IN PARTNERSHIP WITH:
CNRS
Université de Grenoble Alpes

Activity Report 2018

Project-Team POLARIS

Performance analysis and Optimization of LARge Infrastructures and Systems

IN COLLABORATION WITH: Laboratoire d'Informatique de Grenoble (LIG)

RESEARCH CENTER
Grenoble - Rhône-Alpes

THEME
Distributed and High Performance Computing

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

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1. Team, Visitors, External Collaborators

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Nicolas Charpenay [Ecole Normale Supérieure Paris, from Apr 2018 until Aug 2018]
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Etienne Vareille [Inria, from Jun 2018 until Jul 2018]

Administrative Assistant

Annie Simon [Inria]

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, Patrick Loiseau, 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 [87], Jülich and TU Dresden [86], [57], UIUC [75], [90], [78] and ANL [103], Inria Bordeaux [63] and Grenoble [105], ...) but most of these tools build on the classical information visualization mantra [95] 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 [82]. 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 [85] 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 [94], [81], [74] to identify and characterize (in term of performance and resource usage) application phases and present aggregated representations of the trace [93]. Researchers from Jülich and TU Darmstadt have proposed techniques to identify specific communication patterns that incur wait states [100], [50]

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. [49] 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 [61], 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 [53] and the validity of the underlying network models [51], [98]. Many simulators of MPI applications have been developed by renowned HPC groups (e.g., at SDSC [96], BSC [47], UIUC [104], Sandia Nat. Lab. [99], ORNL [60] or ETH Zürich [76] 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) [65], [58], 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 [88]) or simply to generate trajectories with a forward Monte-Carlo simulation leveraging time parallel simulation (pioneered by Fujimoto [69], Lin and Lazowska [80]). One of the strength of the PSI framework is its expressiveness that allows us to easily study networks with finite and infinite capacity queues [59]. 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 [89] or to perform model-checking [48]. 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 [70], [79], [102], and has been successfully applied in various domains: wireless networks [52], computer-based systems [73], [84], [97], epidemic or rumour propagation [62], [77] and bike-sharing systems [66]. It is also used to develop distributed control strategies [101], [83] or to construct approximate solutions of stochastic model checking problems [54], [55], [56].

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 [70], we would like to be able to handle heterogeneous or uncertain dynamics. Typical applications are caching mechanisms [73] or bike-sharing systems [67]. A second point of interest is the use of mean field or large deviation asymptotics to compute the time between two regimes [92] 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 [71] to build distributed control algorithms [64] and optimal pricing mechanisms [72].

3.5. Distributed Learning in Games and Online Optimization

Participants: Nicolas Gast, Bruno Gaujal, Arnaud Legrand, Patrick Loiseau, 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 [68], [91]. 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-géneration wireless systems that can effectively "learn in the dark", without requiring crippling amounts of feedback.

4.3. Energy and Transportation

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. 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.

4.4. Social Computing Systems

Social computing systems are online digital systems that use personal data of their users at their core to deliver personalized services directly to the users. They are omnipresent and include for instance recommendation systems, social networks, online medias, daily apps, etc. Despite their interest and utility for users, these systems pose critical challenges of privacy, security, transparency, and respect of certain ethical constraints such as fairness. Solving these challenges involves a mix of measurement and/or audit to understand and assess issues, and modeling and optimization to propose and calibrate solutions.

5. Highlights of the Year

5.1. Highlights of the Year

- Bruno Gaujal joined the scientific committee of the GDR IM (Informatique Mathématique).
- Arnaud Legrand co-created a MOOC on “Recherche reproductible : principes méthodologiques pour une science transparente” hosted on the FUN platform https://www.fun-mooc.fr/courses/course-v1:inria+41016+session01bis/about.

5.1.1. Awards

- The paper by Nicolas Gast and co-authors received the Best Paper Award at ACM SIGMETRICS 2018.
- The paper by Patrick Loiseau and co-authors was nominated for the Best Paper Award at ACM FAT* 2018.
- The work on “Multi-Agent Online Learning with Imperfect Information” by Panayotis Mertikopoulos and co-authors was shortlisted for the INFORMS George Nicholson Best Student Paper Award.
- Panayotis Mertikopoulos received an Outstanding Reviewer Award at NIPS 2018.
- Benjamin Roussillon was co-laureate of the “Prix de mémoire de master 2018 en RO/AD” (best MSc thesis in operations research) from ROADEF for his Master thesis on “Development of adversarial classifiers using Bayesian games” under the supervision of Patrick Loiseau.

BEST PAPERS AWARDS:

[24]
N. GAST, B. V. HOUDT. *A Refined Mean Field Approximation*, in "ACM SIGMETRICS 2018", Irvine, France, June 2018, 1 p. , https://hal.inria.fr/hal-01891642

[30]
T. SPEICHER, M. ALI, G. VENKATADRI, F. RIBEIRO, G. ARVANITAKIS, F. BENEVENUTO, K. P. GUMMADI, P. LOISEAU, A. MISLOVE. *Potential for Discrimination in Online Targeted Advertising*, in "FAT 2018 - Conference on Fairness, Accountability, and Transparency", New-York, United States, February 2018, vol. 81, pp. 1-15, https://hal.archives-ouvertes.fr/hal-01955343

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.
NEWS OF THE YEAR: There were 3 major releases in 2018: The public API was sanitized (with compatibility wrappers in place). Th documentation was completely overhauled. Our continuous integration was greatly improved (45 Proxy Apps + BigDFT + StarPU + BatSim now tested nightly). Some kernel headers are now installed, allowing external plugins. Allow dynamic replay of MPI apps, controlled by S4U actors. Port the MPI trace replay engine to C++, fix visualization (+ the classical bug fixes and doc improvement).

