Activity Report 2017

Team POLARIS

Performance analysis and optimization of LARge Infrastructures and Systems

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
Grenoble - Rhône-Alpes

THEME
Distributed and High Performance Computing

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Team POLARIS

Creation of the Team: 2016 January 01, updated into Project-Team: 2018 January 01

Keywords:

Computer Science and Digital Science:

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A1.1.4. - High performance computing
A1.1.5. - Exascale
A1.2. - Networks
A1.2.3. - Routing
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Other Research Topics and Application Domains:

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B9.5.7. - Geography
B9.6. - Reproducibility
B9.7.2. - Open data

1. Personnel

Research Scientists

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Panayotis Mertikopoulos [CNRS, Researcher]

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Stephan Plassart [Univ Grenoble Alpes]
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Annie Simon [Inria, Assistant]

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Vania Martin [Univ Grenoble Alpes]

2. Overall Objectives

2.1. Context

Large distributed infrastructures are rampant in our society. Numerical simulations form the basis of computational sciences and high performance computing infrastructures have become scientific instruments with similar roles as those of test tubes or telescopes. Cloud infrastructures are used by companies in such an intense way that even the shortest outage quickly incurs the loss of several millions of dollars. But every citizen also relies on (and interacts with) such infrastructures via complex wireless mobile embedded devices whose nature is constantly evolving. In this way, the advent of digital miniaturization and interconnection has enabled our homes, power stations, cars and bikes to evolve into smart grids and smart transportation systems that should be optimized to fulfill societal expectations.

Our dependence and intense usage of such gigantic systems obviously leads to very high expectations in terms of performance. Indeed, we strive for low-cost and energy-efficient systems that seamlessly adapt to changing environments that can only be accessed through uncertain measurements. Such digital systems also have to take into account both the users' profile and expectations to efficiently and fairly share resources in an online way. Analyzing, designing and provisioning such systems has thus become a real challenge.

Such systems are characterized by their **ever-growing size**, intrinsic **heterogeneity** and **distributedness**, **user-driven** requirements, and an unpredictable variability that renders them essentially **stochastic**. In such contexts, many of the former design and analysis hypotheses (homogeneity, limited hierarchy, omniscient view, optimization carried out by a single entity, open-loop optimization, user outside of the picture) have become obsolete, which calls for radically new approaches. Properly studying such systems requires a drastic rethinking of fundamental aspects regarding the system's **observation** (measure, trace, methodology, design of experiments), **analysis** (modeling, simulation, trace analysis and visualization), and **optimization** (distributed, online, stochastic).

2.2. Objectives

The goal of the POLARIS project is to **contribute to the understanding of the performance of very large scale distributed systems** by applying ideas from diverse research fields and application domains. We believe that studying all these different aspects at once without restricting to specific systems is the key to push forward our understanding of such challenges and to proposing innovative solutions. This is why we intend to investigate problems arising from application domains as varied as large computing systems, wireless networks, smart grids and transportation systems.

The members of the POLARIS project cover a very wide spectrum of expertise in performance evaluation and models, distributed optimization, and analysis of HPC middleware. Specifically, POLARIS' members have worked extensively on:

Experiment design: Experimental methodology, measuring/monitoring/tracing tools, experiment control, design of experiments, and reproducible research, especially in the context of large computing infrastructures (such as computing grids, HPC, volunteer computing and embedded systems).

Trace Analysis: Parallel application visualization (paje, triva/viva, framesoc/ocelotl, ...), characterization of failures in large distributed systems, visualization and analysis for geographical information systems, spatio-temporal analysis of media events in RSS flows from newspapers, and others.

Modeling and Simulation: Emulation, discrete event simulation, perfect sampling, Markov chains, Monte Carlo methods, and others.

Optimization: Stochastic approximation, mean field limits, game theory, discrete and continuous optimization, learning and information theory.

In the rest of this document, we describe in detail our new results in the above areas.

3. Research Program

3.1. Sound and Reproducible Experimental Methodology

Participants: Vincent Danjean, Nicolas Gast, Guillaume Huard, Arnaud Legrand, Jean-Marc Vincent.

Experiments in large scale distributed systems are costly, difficult to control and therefore difficult to reproduce. Although many of these digital systems have been built by men, they have reached such a complexity level that we are no longer able to study them like artificial systems and have to deal with the same kind of experimental issues as natural sciences. The development of a sound experimental methodology for the evaluation of resource management solutions is among the most important ways to cope with the growing complexity of computing environments. Although computing environments come with their own specific challenges, we believe such general observation problems should be addressed by borrowing good practices and techniques developed in many other domains of science.

This research theme builds on a transverse activity on *Open science and reproducible research* and is organized into the following two directions: (1) *Experimental design* (2) *Smart monitoring and tracing*. As we will explain in more detail hereafter, these transverse activity and research directions span several research areas and our goal within the POLARIS project is foremost to transfer original ideas from other domains of science to the distributed and high performance computing community.

3.2. Multi-Scale Analysis and Visualization

Participants: Vincent Danjean, Guillaume Huard, Arnaud Legrand, Jean-Marc Vincent, Panayotis Mertikopoulos.

As explained in the previous section, the first difficulty encountered when modeling large scale computer systems is to observe these systems and extract information on the behavior of both the architecture, the middleware, the applications, and the users. The second difficulty is to *visualize* and *analyze* such *multi-level traces to understand how the performance* of the application *can be improved*. While a lot of efforts are put into visualizing scientific data, in comparison little effort have gone into to developing techniques specifically tailored for understanding the behavior of distributed systems. Many visualization tools have been developed by renowned HPC groups since decades (e.g., BSC [84], Jülich and TU Dresden [83], [54], UIUC [72], [87], [75] and ANL [100], Inria Bordeaux [60] and Grenoble [102], ...) but most of these tools build on the classical information visualization mantra [92] that consists in always first presenting an overview of the data, possibly by plotting everything if computing power allows, and then to allow users to zoom and filter, providing details on demand. However in our context, the amount of data comprised in such traces is several orders of magnitude larger than the number of pixels on a screen and displaying even a small fraction of the trace leads to harmful visualization artifacts [79]. Such traces are typically made of events that occur at very different time and space scales, which unfortunately hinders classical approaches. Such visualization tools have focused on easing interaction and navigation in the trace (through gantcharts, intuitive filters, pie charts and kiviats) but they are very difficult to maintain and evolve and they require some significant experience to identify performance bottlenecks.

