RESEARCH CENTRE

Inria Center at Université Côte d'Azur

2022
ACTIVITY REPORT

Project-Team
NEO

Network Engineering and Operations

DOMAIN

Networks, Systems and Services, Distributed Computing

THEME

Networks and Telecommunications

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Project-Team NEO

Creation of the Project-Team: 2017 December 01

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A1.2.4. – QoS, performance evaluation

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1 Team members, visitors, external collaborators

Research Scientists

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- Sara Alouf [INRIA, Researcher, HDR]
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- Othmane Marfoq [INRIA]
- Angelo Rodio [INRIA]

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- Xinying Zou [INRIA, from Dec 2022]

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- Patrick Brown [Emeritus]
- Lucas Gamertsfelder [Macquarie University, Australia, from Nov 2022]
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2 Overall objectives

NEO is an Inria project-team whose members are located in Sophia Antipolis (S. Alouf, K. Avrachenkov, G. Neglia, and S. M. Perlaza), in Avignon (E. Altman) at LIA (Lab. of Informatics of Avignon) and in Montpellier (A. Jean-Marie). E. Altman is also with the LINCS (Lab. for Information, Networking and Communication Sciences). S. M. Perlaza is also with the ECE department at Princeton Univ., N.J. USA; and the Mathematics Department of the Univ. de la Polynésie française (Laboratoire GAATI), Faaa, Tahiti.

The team is positioned at the intersection of Operations Research and Network Science. By using the tools of Stochastic Operations Research, we model situations arising in several application domains, involving networking in one way or the other. The aim is to understand the rules and the effects in order to influence and control them so as to engineer the creation and the evolution of complex networks.

3 Research program

The problems studied in NEO involve generally optimization, dynamic systems or randomness, and often all at the same time. The techniques we use to tackle these problems are those of Stochastic Operations Research, Applied Probabilities and Information Theory.

Stochastic Operations Research is a collection of modeling, optimization and numerical computation techniques, aimed at assessing the behavior of man-made systems driven by random phenomena, and at helping to make decisions in such a context.

The discipline is based on applied probability and focuses on effective computations and algorithms. Its core theory is that of Markov chains over discrete state spaces. This family of stochastic processes has, at the same time, a very large modeling capability and the potential of efficient solutions. By "solution" is meant the calculation of some *performance metric*, usually the distribution of some random variable of interest, or its average, variance, etc. This solution is obtained either through exact "analytic" formulas, or numerically through linear algebra methods. Even when not analytically or numerically tractable, Markovian models are always amenable to "Monte-Carlo" simulations with which the metrics can be statistically measured.

An example of this is the success of classical Queueing Theory, with its numerous analytical formulas. Another important derived theory is that of the Markov Decision Processes, which allows to formalize *optimal* decision problems in a random environment. This theory allows to characterize the optimal decisions, and provides algorithms for calculating them.

Strong trends of Operations Research are: a) an increasing importance of multi-criteria multi-agent optimization, and the correlated introduction of Game Theory in the standard methodology; b) an increasing concern of (deterministic) Operations Research with randomness and risk, and the consequent introduction of topics like Chance Constrained Programming and Stochastic Optimization. Data analysis is also more and more present in Operations Research: techniques from statistics, like filtering and estimation, or Artificial Intelligence like clustering, are coupled with modeling in Machine Learning techniques like Q-Learning.

4 Application domains

4.1 Network Science

Network Science is a multidisciplinary body of knowledge, principally concerned with the emergence of global properties in a network of individual agents. These global properties emerge from "local" properties of the network, namely, the way agents interact with each other. The central model of "networks" is the graph (of Graph Theory/Operations Research). Nodes represent the different entities managing information and taking decisions, whereas, links represent the fact that entities interact, or not. Links are usually equipped with a "weight" that measures the intensity of such interaction. Adding evolution rules to this quite elementary representation leads to dynamic network models, the properties of which Network Science tries to analyze.

A classical example of properties sought in networks is the famous "six degrees of separation" (or "small world") property: how and why does it happen so frequently? Another ubiquitous property of real-life networks is the Zipf or "scale-free" distribution for degrees. Some of these properties, when properly exploited, lead to successful business opportunities: just consider the PageRank algorithm of Google, which miraculously connects the relevance of some Web information with the relevance of the other information that points to it.

4.2 Network Engineering

In its primary acceptation, Network Science involves little or no engineering: phenomena are assumed to be "natural" and emerge without external interventions. However, the idea comes fast to intervene in order to modify the outcome of the phenomena. This is where NEO is positioned. Beyond the mostly descriptive approach of Network Science, we aim at using the techniques of Operations Research so as to engineer complex networks.

To quote two examples: controlling the spread of diseases through a "network" of people is of primarily interest for mankind. Similarly, controlling the spread of information or reputation through a social network is of great interest in the Internet. Precisely, given the impact of web visibility on business income, it is tempting (and quite common) to manipulate the graph of the web by adding links so as to drive the PageRank algorithm to a desired outcome.

Another interesting example is the engineering of community structures. Recently, thousands of papers have been written on the topic of community *detection* problem. In most of the works, the researchers propose methods, most of the time, heuristics, for detecting communities or dense subgraphs inside a large network. Much less effort has been put in the understanding of community formation process and even much less effort has been dedicated to the question of how one can influence the process of community formation, e.g. in order to increase overlap among communities and reverse the fragmentation of the society.

Our ambition for the medium term is to reach an understanding of the behavior of complex networks that will make us capable of influencing or producing a certain property in a given network. For this purpose, we will develop families of models to capture the essential structure, dynamics, and uncertainty of complex networks. The "solution" of these models will provide the correspondence between metrics of interest and model parameters, thus opening the way to the synthesis of effective control techniques.

In the process of tackling real, very large size networks, we increasingly deal with large graph data analysis and the development of decision techniques with low algorithmic complexity, apt at providing answers from large datasets in reasonable time.

5 Highlights of the year

5.1 Awards

G. Neglia was recognized one of the "top reviewers" of the 25th International Conference on Artificial Intelligence and Statistics (AISTATS) and TPC distinguished member for IEEE International Conference on Computer Communications (INFOCOM).

G. Neglia was awarded a Chair by the Interdisciplinary Institute for Artificial Intelligence *3IA Côte d'Azur*, in the theme "Core Elements of AI".

5.2 New book

K. Avrachenkov and M. Dreveton have co-authored and published a new book [49]: "Statistical Analysis of Networks". Now Publishers, Oct 6, 2022.

5.3 Foreign appointments

S. Perlaza was re-appointed "Visiting Research Collaborator" in the Electrical and Computer Engineering Department at Princeton University for the academic year 2022-2023; and re-appointed "Associate Researcher" in the Laboratory of Algebraic Geometry and Applications to Information Theory (GAATI) at the Université de la Polynésie Française for the academic year 2022-2023.

6 New software and platforms

6.1 New software

6.1.1 marmoteCore

Name: 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 was started within the ANR MARMOTE project: ANR-12-MONU-00019.

News of the Year: No active development. Current development lies now in the MARTO project (next generations of PSI and marmoteCore) and in the forthcoming Marmote project.