- Participants: Adrien Lèbre, Arnaud Legrand, Augustin Degomme, Florence Perronnin, Frédéric Suter, Jean-Marc Vincent, Jonathan Pastor, Luka Stanisic and Martin Quinson
- Partners: CNRS - ENS Rennes
- Contact: Martin Quinson
- URL: https://simgrid.org/

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. Design of Experiments

A large amount of resources is spent writing, porting, and optimizing scientific and industrial High Performance Computing applications, which makes autotuning techniques fundamental to lower the cost of leveraging the improvements on execution time and power consumption provided by the latest software and hardware platforms. Despite the need for economy, most autotuning techniques still require a large budget of costly experimental measurements to provide good results, while rarely providing exploitable knowledge after optimization. In [40], we present a user-transparent (white-box) autotuning technique based on Design of Experiments that operates under tight budget constraints by significantly reducing the measurements needed to find good optimizations. Our approach enables users to make informed decisions on which optimizations to pursue and when to stop. We present an experimental evaluation of our approach and show it is capable of leveraging user decisions to find the best global configuration of a GPU Laplacian kernel using half of the measurement budget used by other common autotuning techniques. We show that our approach is also capable of finding speedups of up to $50\times$, compared to gcc's-O3, for some kernels from the SPAPT benchmark suite, using up to $10\times$ less measurements than random sampling.

7.2. Experimenting with Fog Infrastructures

To this day, the Internet of Things (IoT) continues its explosive growth. Nevertheless, with the exceptional evolution of traffic demand, existing infrastructures are struggling to resist. In this context, Fog computing is shaping the future of IoT applications. Fog computing provides computing, storage and communication resources at the edge of the network, near the physical world. This section describes two independent contributions on how to study and develop FOG infrastructures. These contributions take place in the context of the Inria/Orange Labs joint laboratory.

- Despite its several advantages, Fog computing raises new challenges which slow its adoption down. In particular, there are currently few practical solutions allowing to exploit such infrastructure and to evaluate potential strategies. In [42], we propose a prototype orchestration architecture building on both Grid5000 and Fit-IoT lab (SILECS). This experimental testbed allows to realistically and rigorously evaluate orchestration strategies. In [20], we propose FITOR, an orchestration system for IoT applications in the Fog environment, which extends the actor-model based Calvin framework to cope with Fog environments while offering efficient orchestration mechanisms. In order to optimize the provisioning of Fog-Enabled IoT applications, FITOR relies on O-FSP, an optimized fog service provisioning strategy which aims to minimize the provisioning cost of IoT applications, while meeting their requirements. Based on extensive experiments, the results obtained show that O-FSP optimizes the placement of IoT applications and outperforms the related strategies in terms of i) provisioning cost ii) resource usage and iii) acceptance rate.
- End devices nearing the physical world can have interesting properties such as short delays, responsiveness, optimized communications and privacy. However, these end devices have low stability and are prone to failures. There is consequently a need for failure management protocols for IoT applications in the Fog. The design of such solutions is complex due to the specificities of the environment, i.e., (i) dynamic infrastructure where entities join and leave without synchronization, (ii) high heterogeneity in terms of functions, communication models, network, processing and storage capabilities, and, (iii) cyber-physical interactions which introduce non-deterministic and physical world's space and time dependent events. In [29], [37], we present a fault tolerance approach taking into account these three characteristics of the Fog-IoT environment. Fault tolerance is achieved by saving the state of the application in an uncoordinated way. When a failure is detected, notifications are propagated to limit the impact of failures and dynamically reconfigure the application. Data stored during the state saving process are used for recovery, taking into account consistency with respect to the physical world. The approach was validated through practical experiments on a smart home platform.

7.3. HPC Application Analysis and Visualization

- Programming paradigms in High-Performance Computing have been shifting towards task-based models which are capable of adapting readily to heterogeneous and scalable supercomputers. The performance of task-based application heavily depends on the runtime scheduling heuristics 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. Furthermore, the combination of application structure, scheduler, and hardware information is generally essential to understand performance issues. The papers [36], [6] presents a flexible framework that enables one to combine several sources of information and to create custom visualization panels allowing 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, are detailed to show how our framework can be 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.
- In the context of multi-physics simulations on unstructured and heterogeneous meshes, generating well-balanced partitions is not trivial. The computing cost per mesh element in different phases of the simulation depends on various factors such as its type, its connectivity with neighboring elements or its layout in memory with respect to them, which determines the data locality. Moreover, if different types of discretization methods or computing devices are combined, the performance variability across the domain increases. Due to all these factors, evaluate a representative computing cost per mesh element, to generate well-balanced partitions, is a difficult task. Nonetheless, load balancing is a critical aspect of the efficient use of extreme scale systems since idle-times can represent a huge waste of resources, particularly when a single process delays the overall simulation. In this context, we present in [16] some improvements carried out on an in-house geometric mesh partitioner based on the Hilbert Space-Filling Curve. We have previously tested its effectiveness by partitioning meshes with up to 30 million elements in a few tenths of milliseconds using up to 4096 CPU cores, and we have leveraged its performance to develop an autotuning approach to adjust the load balancing according to runtime measurements. In this paper, we address the problem of having different load distributions in different phases of the simulation, particularly in the matrix assembly and in the solution of the linear system. We consider a multi-partition approach to ensure a proper load balance in all the phases. The initial results presented show the potential of this strategy.

7.4. Energy Optimization and Smart Grids Simulation

Large-scale decentralized photovoltaic (PV) generators are currently being installed in many low-voltage distribution networks. Without grid reinforcements or production curtailment, they might create current and/or voltage issues. In [13], [45], we consider the use the advanced metering infrastructure (AMI) as the basis for PV generation control. We show that the advanced metering infrastructure may be used to infer some knowledge about the underlying network, and we show how this knowledge can be used by a simple feed-forward controller to curtail the solar production efficiently.