Therefore many groups have more recently proposed in combination to these tools some techniques to help identifying the structure of the application or regions (applicative, spatial or temporal) of interest. For example, researchers from the SDSC [82] propose some segment matching techniques based on clustering (Euclidean or Manhattan distance) of start and end dates of the segments that enables to reduce the amount of information to display. Researchers from the BSC use clustering, linear regression and Kriging techniques [91], [78], [71] to identify and characterize (in term of performance and resource usage) application phases and present aggregated representations of the trace [90]. Researchers from Jülich and TU Darmstadt have proposed techniques to identify specific communication patterns that incur wait states [97], [47]

3.3. Fast and Faithful Performance Prediction of Very Large Systems

Participants: Vincent Danjean, Bruno Gaujal, Arnaud Legrand, Florence Perronnin, Jean-Marc Vincent.

Evaluating the scalability, robustness, energy consumption and performance of large infrastructures such as exascale platforms and clouds raises severe methodological challenges. The complexity of such platforms mandates empirical evaluation but direct experimentation via an application deployment on a real-world testbed is often limited by the few platforms available at hand and is even sometimes impossible (cost, access, early stages of the infrastructure design, ...). Unlike direct experimentation via an application deployment on a real-world testbed, simulation enables fully repeatable and configurable experiments that can often be conducted quickly for arbitrary hypothetical scenarios. In spite of these promises, current simulation practice is often not conducive to obtaining scientifically sound results. To date, most simulation results in the parallel and distributed computing literature are obtained with simulators that are ad hoc, unavailable, undocumented, and/or no longer maintained. For instance, Naicken et al. [46] point out that out of 125 recent papers they surveyed that study peer-to-peer systems, 52% use simulation and mention a simulator, but 72% of them use a custom simulator. As a result, most published simulation results build on throw-away (short-lived and non validated) simulators that are specifically designed for a particular study, which prevents other researchers from building upon it. There is thus a strong need for recognized simulation frameworks by which simulation results can be reproduced, further analyzed and improved.

The *SimGrid* simulation toolkit [58], whose development is partially supported by POLARIS, is specifically designed for studying large scale distributed computing systems. It has already been successfully used for simulation of grid, volunteer computing, HPC, cloud infrastructures and we have constantly invested on the software quality, the scalability [50] and the validity of the underlying network models [48], [95]. Many simulators of MPI applications have been developed by renowned HPC groups (e.g., at SDSC [93], BSC [44], UIUC [101], Sandia Nat. Lab. [96], ORNL [57] or ETH Zürich [73] for the most prominent ones). Yet, to scale most of them build on restrictive network and application modeling assumptions that make them difficult to extend to more complex architectures and to applications that do not solely build on the MPI API. Furthermore, simplistic modeling assumptions generally prevent to faithfully predict execution times, which limits the use of simulation to indication of gross trends at best. Our goal is to improve the quality of SimGrid to the point where it can be used effectively on a daily basis by practitioners to *reproduce the dynamic of real HPC systems*.

We also develop another simulation software, *PSI* (Perfect SImulator) [62], [55], dedicated to the simulation of very large systems that can be modeled as Markov chains. PSI provides a set of simulation kernels for Markov chains specified by events. It allows one to sample stationary distributions through the Perfect Sampling method (pioneered by Propp and Wilson [85]) or simply to generate trajectories with a forward Monte-Carlo simulation leveraging time parallel simulation (pioneered by Fujimoto [66], Lin and Lazowska [77]). One of the strength of the PSI framework is its expressiveness that allows us to easily study networks with finite and infinite capacity queues [56]. Although PSI already allows to simulate very large and complex systems, our main objective is to push its scalability even further and *improve its capabilities by one or several orders of magnitude*.

3.4. Local Interactions and Transient Analysis in Adaptive Dynamic Systems

Participants: Nicolas Gast, Bruno Gaujal, Florence Perronnin, Jean-Marc Vincent, Panayotis Mertikopoulos.

Many systems can be effectively described by stochastic population models. These systems are composed of a set of n entities interacting together and the resulting stochastic process can be seen as a continuous-time Markov chain with a finite state space. Many numerical techniques exist to study the behavior of Markov chains, to solve stochastic optimal control problems [86] or to perform model-checking [45]. These techniques, however, are limited in their applicability, as they suffer from the *curse of dimensionality*: the state-space grows exponentially with n.

This results in the need for approximation techniques. Mean field analysis offers a viable, and often very accurate, solution for large n. The basic idea of the mean field approximation is to count the number of entities that are in a given state. Hence, the fluctuations due to stochasticity become negligible as the number of entities grows. For large n, the system becomes essentially deterministic. This approximation has been originally developed in statistical mechanics for vary large systems composed of more than 10^{20} particles (called entities here). More recently, it has been claimed that, under some conditions, this approximation can be successfully used for stochastic systems composed of a few tens of entities. The claim is supported by various convergence results [67], [76], [99], and has been successfully applied in various domains: wireless networks [49], computer-based systems [70], [81], [94], epidemic or rumour propagation [59], [74] and bike-sharing systems [63]. It is also used to develop distributed control strategies [98], [80] or to construct approximate solutions of stochastic model checking problems [51], [52], [53].

Within the POLARIS project, we will continue developing both the theory behind these approximation techniques and their applications. Typically, these techniques require a homogeneous population of objects where the dynamics of the entities depend only on their state (the state space of each object must not scale with n the number of objects) but neither on their identity nor on their spatial location. Continuing our work in [67], we would like to be able to handle heterogeneous or uncertain dynamics. Typical applications are caching mechanisms [70] or bike-sharing systems [64]. A second point of interest is the use of mean field or large deviation asymptotics to compute the time between two regimes [89] or to reach an equilibrium state. Last, mean-field methods are mostly descriptive and are used to analyse the performance of a given system. We wish to extend their use to solve optimal control problems. In particular, we would like to implement numerical algorithms that use the framework that we developed in [68] to build distributed control algorithms [61] and optimal pricing mechanisms [69].

3.5. Distributed Learning in Games and Online Optimization

Participants: Nicolas Gast, Bruno Gaujal, Arnaud Legrand, Panayotis Mertikopoulos.

Game theory is a thriving interdisciplinary field that studies the interactions between competing optimizing agents, be they humans, firms, bacteria, or computers. As such, game-theoretic models have met with remarkable success when applied to complex systems consisting of interdependent components with vastly different (and often conflicting) objectives – ranging from latency minimization in packet-switched networks to throughput maximization and power control in mobile wireless networks.

In the context of large-scale, decentralized systems (the core focus of the POLARIS project), it is more relevant to take an inductive, "bottom-up" approach to game theory, because the components of a large system cannot be assumed to perform the numerical calculations required to solve a very-large-scale optimization problem. In view of this, POLARIS' overarching objective in this area is to *develop novel algorithmic frameworks that offer robust performance guarantees when employed by all interacting decision-makers.*

A key challenge here is that most of the literature on learning in games has focused on *static* games with a *finite number of actions* per player [65], [88]. While relatively tractable, such games are ill-suited to practical applications where players pick an action from a continuous space or when their payoff functions evolve over time – this being typically the case in our target applications (e.g., routing in packet-switched networks or energy-efficient throughput maximization in wireless). On the other hand, the framework of online convex optimization typically provides worst-case performance bounds on the learner's *regret* that the agents can attain irrespectively of how their environment varies over time. However, if the agents' environment is determined chiefly by their interactions these bounds are fairly loose, so more sophisticated convergence criteria should be applied.