URL: `https://gitlab.inria.fr/PSI/marmotecore/`

Publications: hal-01651940, hal-01276456

Contact: Alain Jean-Marie

Participants: Alain Jean-Marie, Hlib Mykhailenko, Benjamin Briot, Franck Quessette, Issam Rabhi, Jean-Marc Vincent, Jean-Michel Fourneau

Partners: Université de Versailles St-Quentin-en-Yvelines, Université Paris Nanterre

7 New results

7.1 Stochastic Modeling

Participants: Sara Alouf, Konstantin Avrachenkov, Younes Ben Mazziane, Patrick Brown, Alain Jean-Marie, Lucas Gamertsfelder, Giovanni Neglia, Samir Medina Perlaza.

7.1.1 Count-Min Sketch with Conservative Updates

Count-Min Sketch with Conservative Updates (CMS-CU) is a popular algorithm to approximately count items' appearances in a data stream. Despite CMS-CU's widespread adoption, the theoretical analysis of its performance is still wanting because of its inherent difficulty. In [31, 19] Y. Ben Mazziane, S. Alouf, and G. Neglia propose a novel approach to study CMS-CU and derive new upper bounds on the expected value and the CCDF of the count estimation error under an i.i.d. request process. The formulas obtained can be successfully employed to derive improved estimates for the precision of heavy-hitter detection methods and improved configuration rules for CMS-CU. The bounds have been evaluated both on synthetic and real traces.

7.1.2 Infinite Dimensional Linear Programming Approach to Optimal Stochastic Control

In [16], K. Avrachenkov together with V. Gaitsgory and L. Gamertsfelder (both from Macquarie Univ., Australia) study asymptotic properties of problems of control of stochastic discrete time systems with time averaging and time discounting optimality criteria and with general compact state and action spaces (equivalently Markov Decision Processes, MDPs), and they establish that the Cesàro and Abel limits of the optimal values in such problems can be estimated with the help of a certain infinite-dimensional (ID) linear programming (LP) problem and its dual.

7.1.3 Online Algorithms for Estimating Change Rates of Web Pages

In [17], K. Avrachenkov and K. Patil (former NEO member) with G. Thoppe (Indian Institute of Science, IISc, Bangalore, India) consider the following optimization problem: maximize the freshness of the local cache of a web crawler subject to the crawling frequencies being within prescribed bounds. While tractable algorithms do exist to solve this problem, these either assume the knowledge of exact page change rates or use inefficient methods such as MLE for estimating the same. The authors provide three novel schemes for online estimation of page change rates, all of which have extremely low running times per iteration. The first is based on the law of large numbers and the second on stochastic approximation. The third is an extension of the second and includes a heavy-ball momentum term. All these schemes only need partial information about the page change process, i.e., they only need to know if the page has changed or not since the last crawled instance. Numerical experiments (based on real and synthetic data) are also provided that demonstrate the superiority of the proposed estimators over existing ones such as MLE. The algorithms are also readily applicable to the synchronization of databases and network inventory management.

7.1.4 Red Light Green Light Method for Solving Large Markov Chains

Discrete-time discrete-state finite Markov chains are versatile mathematical models for a wide range of real-life stochastic processes. One of most common tasks in studies of Markov chains is computation of the stationary distribution. In [15], K. Avrachenkov and P. Brown, in collaboration with N. Litvak (Twente University, the Netherlands) propose a new controlled, easily distributed algorithm for this task, briefly summarized as follows: at the beginning, each node receives a fixed amount of cash (positive or negative), and at each iteration, some nodes receive 'green light' to distribute their wealth or debt proportionally to the transition probabilities of the Markov chain; the stationary probability of a node is computed as a ratio of the cash distributed by this node to the total cash distributed by all nodes together. The proposed method includes as special cases a wide range of known, very different, and previously disconnected methods including power iterations, Gauss-Southwell, and online distributed algorithms. The authors prove exponential convergence of our method, demonstrate its high efficiency, and derive scheduling strategies for the green-light, that achieve convergence rate faster than state-of-the-art algorithms.

7.1.5 Stability and Partial Instability of Multi-Class Retrial Queues

In most standard queueing systems, in the case of overload, customers are either lost or experience very long or infinite delays. However, in many real systems, rejected or significantly delayed customers leave the queue and then return later. This natural phenomenon motivates the development of retrial queues. In retrial queueing models, once a customer is rejected, he or she goes into the orbit and retries from there. This significantly increases the complexity of the system and makes the analysis of retrial queues challenging. There are two main types of retrial: independent retrials and constant rate retrials. In the former case the retrying customers are in "competition" and retry from the orbit independently. In the latter case, retrying customers wait in the orbit, according to the FIFO principle, and retry only when they are at the front of the orbit queue. In [13], K. Avrachenkov overviews the stability conditions for multi-class retrial queues with constant retrial rates. Also, a very interesting phenomenon of partial (or local) stability is discussed when some orbit sizes are stable (tight) whereas the other orbit sizes grow to infinity. This type of queueing models can find application in access control systems, and in particular, in access control system in overload.

7.1.6 Random walks for Gene Prioritization

Prioritizing genes for their role in drug sensitivity, is an important step in understanding drugs mechanisms of action and discovering new molecular targets for co-treatment. In [29], A. Jean-Marie, together with F. Cazals and D. Mazauric (Inria ABS team), J. Roux, A. Sales de Quieroz and G. Sales Santa Cruz (all from Univ. Côte d'Azur), introduce Genetrank, a method to prioritize the genes in some source set for their likelihood to regulate the genes in some target set. Genetrank uses asymmetric random walks with restarts, absorbing states, and a suitable renormalization scheme. NEO's software `Marmote`, successor of `marmoteCore` (Section 6.1.1) was used for the intensive numerical experiments.

7.1.7 Data Injection Attacks in Power Systems

Since 2020, S. Perlaza in collaboration with X. Ye, I. Esnaola, and R. Harrison (Univ. of Sheffield) have studied sparse stealth attack constructions that minimize the mutual information between the state variables and the observations. In [61], the attack construction is formulated as the design of a multivariate Gaussian distribution that aims to minimize the mutual information while limiting the Kullback-Leibler divergence between the distribution of the observations under attack and the distribution of the observations without attack. The sparsity constraint is incorporated as a support constraint of the attack distribution. Two heuristic greedy algorithms for the attack construction are proposed. The first algorithm assumes that the attack vector consists of independent entries, and therefore, requires no communication between different attacked locations. The second algorithm considers correlation between the attack vector entries and achieves a better disruption to stealth tradeoff at the cost of requiring communication between different locations. Numerical evaluations show that it is feasible to construct stealth attacks that generate significant disruption with a low number of compromised sensors.

7.2 Random Graph and Random Matrix Models

Participants: Konstantin Avrachenkov, Maximilien Dreveton.

K. Avrachenkov and M. Dreveton publish a book "Statistical Analysis of Networks" [49] where various random graph models are applied to network inference problems such as community detection also known as graph clustering, graph-based semi-supervised learning and network sampling.