We developed a environment for co-simulating electrical networks, telecommunication networks and online learning algorithms [3]. One the outputs of this work was to allow us to perform realistic numerical simulations of active distribution networks. We used this simulator to compare our proposed controller with two other controller structures: open-loop, and feedback P (U) and Q(U). We demonstrate that our feed-forward controller –that requires no prior knowledge of the underlying electrical network– brings significant performance improvements as it can effectively suppress over-voltage and over-current while requiring low energy curtailment. This method can be implemented at low cost and require no specific information about the network on which it is deployed.

Finally, we study demand-Response (DR) programs, whereby users of an electricity network are encouraged by economic incentives to rearrange their consumption in order to reduce production costs. Such mechanisms are envisioned to be a key feature of the smart grid paradigm. Several recent works proposed DR mechanisms and used analytical models to derive optimal incentives. Most of these works, however, rely on a macroscopic description of the population that does not model individual choices of users. In in[4], we conduct a detailed analysis of those models and we argue that the macroscopic descriptions hide important assumptions that can jeopardize the mechanisms' implementation (such as the ability to make personalized offers and to perfectly estimate the demand that is moved from a timeslot to another). Then, we start from a microscopic description that explicitly models each user's decision. We introduce four DR mechanisms with various assumptions on the provider's capabilities. Contrarily to previous studies, we find that the optimization problems that result from our mechanisms are complex and can be solved numerically only through a heuristic. We present numerical simulations that compare the different mechanisms and their sensitivity to forecast errors. At a high level, our results show that the performance of DR mechanisms under reasonable assumptions on the provider's capabilities are significantly lower than those suggested by previous studies, but that the gap reduces when the population's flexibility increases.

7.5. Simulation of HPC Applications

Beside continuous development and contribution to the SimGrid project, the two following contributions have been published this year. Both build on the SMPI interface which allows to efficiently predict the performance of MPI applications.

- Finite-difference methods are commonplace in High Performance Computing applications. Despite their apparent regularity, they often exhibit load imbalance that damages their efficiency. In [9], we characterize the spatial and temporal load imbalance of Ondes3D, a typical finite-differences application dedicated to earthquake modeling. Our analysis reveals imbalance originating from the structure of the input data, and from low-level CPU optimizations. Ondes3D was successfully ported to AMPI/CHARM++ using over-decomposition and MPI process migration techniques to dynamically rebalance the load. However, this approach requires careful selection of the over-decomposition level, the load balancing algorithm, and its activation frequency. These choices are usually tied to application structure and platform characteristics. We have thus proposed a workflow that leverages the capabilities of SimGrid to conduct such study at low experimental cost. We rely on a combination of emulation, simulation, and application modeling that requires minimal code modification and manages to capture both spatial and temporal load imbalance to faithfully predict the performance of dynamic load balancing. We evaluate the quality of our simulation by comparing simulation results with the outcome of real executions and demonstrate how this approach can be used to quickly find the optimal load balancing configuration for a given application/hardware configuration.
- It is typical in High Performance Computing (HPC) courses to give students access to HPC platforms so that they can benefit from hands-on learning opportunities. Using such platforms, however, comes with logistical and pedagogical challenges. For instance, a logistical challenge is that access to representative platforms must be granted to students, which can be difficult for some institutions or course modalities; and a pedagogical challenge is that hands-on learning opportunities are constrained by the configurations of these platforms. A way to address these challenges is to instead simulate program executions on arbitrary HPC platform configurations. In [19] we focus on simulation in the specific context of distributed-memory computing and MPI programming education. While using simulation in this context has been explored in previous works, our approach offers two crucial advantages. First, students write standard MPI programs and can both debug and analyze the performance of their programs in simulation mode. Second, large-scale executions can be simulated in short amounts of time on a single standard laptop computer.

This is possible thanks to SMPI, an MPI simulator provided as part of SimGrid. After detailing the challenges involved when using HPC platforms for HPC education and providing background information about SMPI, we present SMPI Courseware. SMPI Courseware is a set of in-simulation assignments that can be incorporated into HPC courses to provide students with hands-on experience for distributed-memory computing and MPI programming learning objectives. We describe some these assignments, highlighting how simulation with SMPI enhances the student learning experience.

7.6. Mean Field and Refined Mean Field Methods

Mean field approximation is a popular means to approximate stochastic models that can be represented as a system of N interacting objects. It is know to be exact as N goes to infinity. In a recent series of paper, [24], [25], [7], we establish theoretical results and numerical methods that allows us to define an approximation that is much more accurate than the classical mean field approximation. This new approximation, that we call the *refined mean field approximation*, is based on the computation of an expansion term of the order $1/N$. By considering a variety of applications, that include coupon collector, load balancing and bin packing problems, 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: relative errors are often below 1% for systems with $N = 10$.

In [23], [8], we improve this result in two directions. First, we show how to obtain the same result for the transient regime. Second, we provide a further refinement by expanding the term in $1/N^2$ (both for transient and steady-state regime). Our derivations are inspired by moment-closure approximation, a popular technique in theoretical biochemistry. We provide a number of examples that show: (1) that this new approximation is usable in practice for systems with up to a few tens of dimensions, and (2) that it accurately captures the transient and steady state behavior of such systems.

7.7. Optimization of Networks and Communication

This section describes two independent contributions on the analysis and optimization of networks and communication.

- Telecommunication networks are converging to a massively distributed cloud infrastructure interconnected with software defined networks. In the envisioned architecture, services will be deployed flexibly and quickly as network slices. Our paper [26] addresses a major bottleneck in this context, namely the challenge of computing the best resource provisioning for network slices in a robust and efficient manner. With tractability in mind, we propose a novel optimization framework which allows fine-grained resource allocation for slices both in terms of network bandwidth and cloud processing. The slices can be further provisioned and auto-scaled optimally based on a large class of utility functions in real-time. Furthermore, by tuning a slice-specific parameter, system designers can trade off traffic-fairness with computing-fairness to provide a mixed fairness strategy. We also propose an iterative algorithm based on the alternating direction method of multipliers (ADMM) that provably converges to the optimal resource allocation and we demonstrate the method's fast convergence in a wide range of quasi-stationary and dynamic settings.
- Distributed power control schemes in wireless networks have been well-examined, but standard methods rarely consider the effect of potentially random delays, which occur in almost every real-world network. We present in paper [33] Robust Feedback Averaging, a novel power control algorithm that is capable of operating in delay-ridden and noisy environments. We prove optimal convergence of this algorithm in the presence of random, time-varying delays, and present numerical simulations that indicate that Robust Feedback Averaging outperforms the ubiquitous Foschini-Miljanic algorithm in several regimes.