From an algorithmic standpoint, a further challenge occurs when players can only observe their own payoffs (or a perturbed version thereof). In this bandit-like setting regret-matching or trial-and-error procedures guarantee convergence to an equilibrium in a weak sense in certain classes of games. However, these results apply exclusively to static, finite games: learning in games with continuous action spaces and/or nonlinear payoff functions cannot be studied within this framework. Furthermore, even in the case of finite games, the complexity of the algorithms described above is not known, so it is impossible to decide a priori which algorithmic scheme can be applied to which application.

4. Application Domains

4.1. Large Computing Infrastructures

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

4.2. Next-Generation Wireless Networks

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

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

4.3. Energy and Transportation

Participant: Nicolas Gast.

This work is mainly done within the Quanticol European project.

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

5. Highlights of the Year

5.1. Highlights of the Year

5.1.1. Publications

The paper *On the robustness of learning in games with stochastically perturbed payoff observations* (Panayotis Mertikopoulos and Mario Bravo) has been selected to appear in the John Nash Memorial Special Issues of GEB (Games and Economic Behavior), May 2017.

5.1.2. Grants

Patrick Loiseau has been granted the "Chaire d'excellence" on *Human-aware learning in the digital society* from IDEX Grenoble.

6. New Software and Platforms

6.1. Framesoc

FUNCTIONAL DESCRIPTION: Framesoc is the core software infrastructure of the SoC-Trace project. It provides a graphical user environment for execution-trace analysis, featuring interactive analysis views as Gantt charts or statistics views. It provides also a software library to store generic trace data, play with them, and build other analysis tools (e.g., Ocelotl).

- Participants: Arnaud Legrand and Jean-Marc Vincent
- Contact: Guillaume Huard
- URL: http://soctrace-inria.github.io/framesoc/

6.2. GameSeer

FUNCTIONAL DESCRIPTION: GameSeer is a tool for students and researchers in game theory that uses Mathematica to generate phase portraits for normal form games under a variety of (user-customizable) evolutionary dynamics. The whole point behind GameSeer is to provide a dynamic graphical interface that allows the user to employ Mathematica's vast numerical capabilities from a simple and intuitive front-end. So, even if you've never used Mathematica before, you should be able to generate fully editable and customizable portraits quickly and painlessly.

- Contact: Panayotis Mertikopoulos
- URL: http://mescal.imag.fr/membres/panayotis.mertikopoulos/publications.html

6.3. marmoteCore

Markov Modeling Tools and Environments - the Core
KEYWORDS: Modeling - Stochastic models - Markov model
FUNCTIONAL DESCRIPTION: marmoteCore is a C++ environment for modeling with Markov chains. It consists in a reduced set of high-level abstractions for constructing state spaces, transition structures and Markov chains (discrete-time and continuous-time). It provides the ability of constructing hierarchies of Markov models, from the most general to the particular, and equip each level with specifically optimized solution methods.

This software is developed within the ANR MARMOTE project: ANR-12-MONU-00019.

- Participants: Alain Jean-Marie, Hlib Mykhailenko, Benjamin Briot, Franck Quessette, Issam Rabhi, Jean-Marc Vincent and Jean-Michel Fourneau
- Partner: UVSQ
- Contact: Alain Jean-Marie
- Publications: marmoteCore: a Markov Modeling Platform - marmoteCore: a software platform for Markov modeling
- URL: http://marmotecore.gforge.inria.fr/

6.4. Moca

Memory Organisation Cartography and Analysis
KEYWORDS: High-Performance Computing - Performance analysis

- Contact: David Beniamine
- URL: https://github.com/dbeniamine/MOCA

6.5. Ocelotl

Multidimensional Overviews for Huge Trace Analysis
FUNCTIONAL DESCRIPTION: Ocelotl is an innovative visualization tool, which provides overviews for execution trace analysis by using a data aggregation technique. This technique enables to find anomalies in huge traces containing up to several billions of events, while keeping a fast computation time and providing a simple representation that does not overload the user.

- Participants: Arnaud Legrand and Jean-Marc Vincent
- Contact: Jean-Marc Vincent
- URL: http://soctrace-inria.github.io/ocelotl/

6.6. PSI

Perfect Simulator
FUNCTIONAL DESCRIPTION: Perfect simulator is a simulation software of markovian models. It is able to simulate discrete and continuous time models to provide a perfect sampling of the stationary distribution or directly a sampling of functional of this distribution by using coupling from the past. The simulation kernel is based on the CFTP algorithm, and the internal simulation of transitions on the Aliasing method.

- Contact: Jean-Marc Vincent
- URL: http://psi.gforge.inria.fr/

6.7. SimGrid

KEYWORDS: Large-scale Emulators - Grid Computing - Distributed Applications
SCIENTIFIC DESCRIPTION: SimGrid is a toolkit that provides core functionalities for the simulation of distributed applications in heterogeneous distributed environments. The simulation engine uses algorithmic and implementation techniques toward the fast simulation of large systems on a single machine. The models are theoretically grounded and experimentally validated. The results are reproducible, enabling better scientific practices.

Its models of networks, cpus and disks are adapted to (Data)Grids, P2P, Clouds, Clusters and HPC, allowing multi-domain studies. It can be used either to simulate algorithms and prototypes of applications, or to emulate real MPI applications through the virtualization of their communication, or to formally assess algorithms and applications that can run in the framework.

The formal verification module explores all possible message interleavings in the application, searching for states violating the provided properties. We recently added the ability to assess liveness properties over arbitrary and legacy codes, thanks to a system-level introspection tool that provides a finely detailed view of the running application to the model checker. This can for example be leveraged to verify both safety or liveness properties, on arbitrary MPI code written in C/C++/Fortran.
RELEASE FUNCTIONAL DESCRIPTION:

- Four releases in 2017. Major changes:
  - S4U: many progress, toward SimGrid v4.0. About 80% of the features offered by SimDag and MSG are now integrated, along with examples. Users can now write plugins to extend SimGrid.
  - SMPI: Support MPI 2.2, RMA support, Convert internals to C++.
  - Java: Massive memleaks and performance issues fixed.
  - New models: Multi-core VMs, Energy consumption due to the network
  - All internals are now converted to C++, and most of our internally developped data containers were replaced with std::* constructs.
  - (+ bug fixes, cleanups and documentation improvements)

