focus on the General Purpose Analog Computer of Claude Shannon [75], on recursive analysis [79], on the algebraic approach [70] and on Markov computability [64]. A crucial point for future investigations is to fill the gap between continuous and discrete computational models. This is one deep motivation of our work on computation theories for continuous systems.

4.2. Analysis and verification of adversary systems

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

We are also interested in rewriting techniques, used to describe dynamic systems, in particular in the adversary context. As they were initially developed in the context of automated deduction, the rewriting proof techniques, although now numerous, are not yet adapted to the complex framework of modelling and programming. An important stake in the domain is then to enrich them to provide realistic validation tools, both in providing finer rewriting formalisms and their associated proof techniques, and in developing new validation concepts in the adversary case, i.e., when usual properties of the systems like, for example, termination are not verified. For several years, we have been developing specific procedures for property proofs of rewriting, for the sake of programming, in particular with an inductive technique, already applied with success to termination under strategies [54], [55], [56], to weak termination [57], sufficient completeness [58] and probabilistic termination [60]. The last three results take place in the context of adversary computations, since they allow for proving that even a divergent program, in the sense where it does not terminate, can give the expected results. A common mechanism has been extracted from the above works, providing a generic inductive proof framework for properties of reduction relations, which can be parametrized by the property to be proved [59], [61]. Provided program code can be translated into rule-based specifications, this approach can be applied to correctness proofs of software in a larger context. A crucial element of safety and security of software systems is the problem of resources. We are working in the field of Implicit Computational Complexity. Interpretation based methods like Quasi-interpretations (QI) or sup-interpretations, are the approach we have been developing these last years [66], [67], [68]. Implicit complexity is an approach to the analysis of the resources that are used by a program. Its tools come essentially from proof theory. The aim is to compile a program while certifying its complexity.

5. Highlights of the Year

5.1. Highlights of the Year

We worked on the computable aspects of an elementary problem in real analysis: extending a continuous function on a larger domain. More precisely, if a real-valued function f is defined on an interval $[0, a)$ (with $0 < a < 1$) and is computable there, under which conditions can it be extended to a computable function on $[0, 1]$? Our results show how the answer depends on a and on the way f converges at a. This provides new characterizations of already existing classes of real numbers previously defined in computability theory. Our work was presented at LICS 2017 [19].

6. New Software and Platforms

6.1. Software

6.1.1. FiatLux

FiatLux is a simulation program for cellular automata developed by Nazim Fatès. The project is currently available at the Inria GForge. It is under the CeCILL license.

7. New Results

7.1. Quantum Computing

Participants: Emmanuel Jeandel, Simon Perdrix, Renaud Vilmart.

- **ZX-calculus**

The ZX-Calculus is a powerful graphical language for quantum mechanics and quantum information processing. The completeness of the language – i.e. the ability to derive any true equation – is a crucial question. In the quest for a complete ZX-calculus, supplementarity has been recently proved to be necessary for quantum diagram reasoning [73]. Roughly speaking, supplementarity consists in merging two subdiagrams when they are parameterized by antipodal angles. In [22], we introduce a generalised supplementarity – called cyclotomic supplementarity – which consists in merging n subdiagrams at once, when the n angles divide the circle into equal parts. We show that when n is an odd prime number, the cyclotomic supplementarity cannot be derived, leading to a countable family of new axioms for diagrammatic quantum reasoning. We exhibit another new simple axiom that cannot be derived from the existing rules of the ZX-Calculus, implying in particular the incompleteness of the language for the so-called Clifford+T quantum mechanics. We end up with a new axiomatisation of an extended ZX-Calculus, including an axiom schema for the cyclotomic supplementarity. This work has been presented at MFCS 2017 [22].

The ZX-Calculus is devoted to represent complex quantum evolutions. But the advantages of quantum computing still exist when working with rebits, and evolutions with real coefficients. Some models explicitly use rebits, but the ZX-Calculus cannot handle these evolutions as it is. Hence, in [21], we define an alternative language solely dealing with real matrices, with a new set of rules. We show that three of its non-trivial rules are not derivable from the other ones and we prove that the language is complete for the $\pi/2$-fragment. We define a generalisation of the Hadamard node, and exhibit two interpretations from and to the ZX-Calculus, showing the consistency between the two languages. This work has been presented at QPL 2017 [21].