7.8. Privacy, Fairness, and Transparency in Online Social Medias

Bringing transparency to algorithmic decision making systems and guaranteeing that the system satisfies properties of fairness and privacy is crucial in today's world. To start tackling this broad challenge, we focused on the case of online advertising and we had the following contributions.

- *Transparency properties for social media advertising and audit of Facebook's explanations.* In [15], we took a first step towards exploring the transparency mechanisms provided by social media sites, focusing on the two processes for which Facebook provides transparency mechanisms: the process of how Facebook infers data about users, and the process of how advertisers use this data to target users. We call explanations about those two processes *data explanations* and *ad explanations*, respectively.

  We identify a number of *properties* that are key for different types of explanations aimed at bringing transparency to social media advertising. We then evaluate empirically how well Facebook's explanations satisfy these properties and discuss the implications of our findings in view of the possible purposes of explanations. In particular, for *ad explanations*, we define five key properties: *personalization*, *completeness*, *correctness* (and the companion property of *misleadingness*), *consistency*, and *determinism*, and we show that Facebook's ad explanations are often *incomplete* and sometimes *misleading*. In particular, we observe that Facebook reveals only the most prevalent attribute used by the advertisers, which may allow malicious advertisers to easily obfuscate ad explanations from ad campaigns that are discriminatory or that target privacy-sensitive attributes. For *data explanations*, we define four key properties of the explanations: *specificity*, *snapshot completeness*, *temporal completeness*, and *correctness*; and we show that Facebook's explanations are *incomplete* and often *vague*; hence potentially limiting user control.

  Overall, our study provides a first step towards better understanding and improving transparency in social media advertising. During this work, we developed the tool AdAnalyst (https://adanalyst.mpi-sws.org/), which was instrumental for the study but also provides a transparency tool on its own for the large public, and is anticipated to be the basis of a number of further research studies in transparency.

- *Potential for discrimination in social media advertising.* Recently, online targeted advertising platforms like Facebook have been criticized for allowing advertisers to discriminate against users belonging to sensitive groups, i.e., to exclude users belonging to a certain race or gender from receiving their ads. Such criticisms have led, for instance, Facebook to disallow the use of attributes such as ethnic affinity from being used by advertisers when targeting ads related to housing or employment or financial services. In our paper [30], we systematically investigate the different targeting methods offered by Facebook (traditional attribute- or interest-based targeting, custom audience and lookalike audience) for their ability to enable discriminatory advertising and showed that a malicious advertiser can create highly discriminatory ads without using sensitive attributes (hence banning those features is inefficient to solve the problem). We argue that discrimination measures should be based on the targeted population and not on the attributes used for targeting and propose a discrimination metric in this direction.

- *Identification and resolution of privacy leakages in the Facebook's advertising platform.* In paper [31] we discovered that the information provided to advertisers through the custom audience feature (where an advertisers can upload PIIs (Personally Identifiable Information) of their customers and Facebook matches those with their users) was very severely leaking personal information. Specifically, it was making it possible for a malicious advertiser knowing the email address of a user to discover its phone number. Perhaps even worse, it was allowing a malicious advertiser to de-anonymize visitors of a website he controls. We discovered that the problem was due to the way Facebook computes estimates of the number of users matching a list of PIIs and proposed a solution based on not de-duplicating records with different PIIs belonging to the same users; and we proved the robustness of our solution theoretically. Our work led to Facebook implementing a solution inspired by the one we proposed.

7.9. Optimization Methods

This section describes four independent contributions on optimization.

- In view of solving convex optimization problems with noisy gradient input, we analyze in the paper [11] the asymptotic behavior of gradient-like flows under stochastic disturbances. Specifically, we focus on the widely studied class of mirror descent schemes for convex programs with compact feasible regions, and we examine the dynamics' convergence and concentration properties in the presence of noise. In the vanishing noise limit, we show that the dynamics converge to the solution set of the underlying problem (a.s.). Otherwise, when the noise is persistent, we show that the dynamics are concentrated around interior solutions in the long run, and they converge to boundary solutions that are sufficiently "sharp". Finally, we show that a suitably rectified variant of the method converges irrespective of the magnitude of the noise (or the structure of the underlying convex program), and we derive an explicit estimate for its rate of convergence.
- We examine in paper [12] a class of stochastic mirror descent dynamics in the context of monotone variational inequalities (including Nash equilibrium and saddle-point problems). The dynamics under study are formulated as a stochastic differential equation driven by a (single-valued) monotone operator and perturbed by a Brownian motion. The system's controllable parameters are two variable weight sequences that respectively pre- and post-multiply the driver of the process. By carefully tuning these parameters, we obtain global convergence in the ergodic sense, and we estimate the average rate of convergence of the process. We also establish a large deviations principle showing that individual trajectories exhibit exponential concentration around this average.
- We develop in [17] a new stochastic algorithm with variance reduction for solving pseudo-monotone stochastic variational inequalities. Our method builds on Tseng's forward-backward-forward algorithm, which is known in the deterministic literature to be a valuable alternative to Korpelevich's extragradient method when solving variational inequalities over a convex and closed set governed with pseudo-monotone and Lipschitz continuous operators. The main computational advantage of Tseng's algorithm is that it relies only on a single projection step, and two independent queries of a stochastic oracle. Our algorithm incorporates a variance reduction mechanism, and leads to a.s. convergence to solutions of a merely pseudo-monotone stochastic variational inequality problem. To the best of our knowledge, this is the first stochastic algorithm achieving this by using only a single projection at each iteration.
- One of the most widely used training methods for large-scale machine learning problems is distributed asynchronous stochastic gradient descent (DASGD). However, a key issue in its implementation is that of delays: when a "worker" node asynchronously contributes a gradient update to the "master", the global model parameter may have changed, rendering this information stale. In massively parallel computing grids, these delays can quickly add up if a node is saturated, so the convergence of DASGD is uncertain under these conditions. Nevertheless, by using a judiciously chosen quasilinear step-size sequence, we show in [35] that it is possible to amortize these delays and achieve global convergence with probability 1, even under polynomially growing delays, reaffirming in this way the successful application of DASGD to large-scale optimization problems.