- Participants: Adrien Lèbre, Arnaud Legrand, Augustin Degomme, Florence Perronnin, Frédéric Suter, Jean-Marc Vincent, Jonathan Pastor, Jonathan Rouzaud-Cornabas, Luka Stanisic, Mario Südholt and Martin Quinson
- Partners: CNRS - ENS Rennes
- Contact: Martin Quinson
- URL: http://simgrid.gforge.inria.fr/

6.8. Tabarnac

Tool for Analyzing the Behavior of Applications Running on NUMA ArChitecture
KEYWORDS: High-Performance Computing - Performance analysis - NUMA

- Contact: David Beniamine
- URL: https://dbeniamine.github.io/Tabarnac/

7. New Results

7.1. Simgrid for MPI (SMPI)

Several new results on the usage of Simgrid to assess MPI performance have been published in 2017. The general framework introducing the methodology for a proper use of SimGrid to simulate MPI applications was presented in [5]. One more specific line of work concerns the prediction of the performance and the energy consumption of MPI applications using SimGrid [39], [19]. Other applications have also been simulated using this approach. General capacity planning of supercomputers is analyzed in [35] using simulation. More specifically, we have shown that the HPL benchmark (high Performance Linpack), used to establish the top 500 ranking of the most powerful supercomputers in the world, can be emulated faithfully on a commodity server, at the scale of a supercomputer [36]. We have also shown that SimGrid is reliable and fast enough to evaluate and tune the performance of dynamic load balancing in seismic simulations [22].

7.2. Visualisation for Performance Analysis of Task-Based Applications

The performance of task-based application heavily depends on the runtime scheduling and on its ability to exploit computing and communication resources. Unfortunately, the traditional performance analysis strategies are unfit to fully understand task-based runtime systems and applications: they expect a regular behavior with communication and computation phases, while task-based applications demonstrate no clear phases. Moreover, the finer granularity of task-based applications typically induces a stochastic behavior that leads to irregular structures that are difficult to analyze. We have introduced a flexible framework combining visualization panels to understand and pinpoint performance problems incurred by bad scheduling decisions in task-based applications. Three case-studies using StarPU-MPI, a task-based multi-node runtime system, have been investigated in more details to show how our framework is used to study the performance of the well-known Cholesky factorization. Performance improvements include a better task partitioning among the multi-(GPU,core) to get closer to theoretical lower bounds, improved MPI pipelining in multi-(node,core,GPU) to reduce the slow start, and changes in the runtime system to increase MPI bandwidth, with gains of up to 13% in the total makespan [38].

7.3. Convergence of game dynamics

The study of game dynamics is crucial in understanding the long-run behavior of optimizing agents in an environment that changes dynamically over time, whether endogenously (i.e. via the agents' interactions) or exogenously (i.e. due to factors beyond the agents' influence). Starting with the observation that oblivious agents should seek to at least minimize their regret, we showed in [9] that players that "follow the regularized leader" in continuous time achieve no regret at an optimal rate. The multi-agent implications of this property where subsequently explored in [3], [24] (for games with finite and continuous action sets respectively), where we established a wide range of conditions guaranteeing convergence to Nash equilibrium, even when the players' payoff observations are subject to noise and/or other stochastic disturbances.

7.4. Multi-agent learning

In contrast to [9], [3], [24], the above works focus squarely on multi-agent interactions that occur in discrete time (as is typically the case in practical applications). In the case of games with finite action spaces, we showed in [16] that no-regret learning based on "following the regularized leader" converges to Nash equilibrium in potential games, thus complementing the analysis of [15] where it was shown that this family of learning methods eliminates dominated strategies and converges locally to strict Nash equilibria. The former result was extended to mixed-strategy learning in games with continuous action spaces in [11], while [42], [28] established the convergence of no-regret regularized learning to variationally stable equilibria in continuous games, even with imperfect and/or delayed/asynchronous feedback.

7.5. Selfishness vs efficiency in traffic networks

Empirical studies in real-world networks show that the efficiency ratio between selfishly and socially optimal states (the so-called price of anarchy) is close to 1 in both light and heavy traffic conditions, thus raising the question: can these observations be justified theoretically? In [17] we showed that this is not always the case: the price of anarchy may remain bounded away from 1 for all values of the traffic inflow, even in simple three-link networks with a single O/D pair and smooth, convex costs. On the other hand, for a large class of cost functions (including all polynomials), the price of anarchy does converge to 1 in both heavy and light traffic conditions, and irrespective of the network topology and the number of O/D pairs in the network.

7.6. Online Energy Optimization in Embedded Systems

We have used a Markov Decision Process (MDP) approach to compute the optimal on-line speed scaling policy to minimize the energy consumption of a single processor executing a finite or infinite set of jobs with real-time constraints. We provide several qualitative properties of the optimal policy: monotonicity with respect to the jobs parameters, comparison with on-line deterministic algorithms. Numerical experiments in several scenarios show that our proposition performs well when compared with off-line optimal solutions and out-performs on-line solutions oblivious to statistical information on the jobs [33]. Several extension to online learning (Q-learning) as well as hidden Markov chain theory for offline computation of the statistical parameters of the system are currently being investigated.

7.7. Asymptotic Models

- Mean field approximation is a popular means to approximate large and complex stochastic models that can be represented as N interacting objects. The idea of mean field approximation to study the limit of this system as N goes to infinity.

  In [18], we study how accurate is mean field approximation as N goes to infinity. We show that under very general conditions the expectation of any performance indicator converges at rate $O(1/N)$ to its mean field approximation. In [7] we continue this analysis and establish a result that expresses the constant associated with this $1/N$ term. This allows us to propose what we call a *refined mean field approximation*. By considering a variety of applications, we illustrate that the proposed refined mean field approximation is significantly more accurate that the classic mean field approximation for small and moderate values of N: the relative errors of this refined approximation is often below 1% for systems with $N = 10$.
- Computer system and network performance can be significantly improved by caching frequently used information. When the cache size is limited, the cache replacement algorithm has an important impact on the effectiveness of caching. In [8] we introduce time-to-live (TTL) approximations to determine the cache hit probability of two classes of cache replacement algorithms: h-LRU and LRU(m). Using a mean field approach, we provide both numerical and theoretical support for the claim that the proposed TTL approximations are asymptotically exact. We use this approximation and trace-based simulation to compare the performance of h-LRU and LRU(m). First, we show that they perform alike, while the latter requires less work when a hit/miss occurs. Second, we show that

as opposed to LRU, h-LRU and LRU(m) are sensitive to the correlation between consecutive inter-request times. Last, we study cache partitioning. In all tested cases, the hit probability improved by partitioning the cache into different parts—each being dedicated to a particular content provider. However, the gain is limited and the optimal partition sizes are very sensitive to the problem's parameters.

- Mean field approximation is often use to characterize the transient or steady state performance of a stochastic system. In [6], we use this approach to compute absorbing times. We use mean field approximation to provide an asymptotic expansion of this absorbing time that uses the spectral decomposition of the kernel of the original chains. Our results rely on extreme values theory. We show the applicability of this approach with three different problems: the coupon collector, the erasure channel lifetime and the coupling times of random walks in high dimensional spaces.