- **Causality and Quantum Computing**

  Since the classic no-go theorems by [43] and [65], contextuality has gained great importance in the development of quantum information and computation. This key characteristic feature of quantum mechanics represents one of the most valuable resources at our disposal to break through the limits of classical computation and information processing, with various concrete application

  An important class of contextuality arguments in quantum foundations are the All-versus-Nothing (AvN) proofs, generalising a construction originally due to Mermin. In [11], we present a general formulation of All-versus-Nothing arguments, and a complete characterisation of all such arguments which arise from stabiliser states. We show that every AvN argument for an n-qubit stabiliser state can be reduced to an AvN proof for a three-qubit state which is local Clifford-equivalent to the tripartite GHZ state. This is achieved through a combinatorial characterisation of AvN arguments, the AvN triple Theorem, whose proof makes use of the theory of graph states. This result enables the development of a computational method to generate all the AvN arguments in Z2 on n-qubit stabiliser states. We also present new insights into the stabiliser formalism and its connections with logic. This work has been presented at QPL 2017 [25] and published in the Philosophical Transactions of the Royal Society A [11].

  Analyzing pseudo-telepathy graph games, we propose in [15] a way to build contextuality scenarios exhibiting the quantum supremacy using graph states. We consider the combinatorial structures generating equivalent scenarios. We investigate which scenarios are more multipartite and show that there exist graphs generating scenarios with a linear multipartiteness width. This work has been presented at FCT 2017 [15].

- **Measurement-based Quantum Computing**

  Measurement-based quantum computing (MBQC) is a universal model for quantum computation [74]. The combinatorial characterisation of determinism in this model [51], [48], [69], powered by measurements, and hence, fundamentally probabilistic, is the cornerstone of most of the breakthrough results in this field. The most general known sufficient condition for a deterministic MBQC to be driven is that the underlying graph of the computation has a particular kind of flow called Pauli flow. The necessity of the Pauli flow was an open question [48]. In [23], we show that the Pauli flow is necessary for real-MBQC, and not in general providing counterexamples for (complex) MBQC. We explore the consequences of this result for real MBQC and its applications. Real MBQC and more generally real quantum computing is known to be universal for quantum computing. Real MBQC has been used for interactive proofs by McKague. The two-prover case corresponds to real-MBQC on bipartite graphs. While (complex) MBQC on bipartite graphs are universal, the universality of real MBQC on bipartite graphs was an open question. We show that real bipartite MBQC is not universal proving that all measurements of real bipartite MBQC can be parallelised leading to constant depth computations. As a consequence, McKague techniques cannot lead to two-prover interactive proofs. This work has been presented at FCT 2017 [23].

7.2. Cellular automata as a model of computation

Participants: Nazim Fatès, Irène Marcovici.

The reversibility of classical cellular automata (CA) was examined for the case where the updates of the system are random. In this context, with B. Sethi and S. Das (India), we studied a particular form of reversibility: the possibility of returning infinitely often to the initial condition after a random number of time step,s this is the recurrence property of the system. We analysed this property for the simple rules and described the communication graph of the system [33].

We studied how to coordinate a team of agents to locate a hidden source on a two-dimensional discrete grid. The challenge is to find the position of the source with only sporadic detections. This problem arises in various situations, for instance when insects emit pheromones to attract their partners. A search mechanism named infotaxis was proposed to explain how agents may progressively approach the source by using only intermittent detections. With Q. Ladeveze, an intern, we re-examined in detail the properties of our bio-inspired algorithm that relies on the Reaction–Diffusion–Chemotaxis aggregation scheme to group agents that have limited abilities [38].

To study the robustness of asynchronous CA, we examined the coalescence phenomenon, which consists in observing the cases where two different initial conditions with the same sequence of updates quickly evolve to the same non-trivial configuration. With J. Francès de Mas, an intern, we studied the rules which always coalesce and those which exhibit a phase transition between a coalescing and non-coalescing behaviour. We proposed some formal explanations of non-trivial rapid coalescence giving lower bounds for the coalescence time of ECA 154 and ECA 62, and some first steps towards finding their upper bounds in order to prove that they have, respectively, quadratic and linear coalescence time [34].