In [24] K. Avrachenkov together with M. Hamibouche (Eurecom, France) and L. Cottatellucci (FAU University, Germany) study the spectrum of the normalized Laplacian and its regularized version for random geometric graphs (RGGs) in various scaling regimes. Two scaling regimes are of special interest, the connectivity and the thermodynamic regime. In the connectivity regime, the average vertex degree grows logarithmically in the graph size or faster. In the thermodynamic regime, the average vertex degree is a constant. The authors introduce a deterministic geometric graph (DGG) with nodes in a grid and provide an upper bound to the probability that the Hilbert–Schmidt norm of the difference between the normalized Laplacian matrices of the RGG and DGG is greater than a certain threshold in both the connectivity and thermodynamic regime. Using this result, they show that the RGG and DGG normalized Laplacian matrices are asymptotically equivalent with high probability (w.h.p.) in the full range of the connectivity regime. The authors use the regular structure of the DGG to show that the limiting eigenvalue distribution of the RGG normalized Laplacian matrix converges to a distribution with a Dirac atomic measure at zero. In the thermodynamic regime, the authors approximate the eigenvalues of the regularized normalized Laplacian matrix of the RGG by the eigenvalues of the DGG regularized normalized Laplacian and provide an error bound which is valid w.h.p. and depends upon the average vertex degree.

7.3 Data Analysis and Learning

Participants: Konstantin Avrachenkov, Gabriele Castellano, Alain Jean-Marie, Othmane Marfoq, Giovanni Neglia, Samir Medina Perlaza, Tareq Si Salem.

7.3.1 Online Learning

In [30], T. Si Salem and G. Neglia in collaboration with G. Iosifidis (TU Delft, Netherlands) study the fairness of dynamic resource allocation problem under the α-fairness criterion. They recognize two different fairness objectives that naturally arise in this problem: the well-understood slot-fairness objective that aims to ensure fairness at every timeslot, and the less explored horizon-fairness objective that aims to ensure fairness across utilities accumulated over a time horizon. They argue that horizon-fairness comes at a lower price in terms of social welfare. They study horizon-fairness with regret as a performance metric and prove that vanishing regret cannot be achieved in presence of an unrestricted adversary. They propose restrictions on the adversary's capabilities corresponding to realistic scenarios and an online policy that indeed guarantees vanishing regret under these restrictions. They demonstrate the applicability of the proposed fairness framework to a representative resource management problem considering a virtualized caching system where different caches cooperate to serve content requests.

7.3.2 Reinforcement Learning for Restless Bandits

In [18], K. Avrachenkov and V.S. Borkar (Indian Institute of Technology Bombay, IITB, India) present a novel reinforcement learning algorithm for multi-armed restless bandits with average reward, using the paradigms of Q-learning and Whittle index. Specifically, the authors leverage the structure of the Whittle index policy to reduce the search space of Q-learning, resulting in major computational gains. Rigorous convergence analysis is provided, supported by numerical experiments. The numerical experiments show excellent empirical performance of the proposed scheme.

Then, in [48, 64], K. Avrachenkov in collaboration with V.S. Borkar (Indian Institute of Technology Bombay, IITB, India), U. Ayesta (IRIT, CNRS) and F. Robledo (Univ. Basque Country, Spain) study reinforcement learning for restless bandits with discounted reward. Specifically, they present QWI and QWINN, two algorithms capable of learning the Whittle indices for the total discounted criterion. The key feature is the usage of two timescales, a faster one to update the state-action Q-values, and a relatively slower one to update the Whittle indices. In our main theoretical result the authors show that QWI, which is a tabular implementation, converges to the real Whittle indices. QWINN, an adaptation of QWI algorithm using neural networks to compute the Q-values on the faster timescale, is able to extrapolate information from one state to another and scales naturally to large state-space environments. Numerical computations show that QWI and QWINN converge much faster than the standard Q-learning algorithm, neural-network based approximate Q-learning and other state of the art algorithms.

7.3.3 Federated Learning

The increasing size of data generated by smartphones and IoT devices motivated the development of *Federated Learning* (FL), a framework for on-device collaborative training of machine learning models. Federated learning allows clients to collaboratively learn statistical models while keeping their data local.

Personalized Federated Learning. Federated learning was originally used to train a unique global model to be served to all clients, but this approach might be sub-optimal when clients' local data distributions are heterogeneous. In order to tackle this limitation, recent *personalized federated learning* methods train a separate model for each client while still leveraging the knowledge available at other clients. In [38], O. Marfoq and G. Neglia in collaboration with L. Kameni and R. Vidal (Accenture Labs) exploit the ability of deep neural networks to extract high quality vectorial representations (embeddings) from non-tabular data, e.g., images and text, to propose a personalization mechanism based on local memorization. Personalization is obtained by interpolating a collectively trained global model with a local k-nearest neighbors model based on the shared representation provided by the global model. They provide generalization bounds for the proposed approach in the case of binary classification, and they show on a suite of federated datasets that this approach achieves significantly higher accuracy and fairness than state-of-the-art methods.

Datasets and Benchmarks for Cross-Silo Federated Learning. The cross-silo FL setting corresponds to the case of few (2–50) reliable clients, each holding medium to large datasets, and is typically found in applications such as healthcare, finance, or industry. While previous works have proposed representative datasets for cross-device FL, few realistic healthcare cross-silo FL datasets exist, thereby slowing algorithmic research in this critical application. In [41], O. Marfoq and G. Neglia in collaboration with S. Ayed, S. Silva, M. Lorenzi (Inria team EPIONE), E. Cyffers, P. Mangold, A. Bellet, M. Tommasi (Inria team MAGNET) and other collaborators from Owkin, Inc., EPFL, FeML, Inc., University of Southern California, École Polytechnique, Institut Polytechnique de Paris, Univ. Hospital Bonn, Helmholtz Munich, and Univ. of California at Berkeley propose a novel cross-silo dataset suite focused on healthcare, FLamby (Federated Learning AMple Benchmark of Your cross-silo strategies), to bridge the gap between theory and practice of cross-silo FL. FLamby encompasses 7 healthcare datasets with natural splits, covering multiple tasks, modalities, and data volumes, each accompanied with baseline training code. As an illustration, they additionally benchmark standard FL algorithms on all datasets. The proposed flexible and modular suite allows researchers to easily download datasets, reproduce results and re-use the different components for their research. FLamby is available on GitHub.

Attacks. Multiple recent works show that client's private information can still be disclosed to an adversary who just eavesdrops the messages exchanged between the targeted client and the server. In [46], G. Neglia, together with I. Driouich, C. Xu, and F. Giroire (Inria COATI team) and E. Thomas (Amadeus) propose a novel model-based attribute inference attack in federated learning which overcomes the limits of gradient-based ones. Furthermore, they provide an analytical lower-bound for the success of this attack. Empirical results using real world datasets confirm that this attribute inference attack works well for both regression and classification tasks. Moreover, they benchmark this novel attribute inference attack against the state-of-the-art attacks in federated learning. The attack results in higher reconstruction accuracy especially when the clients' datasets are heterogeneous (as it is common in federated learning). Most importantly, their model-based fashion of designing powerful and explainable attacks enables an effective quantification of the privacy risk in FL.