7.8. Secret Key Generation

Secret key generation (SKG) from shared randomness at two remote locations has been shown to be vulnerable to denial of service attacks in the form of jamming. In [13], [2], we develop as a novel counter-jamming approach by using energy harvesting. The idea is that part of the jamming signal can potentially be harvested and converted into useful communication power. In [14], we investigate the use of frequency hopping/spreading in Rayleigh block fading additive white Gaussian noise (BF-AWGN) channels to counteract attacks from jamming. In both cases, we formulate the problems as a zero-sum game and characterize the unique Nash equilibrium of the game in closed form. Through numerical evaluations, we show that energy harvesting is an efficient counter-jamming approach that offers substantial gains in terms of relative SKG rates. In the case of BF-AWGN channels, we also use numerical results to show that frequency hopping/spreading is an effective technique for combating jamming attacks in SKG systems; a modest increase of the system bandwidth can substantially increase the SKG rates.

7.9. Power control in wireless systems

Channel state information (CSI) is essential for efficient power and spectrum allocation policies. In cognitive radio (CR) channels, although perfect CSI of the direct link (between the secondary transmitter and the secondary receiver) is a reasonable assumption at the secondary transmitter (ST), however, perfect knowledge of its interfering links to the primary receivers (PRs) is not. Power allocation and scheduling algorithms are often based on perfect global CSI at the secondary transmitter (ST). In [31], we analyze the impact of channel estimation errors on both the secondary and primary users. On the one hand, the robustness of water-filling type of algorithms allowing the secondary user (SU) to minimize its power consumption under QoS and CR interference power constraints to channel estimation errors in the SU interfering links is analyzed. On the other hand, the impact of these estimation errors on the PU interference constraints is also analyzed. To this aim, we consider the worst case with respect to these estimation errors. Our analysis shows that the water-filling algorithm provides robustness in terms of power consumption and scheduling of the SU given the realistic estimation error models especially when the SU is overestimating the interfering power gains. We also provide possible solutions to ensure that the created interference is below the tolerated thresholds.

7.10. Routing in SDN-based networks

A new adaptive multi-flow routing algorithm to select end-to-end paths in packet-switched networks has been proposed. This algorithm provides provable optimality guarantees in the following game theoretic sense: The network configuration converges to a configuration arbitrarily close to a pure Nash equilibrium. This algorithm has several robustness properties making it suitable for real-life usage: it is robust to measurement errors, outdated information, and clocks desynchronization. Furthermore, it is only based on local information and only takes local decisions, making it suitable for a distributed implementation. Our SDN-based proof-of-concept is built as an Openflow controller. We also set up an emulation platform based on Mininet to test the behavior of our proof-of- concept implementation in several scenarios. Although real-world conditions do not conform exactly to the theoretical model, all experiments exhibit satisfying behavior, in accordance with the theoretical predictions [20], [21].

7.11. Distributed Best Response

We have designed and analyzed distributed algorithms to compute a Nash equilibrium in random potential games. Our algorithms are based on best-response dynamics, with suitable revision sequences (orders of play). We compute the average complexity over all potential games of best response dynamics under a random i.i.d. revision sequence, since it can be implemented in a distributed way using Poisson clocks. We obtain a distributed algorithm whose execution time is within a constant factor of the optimal centralized one. We also showed how to take advantage of the structure of the interactions between players in a network game: non-interacting players can play simultaneously. This improves best response algorithm, both in the centralized and in the distributed case [32].

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

- ULTRON, bilateral contract with Huawei over 18 months, supporting two postdoctoral researchers, Amélie Heliou and Luigi Vigneri.
- Inria/Orange Labs Laboratory. Polaris is involved in this partnership with Orange Labs by supervising two PhD students members of this common laboratory: Bruno Donnassolo (supervised by Arnaud Legrand, Panayotis Mertikopoulos, and Ilhem Fajjari) and Umar OzeerX (supervised by Jean-Marc Vincent and Gwenn Salaün).
- Cifre contract with Schneider Electric. The PhD thesis of Benoit Vinot (supervised by Nicolas Gast and Florent Cadoux (G2Elab)) is supported by this collaboration.
- A common laboratory between Inria and the Alcatel Lucent-Bell Labs was created in early 2008 and consists on three research groups (ADR). POLARIS leads the ADR on self-optimizing networks (SELFNET). The researchers involved in this project are Bruno Gaujal and Panayotis Mertikopoulos.

9. Partnerships and Cooperations

9.1. Regional Initiatives

Nicolas Gast received a grant from the IDEX UGA that fund a post-doctoral researcher for two years to work on the smart-grid project that focus on distributed optimization in electrical distribution networks.

9.2. National Initiatives

9.2.1. Inria Project Labs

HAC SPECIS: The goal of the HAC SPECIS (High-performance Application and Computers: Studying PErformance and Correctness In Simulation) project is to answer methodological needs of HPC application and runtime developers and to allow to study real HPC systems both from the correctness and performance point of view. To this end, we gather experts from the HPC, formal verification and performance evaluation community. Inria Teams : AVALON, POLARIS, MYRIADS, SUMO, HIEPACS, STORM, MEXICO, VERIDIS.

9.2.2. PGMO Projects

PGMO projects are supported by the Jacques Hadamard Mathematical Foundation (FMJH). Our project (HEAVY.NET) is focused on congested networks and their asymptotic properties.

9.2.3. ANR

- *GAGA (2014–2017)*
  GAGA is an ANR starting grant (JCJC) whose aim is to explore the Geometric Aspects of GAmes. The GAGA team is spread over three different locations in France (Paris, Toulouse and Grenoble), and is coordinated by Vianney Perchet (ENS Cachan). Its aim is to perform a systematic study of the geometric aspects of game theory and, in so doing, to establish new links between application areas that so far appeared unrelated (such as the use of Hessian Riemannian optimization techniques in wireless communication networks).
- *MARMOTE (2013–2017)*
  Partners: Inria Sophia (MAESTRO), Inria Rocquencourt (DIOGEN), Université Versailles-Saint-Quentin (PRiSM lab), Telecom SudParis (SAMOVAR), Université Paris-Est Créteil (*Spécification et vérification de systèmes*), Université Pierre-et-Marie-Curie/LIP6.
  The project aims at realizing a software prototype dedicated to Markov chain modeling. It gathers seven teams that will develop advanced resolution algorithms and apply them to various domains (reliability, distributed systems, biology, physics, economy).
- *NETLEARN (2013–2017)*
  Partners: Université Versailles – Saint-Quentin (PRiSM lab), Université Paris Dauphine, Inria Grenoble (POLARIS), Institut Mines–Telecom (Telecom ParisTech), Alcatel–Lucent Bell Labs (ALBF), and Orange Labs.
  The main objective of the project is to propose a novel approach of distributed, scalable, dynamic and energy efficient algorithms for mobile network resource management. This new approach relies on the design of an orchestration mechanism of a portfolio of algorithms. The ultimate goal of the proposed mechanism is to enhance the user experience, while at the same time ensuring the more efficient utilization of the operator's resources.
- *ORACLESS (2016–2021)*
  ORACLESS is an ANR starting grant (JCJC) coordinated by Panayotis Mertikopoulos. The goal of the project is to develop highly adaptive resource allocation methods for wireless communication networks that are provably capable of adapting to unpredictable changes in the network. In particular, the project will focus on the application of online optimization and online learning methodologies to multi-antenna systems and cognitive radio networks.
- *ANR SONGS, 2012–2016*. Partners: Inria Nancy (Algorille), Inria Sophia (MASCOTTE), Inria Bordeaux (CEPAGE, HiePACS, RunTime), Inria Lyon (AVALON), University of Strasbourg, University of Nantes.