7.10. Multi-agent Learning and Distributed Best Response

This section describes several independent contributions on multi-agent learning.

- In [5], [22], [21], we study how fast can simple algorithms compute Nash equilibria. We study the case of random potential games for which we have designed and analyzed distributed algorithms to compute a Nash equilibrium. 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.

- In [10], we study a class of evolutionary game dynamics defined by balancing a gain determined by the game's payoffs against a cost of motion that captures the difficulty with which the population moves between states. Costs of motion are represented by a Riemannian metric, i.e., a state-dependent inner product on the set of population states. The replicator dynamics and the (Euclidean) projection dynamics are the archetypal examples of the class we study. Like these representative dynamics, all Riemannian game dynamics satisfy certain basic desiderata, including positive correlation and global convergence in potential games. Moreover, when the underlying Riemannian metric satisfies a Hessian integrability condition, the resulting dynamics preserve many further properties of the replicator and projection dynamics. We examine the close connections between Hessian game dynamics and reinforcement learning in normal form games, extending and elucidating a well-known link between the replicator dynamics and exponential reinforcement learning.
- The paper [18] examines the long-run behavior of learning with bandit feedback in non-cooperative concave games. The bandit framework accounts for extremely low-information environments where the agents may not even know they are playing a game; as such, the agents' most sensible choice in this setting would be to employ a no-regret learning algorithm. In general, this does not mean that the players' behavior stabilizes in the long run: no-regret learning may lead to cycles, even with perfect gradient information. However, if a standard monotonicity condition is satisfied, our analysis shows that no-regret learning based on mirror descent with bandit feedback converges to Nash equilibrium with probability 1. We also derive an upper bound for the convergence rate of the process that nearly matches the best attainable rate for single-agent bandit stochastic optimization.
- In [34], we consider a game-theoretical multi-agent learning problem where the feedback information can be lost during the learning process and rewards are given by a broad class of games known as variationally stable games. We propose a simple variant of the classical online gradient descent algorithm, called reweighted online gradient descent (ROGD) and show that in variationally stable games, if each agent adopts ROGD, then almost sure convergence to the set of Nash equilibria is guaranteed, even when the feedback loss is asynchronous and arbitrarily corrrelated among agents. We then extend the framework to deal with unknown feedback loss probabilities by using an estimator (constructed from past data) in its replacement. Finally, we further extend the framework to accomodate both asynchronous loss and stochastic rewards and establish that multi-agent ROGD learning still converges to the set of Nash equilibria in such settings. Together, these results contribute to the broad lanscape of multi-agent online learning by significantly relaxing the feedback information that is required to achieve desirable outcomes.
- Regularized learning is a fundamental technique in online optimization, machine learning and many other fields of computer science. A natural question that arises in these settings is how regularized learning algorithms behave when faced against each other. In the paper [27], we study a natural formulation of this problem by coupling regularized learning dynamics in zero-sum games. We show that the system's behavior is Poincaré recurrent, implying that almost every trajectory revisits any (arbitrarily small) neighborhood of its starting point infinitely often. This cycling behavior is robust to the agents' choice of regularization mechanism (each agent could be using a different regularizer), to positive-affine transformations of the agents' utilities, and it also persists in the case of networked competition, i.e., for zero-sum polymatrix games.

7.11. Blotto games

The Colonel Blotto game is a famous game commonly used to model resource allocation problems in many domains ranging from security to advertising. Two players distribute a fixed budget of resources on multiple battlefields to maximize the aggregate value of battlefields they win, each battlefield being won by the player who allocates more resources to it. The continuous version of the game –where players can choose any fractional allocation– has been extensively studied, albeit only with partial results to date. Recently, the discrete version –where allocations can only be integers– started to gain traction and algorithms were proposed to compute the equilibrium in polynomial time; but these remain computationally impractical for large (or even moderate) numbers of battlefields. In [32], [46], we propose an algorithm to compute very efficiently an approximate equilibrium for the discrete Colonel Blotto game with many battlefields. We provide a theoretical bound on the approximation error as a function of the game's parameters, in particular number of battlefields and resource budgets. We also propose an efficient dynamic programming algorithm to compute the best-response to any strategy that allows computing for each game instance the actual value of the error. We perform numerical experiments that show that the proposed strategy provides a fast and good approximation to the equilibrium even for moderate numbers of battlefields.

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

- Bilateral contrat with Enedis (Linky-Lab), Post-doctoral position for 18th months (Mouhcine Mendil).
- 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 in the context of this common laboratory.
- Cifre contract with Schneider Electric. The PhD thesis of Benoit Vinot (supervised by Nicolas Gast and Florent Cadoux (G2Elab)) is supported by this collaboration.

9. Partnerships and Cooperations

9.1. Regional Initiatives

9.1.1. IDEX UGA

Nicolas Gast received a grant from the IDEX UGA that funds a two-years post-doctoral researcher (Takai Kennouche) for two years (2018 and 2019) to work on the smart-grid project that focus on distributed optimization in electrical distribution networks.

Patrick Loiseau and Panayotis Mertikopoulos received a grant from the IDEX UGA that partly funds a PhD student (Benjamin Roussillon) to work on game theoretic models for adversarial classification.