7.3.4 Distributed Inference

Small IoT devices, such as drones and lightweight battery-powered robots, are emerging as a major platform for the deployment of AI/ML capabilities. Autonomous and semiautonomous device operation relies on the systematic use of deep neural network models for solving complex tasks, such as image classification. The challenging restrictions of these devices in terms of computing capabilities, network connectivity, and power consumption are the main limits to the accuracy of latencysensitive inferences. In [34], G. Castellano and G. Neglia, together with F. Pianese and T. Zhang (Nokia Bell Labs) and D. Carra

(Univ. of Verona, Italy) present ReBEL, a split computing architecture enabling the dynamic remote offload of partial computations or, in alternative, a local approximate labeling based on a jointly-trained classifier. Their approach combines elements of head network distillation, early exit classification, and bottleneck injection with the goal of reducing the average end-to-end latency of AI/ML inference on constrained IoT devices.

7.3.5 Empirical Risk Minimization with Relative Entropy Regularization

In the context of the exploratory action IDEM (Information and Decision Making), in [40, 56, 55] and [57], S. M. Perlaza and A. Jean-Marie, together with G. Bisson (Univ. de la Polynésie française), I. Esnaola (Univ. of Sheffield), and S. Rini (National Chiao Tung Univ.), studied the problem of empirical risk minimization (ERM) with relative entropy regularization (ERM-RER) in the context of supervised learning from the perspective of measure theory. In particular, the relative entropy is assumed to be with respect to a given measure, the reference measure, and not necessarily a probability mesure. This provides a unified treatment of two relevant problems in supervised learning. First, when the reference measure is a probability measure, the ERM-RER problem is shown to be a risk-information minimization problem. Alternatively, when the reference measure is the Lebesgue measure or a counting measure, the solution of the ERM-RER problem is shown to be identical to the solution to an entropy minimization problem with linear constraints, as the one typically induced by Jayne's maximum entropy principle. The main result consists in a number of properties for the solution to the ERM-RER in terms of the reference measure, the regularization factor, and the training data. Some of the most important properties are described hereunder:
(i) The optimal solution to the ERM-RER is a probability measure that is unique and concentrates into a set arbitrarily small containing the minimizers of the empirical risk with arbitrarily high probability. The tradeoff between the cardinality of such set and the probability is governed by the regularization factor.
(ii) The expected value of the empirical risk, with respect to the ERM-RER optimal measure, is decreasing with the regularization factor. Nonetheless, via simple examples, monotonicity of the variance and higher cumulants is shown to be subject to conditions.
(iii) The transport of the ERM-RER optimal measure through the loss function is a sub-Gaussian probability measure. This property is central to study the sensitivity of the empirical risk for a particular data set with respect to changes around the optimal ERM-RER optimal measure.

7.4 Game Theory and Applications

Participants: Eitan Altman, Konstantin Avrachenkov, Mandar Datar, Alain Jean-Marie, Samir Medina Perlaza, Ke Sun.

7.4.1 Dynamic Social Learning under Graph Constraints

In [14], K. Avrachenkov together with V.S. Borkar, S. Moharir and S. M. Shah (all from Indian Institute of Technology Bombay, India) introduce a model of graph-constrained dynamic social choice with reinforcement modeled by positively α-homogeneous rewards. They show that its empirical process, which can be written as a stochastic approximation recursion with Markov noise, has the same probability law as a certain vertex reinforced random walk. Furthermore, its fluid limit has a relation to the replicator dynamics. They use these equivalences to show that for $\alpha > 0$, the asymptotic outcome concentrates around the optimum in a certain limiting sense when 'annealed' by letting $\alpha \to \infty$ slowly.

7.4.2 Stochastic Game with a dynamic set of players

In [22], S. Dhamal (Chalmers Univ. of Technology, Sweden) in collaboration with W. Ben-Ameur and T. Chahed (both from Telecom SudParis, France), E. Altman, A. Sunny (from IIT Palakkad, India) and S. Poojary (Qualcomm India), study a stochastic game with a dynamic set of players, for modeling and analyzing their computational investment strategies in distributed computing. Players obtain a certain reward for solving a problem, while incurring a certain cost based on the invested time and computational power. The authors relate the model to blockchain mining, and show that the framework is applicable to certain other distributed computing settings as well. The authors consider a particular yet natural scenario where the rate of solving the problem is proportional to the total computational power invested by the players. It is shown that, in Markov perfect equilibrium, players with cost parameters exceeding a certain threshold, do not invest; while those with cost parameters less than this threshold, invest maximal power. With extensive simulations and insights through mean field approximation, the authors study the effects of players' arrival/departure rates and the system parameters on the players' utilities.

7.4.3 Games with incomplete information

Asymmetry and/or incompleteness of information in the context of Game Theory typically leads to situations where one of the players can take an extra advantage over her opponent.

One such situation is analyzed in [59] by S.M. Perlaza, K. Sun and A. Jean-Marie. In this paper, two-player, two-action, zero-sum games are studied under the following assumptions: (1) One of the players (the leader) publicly and irrevocably commits to choose its actions by sampling a given probability measure (strategy); (2) The leader announces its action, which is observed by its opponent (the follower) through a binary channel; and (3) the follower chooses its strategy based on the knowledge of the leader's strategy and the noisy observation of the leader's action. Under these conditions, the equilibrium is shown to always exist and be often different from the Nash and Stackelberg equilibria. Even subject to noise, observing the actions of the leader is either beneficial or immaterial to the follower for all possible commitments: acquiring information indeed leads to an improved payoff. When the commitment is observed subject to a distortion, the equilibrium does not necessarily exist. Nonetheless, the leader might still obtain some benefit in some specific cases subject to equilibrium refinements. For instance, ϵ-equilibria might exist in which the leader commits to suboptimal strategies that allow unequivocally predicting the best response of its opponent.

As a preliminary to this analysis, K. Sun has systematically reviewed in [58] the properties of Nash equilibria in two-player, two-action, zero-sum games.

This research is part of the IDEM project (Section 9.4).

7.4.4 Positionalism and Conformism in Public Good Games

Standard models in Economics assume that rational players will seek to optimize some objective utility or profit. Current studies in behavioral Economics, acknowledging that real economic agents depart from this ideal behavior, attempt at incorporating "subjective" components in these optimization programs.