We studied random mixtures of two deterministic Elementary Cellular Automata. There are 8088 such rules, called, diploid cellular automata. We used numerical simulations to perform some steps in the exploration of this space. As the mathematical analysis of such systems is a difficult task, we used numerical simulations to get insights into the dynamics of this class of stochastic cellular automata. We examined phase transitions and various types of symmetry breaking [17].

7.3. Extension of computable functions

Participant: Mathieu Hoyrup.

We worked on the computable aspects of an elementary problem in real analysis: extending a continuous function on a larger domain. More precisely, if a real-valued function f is defined on an interval $[0, a)$ (with $0 < a < 1$) and is computable there, under which conditions can it be extended to a computable function on $[0, 1]$? Although this question has a very simple formulation, it does not have a simple answer. We obtained many results showing how the answer depends on a and on the way f converges at a. Surprisingly, this problem provides new characterizations of already existing classes of real numbers previously defined in computability theory. This work is joint with Walid Gomaa and has been presented at LICS 2017 [19].

7.4. Genericity of weakly computable objects

Participant: Mathieu Hoyrup.

Computability theory abounds with classes of objects, defined for instance in terms of the computability content of the objects. A natural problem is then to compare these classes and separate them when possible. In order to separate two classes, one has to build an object that belongs to one class but not the other. So this object has to be computable in one sense but not the other. We show that in many cases these computability properties have a topological interpretation, and that the object to build must be at the same time computable in some weak topology (*weakly computable*) but *generic* in a stronger topology. We prove a general theorem stating the existence of such objects, thus providing a very handy tool to separate many classes. We use it in the study of the extension of computable functions (previous result) and in other situations. These results are presented in [13].

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Grants with Industry

- PRCE ANR SoftQPro has Atos-Bull as a partner.
- ITEA 3 Quantex involves several industrial partners: Siemens, KPN, Atos-Bull.

9. Partnerships and Cooperations

9.1. National Initiatives

9.1.1. ANR

- Simon Perdrix is PI of the PRCE ANR SoftQPro "Solutions logicielles pour l'optimisation des programmes et ressources quantiques". (2017- 2021) [Atos-Bull, LORIA, CEA, LRI].
- The team is partner of the ANR VanQuTe "Validation des technologies quantiques émergentes" (PRCI with Singapore) [LIP6, LORIA, SUTD, NUS, NTU] (2018-2022)
- The team is a partner in ANR Elica (2014-2019), "Elargir les idées logistiques pour l'analyse de complexité". The CARTE team is well known for its expertise in implicit computational complexity.

9.2. European Initiatives

9.2.1. FP7 & H2020 Projects

Mathieu Hoyrup participates in the Marie-Curie RISE project Computing with Infinite Data coordinated by Dieter Spreen (Univ. Siegen) that has started in April 2017. We organized a workshop CCC'17 in Nancy in June 2017, that was also the first meeting of the project.

9.2.2. Collaborations in European Programs, Except FP7 & H2020

The team is partner of the ITEA3 Quantex project [LORIA, LRI, CEA/Leti, Atos-Bull, Siemens, TUDelft, KPN, EKUT] (2018-2020)

9.3. International Initiatives

Simon Perdrix is member of the STIC AmSud FoQCOSS with Argentina. He visited Quilmes University during 2 weeks in July 2017.

9.4. International Research Visitors

9.4.1. Visits of International Scientists

Ross Duncan (Assistant Prof. at Strathclyde U., Glasgow), spent one month (June 2017) in our team as an invited professor at Université de Lorraine.

9.4.2. Internships

Jordina Francès de Mas, Quentin Ladeveze were interns in our team ; they worked on cellular automata and produced two technical reports (see [34] and [38]).

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events Organisation

10.1.1.1. General Chair, Scientific Chair

- Mathieu Hoyrup is member of the Steering Committee of the Conference Series *Computability in Europe* (CiE) for the period 2017-2021.

10.1.1.2. Member of the Organizing Committees

- Mathieu Hoyrup organized the workshop Continuity, Computability, Constructivity - From Logic to Algorithms (CCC) 2017, Nancy, June 2017.