9.2. National Initiatives

9.2.1. Inria Project Labs

Arnaud Legrand is the leader of the HAC SPECIS project. 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. DGA Grants

Patrick Loiseau and Panayotis Mertikopoulos received a grant from DGA that complements the funding of PhD student (Benjamin Roussillon) to work on game theoretic models for adversarial classification.

9.2.3. 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.

9.2.4. PEPS

Panayotis Mertikopoulos est co-PI of a PEPS I3A project: MixedGAN ("Mixed-strategy generative adversarial networks") (PI: R. Laraki, U. Dauphine).

9.2.5. Fondation Blaise Pascal

Project IAM (Informatique à la Main) funded by fondation Blaise Pascal (Jean-Marc Vincent).

9.2.6. ANR

- *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.
- *CONNECTED (2016–2019)*
  CONNECTED is an ANR Tremplin-ERC (T-ERC) grant coordinated by Patrick Loiseau. The goal of the project is to work on several game-theoretic models involving learning agents and data revealed by strategic agents in response to the learning algorithms, so as to derive better learning algorithms for such special data.

9.3. International Initiatives

9.3.1. Inria International Labs

The POLARIS team is involved in the JLESC (Joint Laboratory for Extreme-Scale Computing) with University of University of Illinois Urbana Champaign, Argonne Nat. Lab and BSC.

9.3.2. Participation in Other International Programs

- *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 three weeks in November 2018.

  More information can be found at http://www.inf.ufrgs.br/licia/.
- *GENE*: Stochastic dynamics of large games and networks. This is a joint project (2018 - 2019) with Universidad de Buenos Aires, Argentina (Matthieu Jonckheere), Universidad de la Republica Uruguay (Federico La Rocca), CNRS (Balakrishna Prabhu) and Universidad ORT Uruguay (Andrés Ferragut).

  Through the creation and consolidation of strong research and formation exchanges between Argentina, France and Uruguay, the GENE project will contribute to the fields of performance evaluation and control of communication networks, using tools of game theory, probability theory and control theory. Some of the challenges this project will address are: (1) Mean-field games and their application to load balancing and resource allocations, (2) Scaling limits for centralized and decentralized load balancing strategies and implementation of practical policies for web servers farms, (3) Information diffusion and communication protocols in large and distributed wireless networks.

- *LEARN*: Learning algorithms for games and applications (2016-2018). 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.

9.4. International Research Visitors

9.4.1. Visits to International Teams

9.4.1.1. Research Stays Abroad

Panayotis Mertikopoulos was a visiting scientist at UC Berkeley / Simons Institute for the Theory of Computing (Feb.-March 2018) and a visiting scientist at U Athens / STSM in the framework of the EU COST Action GAMENET (Apr. - May 2018).

Jean-Marc Vincent is the director of Licia (Laboratoire de Calcul Intensif et d'Informatique Ambiante) and stayed 20 days at Porto Alegre to teaching and nurture research collaborations.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events Organisation

10.1.1.1. General Chair, Scientific Chair

Panayotis Mertikopoulos was involved in the following events:

- 2018 French Days on Optimization and Decision Science ("Journées SMAI MODE 2018"): general co-chair
- 2018 Paris Symposium on Game Theory (Paris, June 2018): co-organizer
- GDO '18: the 2018 Workshop on Games, Dynamics, and Optimization (Vienna, March 2018): co-organizer

10.1.2. Scientific Events Selection

10.1.2.1. Chair of Conference Program Committees

- SBAC-PAD 2018 (Arnaud Legrand: chair of the performance evaluation track)

10.1.2.2. Member of the Conference Program Committees

- Performance 2018 (Bruno Gaujal, Nicolas Gast)
- SIGMETRICS 2018 (Nicolas Gast)
- WiOpt 2018 (Bruno Gaujal, Patrick Loiseau)
- NetGCoop 2018 (Bruno Gaujal, Patrick Loiseau)
- NIPS 2018 (Panayotis Mertikopoulos, Patrick Loiseau)
- ICML 2018 (Patrick Loiseau)
- SuperComputing 2018 (Arnaud Legrand)
- RescueHPC 2018 (Arnaud Legrand)
- EPEW 2018 (Jean-Marc Vincent)
- Valuetools 2018 (Jean-Marc Vincent)
- NetEcon 2018 (Patrick Loiseau)

10.1.3. Journal

10.1.3.1. Member of the Editorial Boards

Patrick Loiseau is Associate Editor of ACM Trans. on Internet Technology and of IEEE Trans. on Big Data.

10.1.4. Invited Talks

- Arnaud Legrand gave a keynote on “Simulation of Large-Scale Distributed Computing Infrastructures” at Orange Labs, Chatillon, October 2018 and on “Reproducible Research”at Inria Rennes in May 2018.
- Bruno Gaujal gave invited presentations at Paris Symposium on Game Theory (Paris), International Symposium on Dynamic Games (Grenoble), New trends in Scheduling (Aussois).
- Panayotis Mertikopoulos gave invited presentations at Trinity College Dublin, Ireland on *Efficient network utility maximization algorithms*, at National Technical University of Athens (Athens Polytechnic) Athens, Greece on *Traffic in congested networks: Equilibrium, efficiency, and dynamics*, at GDO 2018 in Vienna, Austria, and on *Bandit learning in concave N-person games*, at UC Berkeley (Simons Institute for the Theory of Computing), USA on *Online learning in games*.

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

The POLARIS members teach regularly. We only mention here lectures at the Master level.