A. Jean-Marie, together with F. Cabo (Univ. Valladolid) and M. Tiball (INRAe), have considered this question in the context of private contribution to a public good. The standard situation is that selfish players will not find optimal to contribute. However, players may exhibit a *positional* behavior (they get joy from contributing more than their opponent, and displeasure from contributing less), or a *conformist* behavior (the closer to the average they are, the happier they are). In that case, their private optimum may lead to a postitive contribution to the public good. The paper [45, 54] considers the case of two positional players. Nash equilibria of the static game are computed and their dependence on the parameters of the problem is thoroughly studied. A dynamic model of myopic players featuring inertia is also built. It is shown that inertia can lead to an *overshooting* behavior: players may contribute more than what they would at the equilibrium, for some periods of time. Preliminary results for the case where one player is positional and the other one conformist, are presented in [44]

7.4.5 Stackelberg games

M. Datar and E. Altman in collaboration with H. Le Cadre (Inria team INOCS), consider in [21] a market-place in the context of 5G network slicing, where Application Service Providers (ASP), i.e., slice tenants, providing heterogeneous services, are in competition for the access to the virtualized network resource owned by a Network Slice Provider, who relies on network slicing. The authors model the interactions between the end users (followers) and the ASPs (leaders) as a Stackelberg game. The authors show that the competition between the ASPs results in a multi-resource Tullock rent-seeking game. To determine resource pricing and allocation, the authors devise two market mechanisms. First, it is assumed that the ASPs are pre-assigned with fixed shares (budgets) of infrastructure, and rely on a trading post mechanism to allocate the resource. Under this mechanism, the ASPs can redistribute their budgets in bids and customize their allocations to maximize their profits. In case a single resource is considered, it is proved that the ASPs' coupled decision problems give rise to a unique Nash equilibrium. Second, when ASPs have no bound on their budget, the problem is formulated as a pricing game with coupling constraints capturing the shared resource finite capacities, and the market prices are derived as the duals of the coupling constraints. In addition, it is proved that the pricing game admits a unique variational equilibrium. The authors implement two online learning algorithms to compute solutions of the market mechanisms. A third fully distributed algorithm based on a proximal method is proposed to compute the Variational equilibrium solution of the pricing game. Finally, the authors run numerical simulations to analyse the market mechanism's economic properties and the convergence rates of the algorithms.

7.4.6 Learning Correlated Equilibria

In [33], O. Boufous (Orange Labs and Avignon Univ.) R. El-Azouzi (LIA, Avignon Univ.), M. Touati, M. Bouhtou (both from Orange labs) together with E. Altman, consider the problem of learning a correlated equilibrium of a finite non-cooperative game and show a new adaptive heuristic, called Correlated Perturbed Regret Minimization (CPRM) for this purpose. CPRM combines regret minimization to approach the set of correlated equilibria and a simple device suggesting actions to the players to further stabilize the dynamics. Numerical experiments support the hypothesis of the pointwise convergence of the empirical distribution over action profiles to an approximate correlated equilibrium with all players following the devices' suggestions. Additional simulation results suggest that CPRM is adaptive to changes in the game such as departures or arrivals of players.

7.5 Applications in Telecommunications

Participants: Sara Alouf, Eitan Altman, Younes Ben Mazziane, Olga Chuchuk, Mandar Datar, Samir Medina Perlaza, Philippe Nain, Giovanni Neglia, Tareq Si Salem, Sadaf ul Zuhra.

7.5.1 Caching

Caching for Dataset-based Workloads. In [35], O. Chuchuk and G. Neglia together with M. Schulz and D. Duellmann (CERN, Switzerland) explore the benefits of caching for existing scientific workloads, taking the Worldwide LHC (Large Hadron Collider) Computing Grid as an example. It is a globally distributed system that stores and processes multiple hundred petabytes of data and serves the needs of thousands of scientists around the globe. Scientific computation differs from other applications like video streaming as file sizes vary from a few bytes to terabytes and logical links between the files affect user access patterns. These factors profoundly influence caches' performance and, therefore, should be carefully analyzed to select which caching policy to deploy or to design new ones. In this work, they study how the hierarchical organization of the LHC physics data into files and groups of files called datasets affects the request patterns. They then propose new caching policies that exploit dataset-specific knowledge and compare them with file-based ones. Moreover, they show that limited connectivity between the computing and storage sites leads to the delayed hits phenomenon and estimate the consequent reduction in the potential benefits of caching.

Similarity Caching. A similarity cache can reply to a query for an object with similar objects stored locally. In some applications of similarity caches, queries and objects are naturally represented as points in a continuous space. This is for example the case of 360° videos where user's head orientation—expressed in spherical coordinates—determines what part of the video needs to be retrieved, or of recommendation systems where a metric learning technique is used to embed the objects in a finite dimensional space with an opportune distance to capture content dissimilarity. Existing similarity caching policies are simple modifications of classic policies like LRU, LFU, and qLRU and ignore the continuous nature of the space where objects are embedded. In [27], T. Si Salem and G. Neglia in collaboration with A. Sabnis (Univ. of Massachusetts Amherst, USA), M. Garetto (Univ. of Turin, Italy), E. Leonardi (Polytechnic Univ. of Turin, Italy), and R. K. Sitaraman (Univ. of Massachusetts Amherst, USA) propose Grades, a new similarity caching policy that uses gradient descent to navigate the continuous space and find appropriate objects to store in the cache. They provide theoretical convergence guarantees and show Grades increases the similarity of the objects served by the cache in both applications mentioned above. Subsequently, in [28], T. Si Salem and G. Neglia in collaboration with D. Carra (Univ. of Verona) present AÇAI, a new similarity caching policy which improves on the state of the art by using (i) an (approximate) index for the whole catalog to decide which objects to serve locally and which to retrieve from the remote server, and (ii) a mirror ascent algorithm to update the set of local objects with strong guarantees even when the request process does not exhibit any statistical regularity.

Although many similarity caching policies have been proposed, we still do not know how to compute the hit rate even for simple policies, like SIM-LRU and RND-LRU that are straightforward modifications of classic caching algorithms. In [32], Y. Ben Mazziane, S. Alouf, and G. Neglia, together with D. S. Menasche (Federal Univ. of Rio de Janeiro, Brazil) propose the first algorithm to compute the hit rate of similarity caching policies under the independent reference model for the request process. In particular, they show how to extend the popular time-to-live approximation in classic caching to similarity caching. The algorithm is evaluated on both synthetic and real world traces.

7.5.2 Quantum Communications

In [25] P. Nain in collaboration with G. Vardoyan (QuTech, TU Delft, The Netherlands), S. Guha (Univ. Arizona, Tucson) and D. Towsley (Univ. Massachusetts, Amherst), studies the performance of a quantum switch that distributes tripartite entangled states to sets of users. The entanglement switching process requires two steps: first, each user attempts to generate bipartite entanglement between itself and the switch; and second, the switch performs local operations and a measurement to create multipartite entanglement for a set of three users. A simple variant of this system is studied, wherein the switch has infinite memory and the links that connect the users to the switch are identical. This problem formulation is of interest to several distributed quantum applications, while the technical aspects of this work result in new contributions within queueing theory. The state of the system is modeled as continuous time Markov chain and performance metrics of interest (probability of an empty system, switch capacity, expectation and variance of the number of qubit-pairs stored) are computed via the solution of a two-dimensional functional equation obtained by reducing it to a boundary value problem on a closed curve.

7.5.3 Coordinated Iterative Water-Filling Algorithms

In [37], S. Perlaza in collaboration with M. Haddad (Univ. d'Avignon), P. Wiecek (Wrocław Univ. of Science and Technology), O. Habachi (Univ. Clermont Auvergne), and S.M. Shah (National Institute of Technology, Srinagar, India) consider a perfect coordinated water-filling game, in which each user transmits solely on a given carrier. The main goal of the proposed algorithm (FEAT) is to achieve close to optimal performance, while keeping a given level of fairness. The key idea within FEAT is to minimize the ratio between the best and the worst utilities of the users. This is done by ensuring that, at each iteration (channel assignment), a user is satisfied with this assignment as long as it does not lose much more than other users in the system. It has been shown that FEAT outperforms most of the related algorithms in many aspects, especially in interference-limited systems. Indeed, with FEAT we can ensure a near-optimal, fair and energy efficient solution with low computational complexity. In terms of robustness, it turns out that the balance between being nearly globally optimal and good from an individual point of view seems hard to sustain with a significant number of users. Also notice that, in this regard, global optimality gets less affected than the individual one, which offers hope that such an accurate water-filling algorithm can be designed around competition in interference-limited systems.