  The last decade has brought tremendous changes to the characteristics of large scale distributed computing platforms. Large grids processing terabytes of information a day and the peer-to-peer technology have become common even though understanding how to efficiently exploit such platforms still raises many challenges. As demonstrated by the USS SimGrid project funded by the ANR in 2008, simulation has proved to be a very effective approach for studying such platforms. Although even more challenging, we think the issues raised by petaflop/exaflop computers and emerging cloud infrastructures can be addressed using similar simulation methodology.

  The goal of the SONGS project (Simulation of Next Generation Systems) is to extend the applicability of the SimGrid simulation framework from grids and peer-to-peer systems to clouds and high performance computation systems. Each type of large-scale computing system will be addressed through a set of use cases and led by researchers recognized as experts in this area. Any sound study of such systems through simulations relies on the following pillars of simulation methodology: Efficient simulation kernel; Sound and validated models; Simulation analysis tools; Campaign simulation management. Such aspects are also addressed in the SONGS project.

9.2.4. National Organizations

- Jean-Marc Vincent is member of the scientific committees of the CIST (Centre International des Sciences du Territoire).
- *REAL.NET (2017)*
  REAL.NET is a CNRS PEPS starting grant (JCJC) coordinated by Panayotis Mertikopoulos. Its objective is to provide dynamic control methodologies for nonstationary stochastic optimization problems that arise in wireless communication networks.

9.3. European Initiatives

9.3.1. FP7 & H2020 Projects

9.3.1.1. QUANTICOL

Program: The project is a member of Fundamentals of Collective Adaptive Systems (FOCAS), a FET-Proactive Initiative funded by the European Commission under FP7.

Project acronym: QUANTICOL

Project title: A Quantitative Approach to Management and Design of Collective and Adaptive Behaviours

Duration: 04 2013 – 03 2017

Coordinator: Jane Hillston (University of Edinburgh, Scotland)

Other partners: University of Edinburgh (Scotland); Istituto di Scienza e Tecnologie della Informazione (Italy); IMT Lucca (Italy) and University of Southampton (England).

Abstract: The main objective of the QUANTICOL project is the development of an innovative formal design framework that provides a specification language for collective adaptive systems (CAS) and a large variety of tool-supported, scalable analysis and verification techniques. These techniques will be based on the original combination of recent breakthroughs in stochastic process algebras and associated verification techniques, and mean field/continuous approximation and control theory. Such a design framework will provide scalable extensive support for the verification of developed models, and also enable and facilitate experimentation and discovery of new design patterns for emergent behaviour and control over spatially distributed CAS.

9.3.1.2. HPC4E

Title: HPC for Energy

Program: H2020

Duration: 01 2016 – 01 2018

Coordinator: Barcelona Supercomputing Center

Inria contact: Stephane Lanteri

Other partners:

- Europe: Lancaster University (ULANC), Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Repsol S.A. (REPSOL), Iberdrola Renovables Energía S.A. (IBR), Total S.A. (TOTAL).
- Brazil: Fundação Coordenação de Projetos, Pesquisas e Estudos Tecnoclógicos (COPPE), National Laboratory for Scientific Computation (LNCC), Instituto Tecnológico de Aeronáutica (ITA), Petroleo Brasileiro S. A. (PETROBRAS), Universidade Federal do Rio Grande do Sul (INF-UFRGS), Universidade Federal de Pernambuco (CER-UFPE)

Abstract: The main objective of the HPC4E project is to develop beyond-the-state-of-the-art high performance simulation tools that can help the energy industry to respond future energy demands and also to carbon-related environmental issues using the state-of-the-art HPC systems. The other objective is to improve the cooperation between energy industries from EU and Brazil and the cooperation between the leading research centres in EU and Brazil in HPC applied to energy industry. The project includes relevant energy industrial partners from Brazil and EU, which will benefit from the project's results. They guarantee that TRL of the project technologies will be very high. This includes sharing supercomputing infrastructures between Brazil and EU. The cross-fertilization between energy-related problems and other scientific fields will be beneficial at both sides of the Atlantic.

Polaris is a member of the COST program on *Game Theory in Europe*.

9.3.2. Collaborations with Major European Organizations

TU Wien: Research Group Parallel Computing, Technische Universität Wien (Austria). We collaborate with Sascha Hunold on experimental methodology and reproducibility of experiments in HPC. In particular we co-organize the REPPAR workshop on "Reproducibility in Parallel Computing".

BSC (Barcelona): Barcelona Supercomputer Center (Spain). We collaborate with the performance evaluation group through the HPC4E project and through the JLESC.

University of Edinburgh, Istituto di Scienza e Tecnologie della Informazione and IMT Lucca. we used to strongly collaborate through the Quanticol European project. Several projects are still actively developed, concerning the mean field and refined mean field approximation.

9.4. International Initiatives

9.4.1. Inria International Labs

9.4.1.1. North America

- JLESC (former JLPC) (Joint Laboratory for Extreme-Scale Computing) with University of University of Illinois Urbana Champaign, Argonne Nat. Lab and BSC. Several members of POLARIS are partners of this laboratory, and have done several visits to Urbana-Champaign or NCSA.

9.4.2. Inria International Partners

9.4.2.1. Declared Inria International Partners

- POLARIS has strong connections with both UFRGS (Porto Alegre, Brazil) and USP (Sao Paulo, Brazil). The creation of the LICIA common laboratory (see next section) has made this collaboration even tighter.
- POLARIS has strong bounds with the University of Illinois Urbana Champaign and Barcelona Supercompter Center, within the (Joint Laboratory on Petascale Computing, see previous section).

9.4.3. Participation in Other International Programs

LICIA Bresil: Polaris is member of the common laboratory with Bresil. The founding director of LICIA is Jean-Marc Vincent.