- Master: Bruno Gaujal and Mouhcine Mendil, *“Advanced Performance Evaluation”*, 18h (M2), ENSIMAG
- Master: Bruno Gaujal and Panayotis Mertikopoulos, *“Online decision making”*, M2 ENS Lyon
- Master: Bruno Gaujal and Ana Busic, *“Cours théorie des réseaux”*, M2 MPRI, Paris
- Master M2R : Nicolas Gast *“Optimization Under Uncertainties”*, 18h (M2), Master ORCO, Grenoble.
- Master: Arnaud Legrand and Jean-Marc Vincent, *“Scientific Methodology and Performance Evaluation”*, 18h M2, M2R MOSIG
- Master: Arnaud Legrand, *“Scientific Methodology and Performance Evaluation”*, 18h M2, ENS Rennes
- Master: Panayotis Mertikopoulos, *“Advanced optimization algorithms”*, 16h M2, University of Athens, Athens, Greece
- Master: Guillaume Huard, *“Conception des Systèmes d’Exploitation”* (M1), Université Grenoble-Alpes
- Master: Guillaume Huard, *“Conception des Systèmes d’Exploitation”* (M1), Université Grenoble-Alpes
- Master: Florence Perronnin, *“Simulation”*, M1, Université Versailles – Saint-Quentin
- Master: Arnaud Legrand and Florence Perronnin, *“Probabilités–Simulation”* and *“Performance evaluation”* 72 h (M1), RICM4 Polytech Grenoble
- Master: Jean-Marc Vincent, Mathematics for computer science, 18 h , (M1) Mosig.
- Master/PhD: Jean-Marc Vincent, Litterate Programming and Statistics, UFRGS (Porto Alegre, Brazil)
- Master: Vincent Danjean, Architecture and Software project, engineering school
- Master: Vincent Danjean, Conception of operating systems, concurrent programming and systems project, MOSIG and CS Master, Grenoble

  E-learning Arnaud Legrand has designed and organized a MOOC on Reproducible Research with Konrad Hinsen (CNRS/Centre de Biophysique Moléculaire) and Christophe Pouzat (CNRS/Mathématiques Appliquées à Paris 5) with the support of the Inria MOOC-lab.

This MOOC is hosted on the FUN platform https://www.fun-mooc.fr/courses/course-v1:inria+41016+session01bis/about and the first edition (Oct-Dec 2018) targets graduate students, PhD students, post-doc, engineers and researchers working in any scientific domain relying on computations. In this MOOC, some modern and reliable tools are presented: GitLab for version control and collaborative working, Computational notebooks (Jupyter, RStudio, and Org-Mode) for efficiently combining the computation, presentation, and analysis of data. More than 3,400 people have registered to the first edition.

10.2.2. Supervision

Stephane Durand (PhD UGA defended on Dec. 11, 2018): Distributed Best Response Algorithms in random Potential Games, co-advised by Bruno Gaujal and Federica Garin (funded by Labex Persyval, Grenoble).

Benoit Vinot (PhD UGA defended on April 2018): Design of a distributed information system for the control of flexibilities in a power distribution network: modelling, simulation and implementation, co-advised by Nicolas Gast and Florent Cadoux

Vinicius Garcia Pinto (PhD in co-tutelle with UFRGS defended in 2018): 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 (PhD in co-tutelle with UFRGS defended in 2018): 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).

Alexis Janon (PhD in progress, 2018-...): Tasks Placement on Hierarchical Computational Platforms, co-advised by Guillaume Huard and Arnaud Legrand (funded by the French Ministry)

Stephan Plassart (PhD in progress, 2016-...): Energy Optimization in Embedded Systems, co-advised by Bruno Gaujal and Alain Girault (funded by Labex Persyval, Grenoble).

Baptiste Jonglez (PhD in progress, 2016-...): Leveraging Diversity in Communication Networks, co-advised by Bruno Gaujal and Martin Heusse (funded by Univ Grenoble Alpes).

Vitalii Emelianov (PhD in progress, 2018-...): Fairness and transparency in data-driven decision making, co-advised by Patrick Loiseau and Nicolas Gast (funded by Inria).

Benjamin Roussillon (PhD in progress, 2018-...): Classification in the presence adversarial data: models and solutions, co-advised by Patrick Loiseau and Panayotis Mertikopoulos (funded by IDEX UGA and DGA).

Dong Quan Vu (PhD in progress, 2017-...): Learning in Blotto games and applications to modeling attention in social networks, co-advised by Patrick Loiseau and Alonso Silva (Cifre PhD with Nokia Bell-Labs)

Athanasios Andreou (PhD in progress, 2015-...): Bringing transparency to personalized systems through statistical inference, co-advised by Patrick Loiseau and Oana Goga (funded by Institut Mines Telecom and ANR)

Alexandre Marcastel (PhD in progress, 2015-...): co-advised by E. Veronica Belmega, Panayotis Mertikopoulos and Inbar Fijalkow

Kimon Antonakopoulos (PhD in progress, 2017-...): Variational inequalities and optimization, co-advised by E. Veronica Belmega, Panayotis Mertikopoulos and Bruno Gaujal

Bruno Donassolo (PhD in progress, 2017-...): Decentralized management of applications in Fog computing environments, co-supervised by Panayotis Mertikopoulos, Arnaud Legrand and Ilhem Fajjari (Cifre PhD with Orange)

Pedro Bruel (PhD in progress 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 (PhD in progress 2017-...): Capacity planning and performance evaluation of supercomputers, advised by Arnaud Legrand (funded by the French Ministry for Research).

Christian Heinrich (PhD in progress 2015-...): Modeling of performance and energy consumption of HPC systems, advised by Arnaud Legrand (funded by Inria).

Umar Ozeer (PhD in progress 2017-...): co-advised by Jean-Marc Vincent, Gwen Salaün, François-Gaël Ottogalli and Loic Letondeur (within the Inria-Orange lab).