7.5.4 Simultaneous Information and Energy Transmission with Finite Constellations

Battery dependency is a critical issue when communications systems are deployed in hard-to-reach locations, e.g., remote geographical areas, concrete structures, human bodies, or disaster/war zones. In this case, the lifetime of the electronic devices or even the whole communications system is determined by the battery life. An effective remedy is using energy harvesting technologies. Specifically, energy can be harvested from different ambient sources such as light, vibrations, heat, chemical reactions, physiological processes, or the radio frequency (RF) signals produced by other communications systems. This observation rises the idea of simultaneous information and energy transmission (SIET) via RF. In [43] and [60], S. Perlaza, E. Altman and S. ul-Zuhra in collaboration with H. V. Poor (Princeton Univ.) and M. Skoglund (KTH) characterized an achievable information-energy region of simultaneous information and energy transmission over an additive white Gaussian noise channel. This analysis is performed in the finite block-length regime with finite constellations. More specifically, a method for constructing a family of codes is proposed and the set of achievable tuples of information rate, energy rate, decoding error probability (DEP) and energy outage probability (EOP) is characterized. Using existing converse results, it is shown that the construction is information rate, energy rate, and EOP optimal. The achieved DEP is, however, sub-optimal.

7.5.5 Evaluation and optimization in 5G and 6G

In [36], A. Dejonghe (Orange Labs and Avignon Univ.), Z. Altman, (Orange Labs), F. de Pellegrini (Avignon Univ.) and E. Altman, consider the problem of the integration of RIS elements in upcoming 6G networks. This paper introduces a new link-layer scheme for RIS-enabled communications building on existing models for the physical layer of RIS technologies. The scheme is able to integrate the selection of precoders/beams in a codebook and scheduling of UEs at once. Furthermore, elements for the integration of the proposed scheme in current 3GPP-5G specifications are addressed. The scheduler combines a slow mechanism operating at the downlink OFDMA frame scale with a standard proportional fair scheduler operating at the OFDMA slot scale and accommodating both LOS and nonLOS UEs. The authors introduce an optimization framework for the proposed scheduler whose performance is hence simulated in a reference scenario. The spectral efficiency figures in their tests confirm a large gain of the scheme against a baseline direct path scheme. Finally, the scheduler optimization permits to achieve a further improvement of 15-20% for non line-of-sight users.

7.5.6 Multi Resource Allocation for Network Slices with Multi-Level fairness

To satisfy demanding quality of service requirements for slice tenants and their end-users, Infrastructure Providers (InPs) need to perform efficient resource allocation. In the context of network slicing, the key challenge is the presence of multiple resource types and competing service providers (SPs) with heterogeneous characteristics and preferences. The main goal in this context is devising efficient mechanisms to create slices while ensuring fairness both among slice tenants as well as across their end-users. To address the aforementioned challenges, M. Datar, N. Modina, R. El-Azouzi and F. de Pellegrini (Avignon Univ.) formulate in [39] the multi-resource allocation for network slicing in the form of a Fisher Market model, where SPs act as buyers and a set of resources (divisible goods) is made available by the InP at different locations. Within the Fisher market framework, a generalized alpha-fairness resource allocation for SPs able to adapt the degree of fairness as a function of a nonnegative parameter alpha, striking the trade-off between fairness and efficiency. Given the resource prices, each SP with a certain budget – namely the market power of the SP – buys the optimal set of multi-resources to maximize its utility under the budget constraints. The Market Equilibrium is computed as a price vector for each resource type that ensures market clearance, i.e., the demand of a resource equals its supply. In this paper, it is shown that it is possible to let such market equilibrium correspond to the allocations maximizing alpha-fair utility, which is obtained under non-linear pricing. Furthermore, the authors obtain a closed-form of the pricing as a function of alpha and resources purchased by SP.

8 Bilateral contracts and grants with industry

8.1 Bilateral contracts with industry

NEO members are involved in the Inria-Nokia Bell Labs joint laboratory: the joint laboratory consists of five ADRs (Action de Recherche/ Research Action) in its third phase (starting October 2017). NEO members participated in the former ADR “Distributed Learning and Control for Network Analysis” and participate in ADR “Rethinking the network: virtualizing network functions, from middleboxes to application” (see §8.1.1);

NEO has contracts with Accenture (see §8.1.2 and §8.1.3), SAP (see §8.1.4), and MyDataModels (see §8.1.5).

8.1.1 ADR Nokia on the topic "Rethinking the network: virtualizing network functions, from middleboxes to application" (October 2017 – February 2022)

Participants: Sara Alouf, Gabriele Castellano, Giovanni Neglia.

- Contractor: Nokia Bell Labs
- Collaborators: Fabio Pianese, Tianzhu Zhang

A growing number of network infrastructures are being presently considered for a software-based replacement: these range from fixed and wireless access functions to carrier-grade middle boxes and server functionalities. On the one hand, performance requirements of such applications call for an increased level of software optimization and hardware acceleration. On the other hand, customization and modularity at all layers of the protocol stack are required to support such a wide range of functions. In this scope the ADR focuses on two specific research axes: (1) the design, implementation and evaluation of a modular NFV architecture, and (2) the modelling and management of applications as virtualized network functions. Our interest is in low-latency machine learning prediction services and in particular how the quality of the predictions can be traded off with latency. The postdoc of G. Castellano was funded by this project.

8.1.2 Accenture contract on the topic "Distributed Machine Learning for IoT applications" (Dec 2019 – November 2023)

Participants: Othmane Marfoq, Giovanni Neglia.

- Contractor: Accenture Labs
- Collaborators: Laetitia Kameni, Richard Vidal

IoT applications will become one of the main sources to train data-greedy machine learning models. Until now, IoT applications were mostly about collecting data from the physical world and sending them to the Cloud. Google's federated learning already enables mobile phones, or other devices with limited computing capabilities, to collaboratively learn a machine learning model while keeping all training data locally, decoupling the ability to do machine learning from the need to store the data in the cloud. While Google envisions only users' devices, it is possible that part of the computation is executed at other intermediate elements in the network. This new paradigm is sometimes referred to as Edge Computing or Fog Computing. Model training as well as serving (provide machine learning predictions) are going to be distributed between IoT devices, cloud services, and other intermediate computing elements like servers close to base stations as envisaged by the Multi-Access Edge Computing framework. The goal of this project is to propose distributed learning schemes for the IoT scenario, taking into account in particular its communication constraints. O. Marfoq is funded by this project. A first 12-month pre-PhD contract has been followed by a PhD grant.

8.1.3 Accenture "Plan de Relance" (PLR) contract on the topic "Energy-Aware Federated Learning" (Oct 2022 – September 2024)

Participants: Giovanni Neglia, Charlotte Rodriguez.