10.1.2. Scientific Events Selection

10.1.2.1. Member of the Conference Program Committees

- Mathieu Hoyrup was co-chair of the workshop Continuity, Computability, Constructivity - From Logic to Algorithms (CCC) 2017, Nancy, June 2017.
- Emmanuel Jeandel was PC member of STACS 2017 (https://stacs2017.thi.uni-hannover.de/) and CIE 2017 (http://math.utu.fi/cie2017/).
- Romain Péchoux is PC member of the ETAPS affiliated workshop DICE 2018 (http://cl-informatik.uibk.ac.at/users/zini/events/dice18/).
- Simon Perdrix was PC member of QPL'17 (14th International Conference on Quantum Physics and Logic, 2017, Nijmegen, the Netherlands) ; IQFA'17 (Quantum Information: Foundations and Applications, 8th IQFA's Colloquium, 2017, Nice, France). He is PC member of the forthcoming MCU'18 (8th Conference on Machines, Computations and Universality) and DCM'18 (12th International Workshop on Developments in Computational Models, FLoC 2018, Oxford, UK).
- Nazim Fatès was a member of the PC of AUTOMATA 2017.

10.1.2.2. Reviewer

- Mathieu Hoyrup reviewed articles for CiE and LICS.
- Romain Péchoux reviewed articles for ISMVL and STACS.
- Simon Perdrix reviewed articles for LICS.

10.1.3. Journal

10.1.3.1. Member of the Editorial Boards

- Emmanuel Jeandel is member of the editorial board of RAIRO-ITA.
- Simon Perdrix is co-editor of the ERCIM issue on Quantum Computing.

10.1.3.2. Reviewer - Reviewing Activities

- Mathieu Hoyrup reviewed articles for Foundations of Computational Mathematics, Theory of Computing Systems, Mathematical Reviews.
- Romain Péchoux reviewed articles for Journal of Automated Reasoning and AMS Mathematical Reviews.
- Nazim Fatès served as a reviewer for *Natural computing* and *Theoretical computer science*.

10.1.4. Invited Talks

- Emmanuel Jeandel gave a course on Computability in Symbolic Dynamics on the Pingree Park Dynamics Workshop, http://web.cs.du.edu/~rpavlov/Pingree2017
- Emmanuel Jeandel gave a course on the Undecidability of the Domino Problem in the Winter School “Tiling Dynamical System” in Marseille, http://akiyama-arnoux.weebly.com/school.html
- Emmanuel Jeandel gave an invited talk on Higman-like theorems in symbolic dynamics at Logic Colloquium 2017, http://www.math-stockholm.se/konferenser-och-akti/logic-in-stockholm-2/logic-colloquium-201
- Romain Péchoux gave an invited talk on Higher order interpretations for higher order programs, cs department, Trinity College, Dublin.
- Simon Perdrix gave an invited talk on Measurement-based quantum computation at QPL’17 (14th International Conference on Quantum Physics and Logic, 2017).
- Simon Perdrix gave an invited talk on quantum algorithms at the event "l’Ordinateur Quantique" organised at IHP by the Fondation Sciences Mathématiques de Paris.

10.1.5. Leadership within the Scientific Community

Nazim Fatès is the vice-chair of the IFIP international working group 1.5 on Cellular automata and discrete dynamical systems.

Simon Perdrix is

- head of the GT IQ (groupe de Travail Informatique Quantique) @ GdR IM.
- board of GdR IQFA (Ingénierie Quantique, des aspects Fondamentaux aux Applications).

10.1.6. Scientific Expertise

Nazim Fatès was a project reviewer for the CONYCIT, the Chilean state agency for scientific research.

10.1.7. Research Administration

- Emmanuel Jeandel is the leader of the CARTE team.
- Isabelle Gnaedig is:
  - vice-leader of the CARTE team,
  - member of the scientific mediation committee at Inria Nancy Grand-Est.
- Emmanuel Hainry is:
  - member of the CNU (Conseil National des Universités), Section 27.
  - organizer of the CARTE Seminar.
- Simon Perdrix is Scientific Secretary at CoNRS Section 6.