9.4.3.1. South America

- *LICIA:* The CNRS, Inria, the Universities of Grenoble, Grenoble INP, and Universidade Federal do Rio Grande do Sul have created the LICIA (*Laboratoire International de Calcul intensif et d'Informatique Ambiante*). LICIA's main research themes are high performance computing, language processing, information representation, interfaces and visualization as well as distributed systems. Jean-Marc Vincent is the director of the laboratory on the French side and visited Porto Alegre for two weeks in November 2016.

  More information can be found at http://www.inf.ufrgs.br/licia/.

- *ECOS-Sud:* POLARIS is a member of the Franco-Chilean collaboration network LEARN with CONICYT (the Chilean national research agency), formed under the ECOS-Sud framework. The main research themes of this network is the application of continuous optimization and game-theoretic learning methods to traffic routing and congestion control in data networks. Panayotis Mertikopoulos was an invited researcher at the University of Chile in October 2016.

  More information can be found at http://www.conicyt.cl/pci/2016/02/11/programa-ecos-conicyt-adjudica-proyectos-para-el-ano-2016.
- POLARIS is the co-recipient of a project *STIC AmSud* that involves partners from Inria and CNRS (France), MINCYNT (Argentina) and ANII (from Uruguay).

9.5. International Research Visitors

9.5.1. Visits to International Teams

9.5.1.1. Research Stays Abroad

- 3/17: Panayotis Mertikopoulos visited Stanford University (Z. Zhou, N. Bambos, P. Glynn, S. Boyd)
- 04/17:Panayotis Mertikopoulos visited University of Wisconsin-Madison (W. Sandholm)
- 10/17:Panayotis Mertikopoulos visited Lancaster University (D. Leslie)
- 11/17:Panayotis Mertikopoulos visited U. Marseille-Aix (M. Faure, S. Bervoets).

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events Organisation

10.1.1.1. General Chair, Scientific Chair

- Panayotis Mertikopoulos has been the co-organizer of the *MODE Days* (03/2017).
- Arnaud Legrand has co-organized the International Workshop on Reproducibility in Parallel Computing (RepPar) in conjunction with IPDPS.

10.1.1.2. Member of the Organizing Committees

- Nicolas Gast was co-organizer of the workshop YEQT XI: "Winterschool on Energy Systems" organized in TU Eindhoven in December 2017).
- E. Veronica Belmega was co-organizer of a day of the GdR ISIS about "Game Theory, Optimisation and Learning: Interplay and Applications to Signal Processing" (8 November 2017).

10.1.2. Scientific Events Selection

10.1.2.1. Chair of Conference Program Committees

- Nicolas Gast was co-chair of the track "Performance Evaluation, Control, and Optimization (incl. queueing, game theory, machine learning)" of the convergence ITC 29.

10.1.2.2. Member of the Conference Program Committees

- Bruno Gaujal and Nicolas Gast have been member of the *IFIP Performance* Committee.
- Nicolas Gast has been member of the *ACM Sigmetrics* and *ACM E-Energy* committees.
- Arnaud Legrand has been member of the *CCgrid, Cluster* and *PPAM* committees.
- E. Veronica Belmega was a member of the technical program committees of Green Computing, Networking and Communications Symposium at ICNC 2017, IEEE BlackSeaComm, IEEE ICC 2017, Wireless Communications Symposium (ICC'17 WCS), and IEEE Wireless Communications and Networking Conference, WCNC.

10.1.3. Journal

10.1.3.1. Member of the Editorial Boards

- E. Veronica Belmega is an executive editor for the Transactions on Emerging Telecommunications Technologies.
- Nicolas Gast is member of the editorial board of Performance Evaluation.
- E. Veronica Belmega serves as an Associate Editor for the IET Signal Processing journal.

10.1.3.2. Reviewer - Reviewing Activities

The members of the POLARIS team regularly review articles for JPDC, DAM, IEEE Transactions on Networking/Automatic Control/Cloud Computing/Parallel and Distributed Computing/Information Theory/Signal Processing/Wireless Communications, SIAM Journal on Optimization/Control and Optimization, and others.

10.1.4. Invited Talks

- Arnaud Legrand has been invited to give invited keynotes on reproducible research: (Keynote at the LIRIS, Lyon, Nov. 2017, at the PRECIS Spring school, Fréjus, May 2017, at the Grenoble Data Science Institute, Apr. 2017, at the LIG, Grenoble, Mar. 2017 and at the ENS Rennes, Feb. 2017.)
- Bruno Gaujal has been invited to give the opening lecture for the class of 2021 at ENS Cachan, Sept. 2017.
- Nicolas Gast gave an invited talk at IBM New-York in April 2017 and at Imperial College London in December 2017.

10.1.5. Leadership within the Scientific Community

- Panayotis Mertikopoulos is a member of the committee of the MODE group of the SMAI.
- Bruno Gaujal is a member of the scientific bureau of the GDRIM.

Arnaud Legrand organize a series of webinars on reproducible research and whose aim is to introduce the audience to one particular aspect of reproducible research and to illustrate how this aspect can be addressed with state-of-the-art tools. To this end, experts of a given topic are invited and their seminar is screencast so that researchers from other universities can easily follow it. This year, the following topics have been covered:

1. Publication Modes Favoring Reproducible Research
2. Artifact evaluation in computer systems' conferences
3. Experimental testbeds in Computer Science
4. Statistical and Reproducibility Issues in Human Computer Interactions
5. An Approach to Practical Falsifiable Research: the Popper Convention

All the corresponding videos and materials are available at the following address: https://github.com/alegrand/RR_webinars/

10.1.6. Research Administration

- Bruno Gaujal has been the president of the jury for hiring CR2 Researchers in Inria Grenoble Rhône-Alpes.
- E. Veronica Belmega was member of an Associate Professor (Maître de Conférences) hiring committee, ENSEA.
- Nicolas Gast is member of the "conseil du laboratoire" of the LIG (Laboratoire d'Informatique de Grenoble).
- Bruno Gaujal is member of the "bureau du LIG" (Laboratoire d'informatique de Grenoble)
- Panayotis Mertikopoulos serves as the graduate students liaison (*chargé de mission doctorants*) for the Laboratoire d'Informatique de Grenoble
- Bruno Gaujal was president of the CR2 admissibility jury of Inria-Grenoble.

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Master: Bruno Gaujal and Nicolas Gast, *"Advanced Performance Evaluation"*, 18h (M2), ENSIMAG

Master M2R : Nicolas Gast *"Optimization Under Uncertainties"*, 18h (M2), Master ORCO, Grenoble.

Master: Guillaume Huard, *"Conception des Systèmes d'Exploitation"* (M1), Université Grenoble-Alpes

Master: Arnaud Legrand and Jean-Marc Vincent, *"Scientific Methodology and Performance Evaluation"*, 15h (22.5h) M2, M2R MOSIG

Master: Arnaud Legrand, *"Parallel Systems"*, 21h (31.5h) M2R, M2R Mosig.