- Contractor: Accenture Labs
- Collaborators: Laura Degioanni, Laetitia Kameni, Richard Vidal

Deep neural networks have enabled impressive accuracy improvements across many machine learning tasks. Often the highest scores are obtained by the most computationally-hungry models. As a result, training a state-of-the-art model now requires substantial computational resources which demand considerable energy, along with the associated economic and environmental costs. Research and development of new models multiply these costs by thousands of times due to the need to try different model architectures and different hyper-parameters. In this project, we investigate a more algorithmic/system-level approach to reduce energy consumption for distributed ML training over the Internet. The postdoc of C. Rodriguez is funded by this project.

8.1.4 Cifre contract with SAP “Privacy and fairness for ML” (December 2021 – December 2024)

Participants: Caelin Kaplan, Giovanni Neglia.

- Contractor: SAP Labs France
- Collaborators: Anderson Santana de Oliveira

There are increasing concerns among scholars and the public about bias, discrimination, and fairness in AI and machine learning. Decision support systems may present biases, leading to unfair treatment of some categories of individuals, for instance, systematically assigning high risk of recidivism in a criminal offense analysis system. Essentially, the analysis of whether an algorithm’s output is fair (e.g. does not disadvantages a group with respect to others) depends on substantial contextual information that often requires human intervention. There are though several metrics for fairness that have been developed, which may rely on collecting additional sensitive attributes (e.g., ethnicity) before imposing strong privacy guarantees to be used in any situation. It is known that differential privacy has the effect of hiding outliers from the data analysis, perhaps compounding existing bias in certain situations. This project encompasses the search for a mitigating strategy. The PhD thesis of C. Kaplan is funded by this project.

8.1.5 MyDataModels contract on the topic “Semi-supervised variational autoencoders for versatile data” (June 2019 – May 2022)

Participants: Konstantin Avrachenkov, Mikhail Kamalov.

- Contractor: MyDataModels
- Collaborators: Denis Bastiment, Aurélie Boisbunon

Variational autoencoders are highly flexible machine learning techniques for learning latent dimension representation. This model is applicable for denoising data as well as for classification purposes. In this thesis we plan to add semi-supervision component to the variational autoencoder techniques. We plan to develop methods which are universally applicable to versatile data such as categorical data, images, texts, etc. Initially starting from static data we aim to extend the methods to time-varying data such as audio, video, time-series, etc. The proposed algorithms can be integrated into the internal engine of MyDataModels company and tested on use cases of MyDataModels. This contract financed the PhD candidate M. Kamalov. His thesis was defended in December 2022.

9 Partnerships and cooperations

Participants: Sara Alouf, Eitan Altman, Konstantin Avrachenkov, Vinay Kumar Bindiganavile Ramadas, Mandar Datar, Francescomaria Faticanti, Alain Jean-Marie, Ashok Krishnan Komalan Sindhu, Vijith Kumar Kizhakke Purakkal, Othmane Marfoq, Girik Maskara, Giovanni Neglia, Samir Medina Perlaza, Angelo Rodio, Tareq Si Salem, Ke Sun, Sadaf Ul Zuhra, Xinying Zou.

9.1 International initiatives

9.1.1 Inria associate team not involved in an IIL or an international program

LION

Participants: Eitan Altman, Konstantin Avrachenkov, Giovanni Neglia, Samir Medina Perlaza.

Title: Learning In Operations and Networks

Duration: 2022 →

Coordinator: Kavitha Veeraruna (vkavitha@iitb.ac.in)

Partners:

- Indian Institute of Technology Bombay Bombay (Inde)

Inria contact: Eitan Altman

Summary: Artificial Intelligence has affected all walks of life. We propose to study its application in various domains like 1) Learning and Control in Healthcare: Our aim is to use novel AI methodologies, to predict the results of possible actions of involved decision-makers, using the available data. 2)Dual Learning Algorithms in wireless networks: We aim to develop learning algorithms for beam alignment in 5G Wireless networks to maintain high rates. We propose to use AoI as a metric. 3) Distributed and reinforcement learning: We will develop and analyze Deep Q Network (DQN) based learning algorithms and analyze their performance.

9.1.2 Participation in other International Programs

Thomas Jefferson Fellowship

Participants: Samir Medina Perlaza, Sadaf ul Zuhra.

Funding institution: The Embassy of France in the United States of America

Partner Institution: Rensselaer Polytechnic Institut, N.Y., USA and Princeton Univ., N.J. USA.

Date/Duration: 2019–2022

Summary: This fellowship, essentially for mobility between the USA and France, supports our research in foundational questions pertinent to two emerging wireless communication technologies: (i) energy harvesting (EH) systems, and (ii) ultra low-latency systems for critical missions (e.g., remote surgery). The EH technology enables charging batteries from ambient sources, and leads to energy self-sustainability by eliminating the critical dependence of wireless systems on manual battery charging. Designing EH technology in mission-critical (MC) systems, the operation of which hinges on reliable communication with ultra low latency, necessitates addressing foundational questions for a principled design of the MC systems. This project explores two strongly symbiotic research directions for establishing the fundamental limits of (i) data transmission and, (ii) simultaneous energy and data transmission, in MC systems empowered by EH. The expected results have applications in, e.g., disaster relief, medical instruments, cyber-physical systems, and the Internet of things.

9.2 International research visitors

9.2.1 Visits of international scientists

Other international visits to the team

Gaetan Bisson

Status: Associate Professor

Institution of origin: Univ. of French Polynesia

Country: French Polynesia

Dates: 4–8/7/2022

Context of the visit: Collaboration on the IDEM project (Section 9.4).

Mobility program/type of mobility: research stay

Andrei Bobu

Status: Research Engineer

Institution of origin: Criteo

Country: Cyprus

Dates: 29/11–1/12/2022

Context of the visit: Andrey Bobu is a former postdoc at NEO and we still collaborate with him on the topic of geometric random graphs.

Mobility program/type of mobility: research stay

Vivek Borkar

Status: Professor

Institution of origin: Indian Institute of Technology Bombay

Country: India

Dates: 10–30/7/2022

Context of the visit: Collaboration on inference and optimization on dynamic graphs.

Mobility program/type of mobility: research stay

Damiano Carra

Status: Professor

Institution of origin: Univ. Verona

Country: Italy

Dates: 19–23/9/2022

Context of the visit: Collaboration on the MAMMALS project (9.4).

Mobility program/type of mobility: research stay

Lucas Gamertsfelder

Status: PhD student

Institution of origin: Macquarie Univ.

Country: Australia

Dates: 1/11/2022–28/2/2023

Context of the visit: Work on sufficient conditions for strong duality in linear programming associated to MDP and POMDP.

Mobility program/type of mobility: research stay

Emilio Leonardi

Status: Professor

Institution of origin: Politecnico di Torino

Country: Italy

Dates: 5–9/9/2022

Context of the visit: Collaboration on distributed optimization with heterogeneous resource constraints.

Mobility program/type of mobility: research stay

Lasse Leskela

Status: Associate Professor

Institution of origin: Aalto Univ.

Country: Finland

Dates: 31/3–9/4/2022

Context of the visit: Collaboration on community detection in non-binary, temporal and geometric networks.