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Licence :

- Isabelle Gnaedig:
  - To the limits of the computable, 6 hours, Opening course-conference of the collegium "Lorraine INP", Nancy, France
- Emmanuel Hainry:
  - Systèmes d’exploitation, 30h, L1, IUT Nancy Brabois, Université de Lorraine, France
  - Algorithmique, 40h, L1, IUT Nancy Brabois, Université de Lorraine, France

  - Web dynamique, 60h, L1, IUT Nancy Brabois, Université de Lorraine, France
  - Bases de données, 30h, L1, IUT Nancy Brabois, Université de Lorraine, France
  - Programmation objet, 12h, L2, IUT Nancy Brabois, Université de Lorraine, France
  - Complexité, 30h, L2, IUT Nancy Brabois, Université de Lorraine, France
- Mathieu Hoyrup:
  - Bases de la Programmation Orientée Objet, 20 HETD, L2, Université de Lorraine, France
  - Interfaces Graphiques, 10 HETD, L2, Université de Lorraine, France
- Emmanuel Jeandel:
  - Algorithmics and Programming 1, 60h, L1 Maths-Info
  - Algorithmics and Programming 4, 30h, L3 Informatique
  - Modelling Using Graph Theory, 30h, L3 Informatique
  - Networking, 15h, L2 Informatique
  - Formal Languages, 30h, L3 Informatique
- Romain Péchoux:
  - Programmation orientée objet, 61,5h, L3 MIASHS
  - Programmation orientée objet, 53,5h, L2 MIASHS
  - Outils logiques pour l'informatique, 35h, L1 MIASHS
  - Bases de données, 40h, L3 Sciences de la Gestion

Master:

- Isabelle Gnaedig:
  - Design of Safe Software, Coordination of the module, M2, Telecom-Nancy (Université de Lorraine), Nancy, France,
  - Rule-based Programming, 20 hours, M2, Telecom-Nancy (Université de Lorraine), Nancy, France.
- Emmanuel Jeandel:
  - Algorithmics and Complexity, 30h, M1 Informatique
- Romain Péchoux:
  - Mathematics for computer science, 30h, M1 SCA
  - Implicit Complexity, 15h, M2 Informatique
- Simon Perdrix:
  - Pépites Algorithmiques, 6h, M1/M2 at Ecole des Mines de Nancy.
- Nazim Fatès:
  - Systèmes complexes adapatatifs, M2, 10h, Informatique (UL)
  - Agents intelligents et collectifs M1, 15h, Sciences cognitives (UL)

10.2.2. Supervision

- Emmanuel Jeandel and Simon Perdrix supervised the Master Thesis of David Zonneveld on quantum circuits.
- Nazim Fatès and Irène Marcovici supervised the Erasmus Mundus master's thesis of Jordina Francès de Mas [34].
- Emmanuel Jeandel and Simon Perdrix are advisors of Renaud Vilmart, PhD student (UL) since October 2016.

- Romain Péchoux is coadvisor of Pierre Mercuriali, PhD student, Université de Lorraine (50%, advisor: Miguel Couceiro, PR, Université de Lorraine).

10.2.3. Juries

- Emmanuel Jeandel reviewed the PhD thesis of Guilhem Gamard (Université Paul-Valery-Montpellier) and participated in the PhD defense of Laurent Grémy (Université de Lorraine), David Cattanéo (Université de Grenoble) and Sebastian Barbieri (ENS Lyon)
- Simon Perdrix participated in the PhD defense of Ruben Cohen (U. Paris Sud).

10.3. Popularization

- Nazim Fatès contributed to a booklet on the theme "Mathématiques et langages" edited by the Commission française pour l'enseignement des mathématiques (CFEM) for the forum "Mathématiques vivantes" (see http://forum-maths-vivantes.fr/-Panorama).
- This text appeared in a revised version on the CNRS website "images des mathématiques" [27].
- Nazim Fatès participated to a meeting ("projection-debat") at the Réseau et transport de l'électricité (RTE) at Villers-lès-Nancy on the these "Visages de la robotique", organised by "Sciences en lumière" (formerly Festival du film de chercheur).
- Nazim Fatès participated to a workshop on ethics in the "Forum des Sciences cognitives" organised by the "UFR mathématiques et informatique".
- Simon Perdrix gave an invited talk on quantum algorithms at the event "Mathématiques en mouvement sur l'Ordinateur quantique" organised by the Fondation Sciences Mathématiques de Paris at IHP.

11. Bibliography

Major publications by the team in recent years

[1] O. Bournez, D. Graça, E. Hainry. *Computation with perturbed dynamical systems*, in "Journal of Computer and System Sciences", August 2013, vol. 79, n^{o} 5, pp. 714-724 [*DOI :* 10.1016/j.jcss.2013.01.025], http://hal.inria.fr/hal-00861041

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