Master: Arnaud Legrand, *"Scientific Methodology and Performance Evaluation"*, 24h (36h), ENS Lyon.

Master: Panayotis Mertikopoulos, *"Selected Topics in the Theory of Stochastic Processes"*, 16h M2, University of Athens, Athens, Greece

Master: Florence Perronnin, *"Simulation"*, M1, Université Versailles – Saint-Quentin

Master: Florence Perronnin, *"Probabilités–Simulation"*, RICM4 Polytech Grenoble

Master: Arnaud Legrand and Jean-Marc Vincent, Probability and simulation, performance evaluation 72 h, (M1), RICM, Polytech Grenoble.

Master: Jean-Marc Vincent, Mathematics for computer science, 18 h , (M1) Mosig.

DU: Jean-Marc Vincent, *"Informatique et sciences du numérique"*, 20 h, (Professeurs de lycée).

Master M2P: Florence Perronnin *Probability and Simulation, Performance Evaluation*, Polytech Grenoble.

Master M2R: Panayotis Mertikopoulos *Selected Topics in Probability Theory* University of Athens , *Online Learning and Optimal Decision Making* MIF, ENS Lyon.

Master M2R: Bruno Gaujal *Online Learning and Optimal Decision Making* MIF, ENS Lyon, *Foundations of Network Performance*, MPRI, Paris.

Master M2R: Vincent Danjean *Operating Systems*, MOSIG, Grenoble

Master M2R: Arnaud Legrand *Parallel Systems* and *Scientific Methodology and Performance Evaluation*, MOSIG, Grenoble, *Scientific Methodology and Performance Evaluation*, ENS Rennes.

Highschool Professors: Vincent Danjean is responsible of the University Dept. for Highschool Professors Training in Computer Science

Mooc: Arnaud Legrand is currently designing a MOOC on Reproducible Research with Konrad Hinsen (CNRS/Centre de Biophysique Moléculaire) and Christophe Pouzat (CNRS/ Mathématiques Appliquées in Paris 5) with the support of the Inria MOOC-lab. The diffusion of this MOOC is planned for 2018 on FUN-MOOC.

10.2.2. Supervision

- Alexandre Marcastel (PhD) - 2015-... (E. Veronica Belmega, Panayotis Mertikopoulos, co-advised with Inbar Fijalkow)
- Irched Chafaa (PhD) - 2017-... 75% (E. Veronica Belmega (co-advised with Merouane Debbah)
- Kimon Antonakopoulos (PhD) - 2017-... (E. Veronica Belmega, Panayotis Mertikopoulos and Bruno Gaujal)
- Pedro Bruel (co-advised with USP 2017-. . .): Design of experiments and autotuning of HPC computation kernels (co-advised by Arnaud Legrand, Alfredo Goldman and Brice Videau, funded by the Brazilian Government).

- Tom Cornebize (2017-...): Capacity planning and performance evaluation of supercomputers (funded by the French Ministery for Research) (advised by Arnaud Legrand).
- Bruno Luis de Moura Donassolo (CIFRE Orange 2017-...): Decentralized management of applications in Fog computing environments (co-advised by Arnaud Legrand, Panayotis Mertikopoulos and Ilhem Fajari, funded by Orange).
- Vinicius Garcia Pinto (co-tutelle with UFRGS 2013-...): Performance analysis and visualization of dynamic task-based applications (co-advised by Arnaud Legrand, Lucas Schnorr and Nicolas Maillard, funded by the Brazilian government).
- Rafael Tesser (co-tutelle with UFRGS 2013-...): Simulation and performance evaluation of dynamical load balancing of an over-decomposed Geophysics application (co-advised by Arnaud Legrand, Lucas Schnorr and Philippe Navaux, funded by the Brazilian government).
- Christian Heinrich (2015-...): Modeling of performance and energy consumption of HPC systems (advised by Arnaud Legrand) (funded by Inria).
- Stephan Plassard (2016-...), Energy Optimization in Embedded Systems (co-advised by Bruno Gaujal and Alain Girault) (funded by Labex Persyval, Grenoble).
- Stephane Durand (2015-..) Distributed Best Response Algorithms in random Potential Games (co-advised by Bruno Gaujal and Federica Garin) (funded by Labex Persyval, Grenoble).
- Baptiste Jonglez (2016-...) Leveraging Diversity in Communication Networks (co-advised by Bruno Gaujal and Martin Heusse), (funded by Univ Grenoble Alpes).
- Kimon Antonakopoulos (2017-...) Variational Inequalities and Pptimization (co-advised by Bruno Gaujal and Panayotis Mertikopoulos), (funded by Inria)

10.2.3. Juries

- Arnaud Legrand has served in the PhD jury of Tien-Dat Phan (reviewer) (Nov. 2017).
- Vincent Danjean and Arnaud Legrand have served on the master thesis jury for the MOSIG master program.
- Florence Perronnin have served on the master thesis jury for the MIAGE master program.
- Bruno Gaujal has served in the PhD jurys of Alemayehu Addisu Desta (Dec. 2017) (member), Shabbir Ali (Jul. 2017) (reviewer), and Habilitation Thesis of Lin Chen (Jul. 2017) (reviewer).
- E. Veronica Belmega has served as an examiner on the PhD jury of Dora BOVIZ (Nokia, Paris-Saclay); Faton MALIQI (Centrale Supelec) Chao ZHANG (Centrale Supelec)

10.3. Popularization

The POLARIS team is actively involved in various scientific popularization activities. In addition to participating in the Fête de la Science (Guillaume Huard, Florence Perronnin, Jean-Marc Vincent), the POLARIS team also participates in the organization of the “Conference Inria”. Jean-Marc Vincent has also organized (and/or participated in) several training courses for computer science teachers (at a high school level) and has supervised several MathC2+ trainees.

- Vincent Danjean and Florence Perronnin have participated to the “fête de la Science” on the *unplugged computer science* stand. Florence Perronnin was involved in the meeting days between industry and education, organized by the “Maison pour la Science”.
- E. Veronica Belmega: "Introduction à la theorie des jeux et ses applications en communications", invited talk, Lycee Chrestien de Troyes, France, Nov. 2017.

11. Bibliography

Publications of the year

Doctoral Dissertations and Habilitation Theses

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Articles in International Peer-Reviewed Journals

[2] E. V. BELMEGA, A. CHORTI. *Protecting Secret Key Generation Systems Against Jamming: Energy Harvesting and Channel Hopping Approaches*, in "IEEE Transactions on Information Forensics and Security", November 2017, vol. 12, n^O 11, pp. 2611-2626 [*DOI :* 10.1109/TIFS.2017.2713342], https://hal.archives-ouvertes.fr/hal-01668735

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