Amélie Héliou (PostDoc, Sep. 2017-May 2018): co-supervised by Panayotis Mertikopoulos and Bruno Gaujal

Mouhcine Mendil (PostDoc, 2017-...): supervised by Nicolas Gast

Takai Kennouche (PostDoc, 2017-...): supervised by Nicolas Gast

Luigi Vigneri (PostDoc, Sep. 2017-Sep.2018): co-supervised by Panayotis Mertikopoulos and G. Paschos

Olivier Bilenne (PostDoc, 2018-...): co-supervised by Panayotis Mertikopoulos and E. V. Belmega

10.2.3. Juries

- Bruno Gaujal was president of the jury for the CRCN Inria Grenoble Rhone-Alpes competition.
- Jean-Marc Vincent was member of the jury of Capes de mathématiques (option Informatique).
- Bruno Gaujal was reviewer of the PhD of Adil Salim (Telecom Paris Tech) and Panayotis Mertikopoulos was examinator.
- Nicolas Gast was reviewer of the PhD of Fabbio Cecchi (Univ. Eindhoven).
- Arnaud Legrand was president of the jury for the PhD of Louis Poirel (Univ. Bordeaux).
- Arnaud Legrand was president of the jury for the PhD of Nicolas Denoyelle (Univ. Bordeaux).
- Arnaud Legrand was president of the jury for the PhD of Valentin Reis (Univ. Grenoble Alpes).
- Arnaud Legrand was examinator of the jury for the PhD of Marcos Amaris Gonzales (Univ. São Paulo).

10.3. Popularization

10.3.1. Internal or external Inria responsibilities

- Jean-Marc Vincent is responsible for the mediation in the Inria Rhône-Alpes center in relation with the Rectorat de l'Académie de Grenoble (organisation of ISN conferences, Class'Code for digital referents)
- Jean-Marc Vincent coordinates the group "Info sans ordi" (computer science without computer)–in which Florence Perronnin participates

10.3.2. Articles and contents

Jean-Marc Vincent has coordinated and participated to the redaction of the 96 pages special issue of *Tangente* on *Informatique Débranchée*: http://www.infinimath.com/librairie/descriptif_livre.php?type=magazines&theme=7&soustheme=26&ref=2568#article.

10.3.3. Education

- Highschool Professors: Vincent Danjean is responsible of the University Dept. for Highschool Professors Training in Computer Science (in relation with the rectorat).
- Highschool Professors: Jean-Marc Vincent is member of the steering committee for the training of Highschool Professors towards the new option NSI (Numérique et Sciences Informatiques) for Baccalauréat and participated in the creation of a inter-university diploma in CS.
- Arnaud Legrand gave a lecture on “Reproducible Research” at CIRM in May 2018 to the computer science teachers of classes préparatoires.
- Bruno Gaujal: Course on game theory at the 7 laux of ENS Lyon students
- Bruno Gaujal: Course on dynamique optimization for high school teachers.
- Florence Perronnin: creation of an option in Licence on “Sciences Informatiques et Médiation” (CS and mediation)

10.3.4. Interventions

- Arnaud Legrand made a podcast with Interstice on reproducible research https://interstices.info/la-recherche-reproductible-pour-une-science-transparente/
- Participation to mediation events of the center (Fête de la science, journées math C2+, journée login)
- Participation to mediation actions Inria/Irem/Maison for Science (Jean-Marc Vincent)

11. Bibliography

Publications of the year

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[2] R. KELLER TESSER. *A Simulation Workflow to Evaluate the Performance of Dynamic Load Balancing with Over-decomposition for Iterative Parallel Applications*, Universidade Federal Do Rio Grande Do Sul, April 2018, https://tel.archives-ouvertes.fr/tel-01962082

[3] B. VINOT. *Design of a distributed information system for the control of flexibilities in a power distribution network: modelling, simulation and implementation*, UGA - Université Grenoble Alpes ; MSTII, June 2018, https://tel.archives-ouvertes.fr/tel-01875320

Articles in International Peer-Reviewed Journals

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[6] V. GARCIA PINTO, L. M. SCHNORR, L. STANISIC, A. LEGRAND, S. THIBAULT, V. DANJEAN. *A Visual Performance Analysis Framework for Task-based Parallel Applications running on Hybrid Clusters*, in "Concurrency and Computation: Practice and Experience", April 2018, vol. 30, n^{o} 18, pp. 1-31 [*DOI :* 10.1002/CPE.4472], https://hal.inria.fr/hal-01616632

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Invited Conferences

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International Conferences with Proceedings

[14] A. ANDREOU, M. SILVA, F. BENEVENUTO, O. GOGA, P. LOISEAU, A. MISLOVE. *Measuring the Facebook Advertising Ecosystem*, in "NDSS 2019 - Proceedings of the Network and Distributed System Security Symposium", San Diego, United States, February 2019 [*DOI :* 10.14722/NDSS.2019.23280], https://hal.archives-ouvertes.fr/hal-01959145

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[21] S. DURAND, F. GARIN, B. GAUJAL. *Distributed Best Response Algorithms for Potential Games*, in "ECC 2018 - 16th European Control Conference", Limassol, Cyprus, June 2018, pp. 1-6, https://hal.inria.fr/hal-01726836

[22] S. DURAND, F. GARIN, B. GAUJAL. *Efficiency of Best Response Dynamics with High Playing Rates in Potential Games*, in "IFIP WG 7.3 Performance 2018 - 36th International Symposium on Computer Performance, Modeling, Measurements and Evaluation", Toulouse, France, December 2018, pp. 1-2, https://hal.inria.fr/hal-01940150

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N. GAST, B. V. HOUDT. *A Refined Mean Field Approximation*, in "ACM SIGMETRICS 2018", Irvine, France, June 2018, 1 p. , https://hal.inria.fr/hal-01891642.

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T. SPEICHER, M. ALI, G. VENKATADRI, F. RIBEIRO, G. ARVANITAKIS, F. BENEVENUTO, K. P. GUMMADI, P. LOISEAU, A. MISLOVE. *Potential for Discrimination in Online Targeted Advertising*, in "FAT 2018 - Conference on Fairness, Accountability, and Transparency", New-York, United States, February 2018, vol. 81, pp. 1-15, https://hal.archives-ouvertes.fr/hal-01955343.

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