Mobility program/type of mobility: research stay

Nelly Litvak

Status: Professor

Institution of origin: Univ. of Twente

Country: The Netherlands

Dates: 29/5–7/6/2022

Context of the visit: Collaboration on analysis of RLGL method for the resolution of large Markov chains.

Mobility program/type of mobility: research stay

Rahul Misra

Status: PhD student

Institution of origin: Aalborg Univ.

Country: Denmark

Dates: 1/6–31/8/2022

Context of the visit: Collaboration on Stochastic Games and Constrained Markov Decision Processes.

Mobility program/type of mobility: research stay

Fabio Pianese

Status: Researcher

Institution of origin: Nokia Bell Labs

Country: France

Dates: 15–29/10/2022

Context of the visit: Collaboration on distributed dynamic policy for model allocation in inference delivery networks.

Mobility program/type of mobility: research stay

Francisco Robledo Relano

Status: PhD student

Institution of origin: LAAS-CNRS

Country: France

Dates: 6–20/11/2022

Context of the visit: Collaboration on the estimation of convergence time of Gittins and Whittle based index policies.

Mobility program/type of mobility: research stay

Jan Schuurmans

Status: Researcher and CEO

Institution of origin: DotX Control Solutions

Country: The Netherlands

Dates: 14/2–6/3/2022, 7–21/12/2022

Context of the visit: project TESTBED2 (see §9.3.1).

Mobility program/type of mobility: research stay

Flora Spieksma

Status: Professor

Institution of origin: Leiden Univ.

Country: The Netherlands

Dates: 12–23/6/2022

Context of the visit: Collaboration on deviation matrix for Markov processes and its applictaions to retrial queues.

Mobility program/type of mobility: research stay

Ali Tajer

Status: Associate Professor

Institution of origin: Rensselaer Polytechnic Institut (RPI)

Country: USA

Dates: 23/6–24/6/2022

Context of the visit: Collaboration on Machine Learning and Energy Systems.

Mobility program/type of mobility: Thomas Jefferson Funds from The Embassy of France in the USA

9.2.2 Visits to international teams

Research stays abroad

Konstantin Avrachenkov

Visited institution: Univ. of Liverpool

Country: United Kingdom

Dates: 27/6–2/7/2022

Context of the visit: Collaboration on MDP and POMDP

Mobility program/type of mobility: research stay

Visited institution: Aalto Univ.

Country: Finland

Dates: 31/7–10/08/2022

Context of the visit: Collaboration on community detection in non-binary, temporal and geometric networks

Mobility program/type of mobility: research stay

Visited institution: Univ. of Twente

Country: The Netherlands

Dates: 9–15/10/2022

Context of the visit: Collaboration on RLGL method

Mobility program/type of mobility: research stay

Visited institution: Indian Institute of Technology Bombay

Country: India

Dates: 7–15/12/2022

Context of the visit: Collaboration on Reinforcement Learning methods

Mobility program/type of mobility: research stay in the context of Cefipra LION project

Vinay Kumar Bindiganavile Ramadas

Visited institution: Aalto Univ.

Country: Finland

Dates: 31/7–14/08/2022

Context of the visit: Collaboration on community detection in non-binary, temporal and geometric networks

Mobility program/type of mobility: research stay

Mikhail Kamalov

Visited institution: Indian Institute of Technology Bombay

Country: India

Dates: 8/4–6/5/2022

Context of the visit: Collaboration on distributed approaches for semi-supervised learning

Mobility program/type of mobility: research stay

Samir Medina Perlaza

Visited institution: Univ. of Sheffield

Country: United Kingdom

Dates: 13–18/6/2022

Context of the visit: Collaboration with Prof. I. Esnaola, Prof. R. Harrison and co-advisorship of Ph.D. students F. Daunas (NEO) and X. Ye (NEO).

Mobility program/type of mobility: Research Stay

Visited institution: Univ. Rensselaer Polytechnic Institute and Univ. of Princeton

Country: United States

Dates: 24/7–5/8/2022

Context of the visit: Collaboration with Prof. H. V. Poor (Princeton Univ.) and Prof. Ali Tajer (RPI)

Mobility program/type of mobility: Thomas Jefferson Funds of The Embassy of France in the United States.

Visited institution: Univ. of of French Polynesia

Country: French Polynesia

Dates: 18/11–26/12/2022

Context of the visit: Collaboration with Dr. Gaetan Bisson.

Mobility program/type of mobility: research stay

Tareq Si Salem

Visited institution: Technical Univ. Delft

Country: The Netherlands

Dates: 1/3–31/7/2022

Context of the visit: collaboration on topics related to network optimization and economics

Mobility program/type of mobility: research stay

Sadaf Ul Zuhra

Visited institution: Princeton Univ.

Country: USA

Dates: 15/5–31/12/2022

Context of the visit: Collaboration with Prof. H. V. Poor (Princeton Univ.)

Mobility program/type of mobility: H2020 Project TESTBED2.

9.3 European initiatives

9.3.1 H2020 projects

TESTBED2

Participants: Samir Medina Perlaza, Sadaf Ul Zuhra.

Project Acronym: TESTBED2

Project Title: Testing and Evaluating Sophisticated information and communication Technologies for enaBling scalablE smart griD Deployment

Coordinator: Univ. of Durham, UK.

Duration: February 2020 – June 2025

Other Partners: The Univ. of Durham (UDUR); Univ. of Tuebingen (EKUT); Heriot-Watt Univ. (HWU); Univ. of Klagenfurt (AAU); Univ. of Northumbria at Newcastle (UNN); DotX Control Solutions (DotX); BEIA Consult International (BEIA); DEPSys (DEPS); Hellenic Telecommunications Organization S.A (OTE); Princeton Univ. (PU); Univ. of California, Santa Barbara (UC); Univ. of Nebraska–Lincoln (UNL); Institute of Electrical Engineering of the Chinese Academy of Sciences (CAS); China Electric Power Research Institute (EPRI); Southeast Univ. (SEU); and Jinan Univ. (JNU)

Abstract: TESTBED2 is a major interdisciplinary project that combines wisdoms in three academic disciplines - Electronic & Electrical Engineering, Computing Sciences and Macroeconomics, for developing new techniques to improve the scalability of smart grid services, particularly considering the joint evolution of decarbonised power, heat and transport systems. Moreover, new experimental testbeds will be created to evaluate scalable smart grid solutions. Overall, the main objective of this project is to coordinate the action of 12 Universities and 5 companies (3 SMEs and 2 large companies) with complementary expertise to develop and test various promising strategies for ensuring the scalability of smart grid services, thereby facilitating successful deployment and full roll-out of smart grid technologies.

9.4 National initiatives

AO BPI/PLR/PIA 5G Events Lab

Participants: Eitan Altman, Mandar Datar, Ashok Krishnan Komalan Sindhu, Vijith Kumar Kizhakke Purakkal, Giovanni Neglia, Samir Medina Perlaza, Sadaf Ul Zuhra.

Project Acronym: 5G Events Labs

Project Title: 5G Events Labs

Coordinator: Orange

Duration: November 2020 – November 2023

Other Partners: CEA Saclay, Ericsson.

Abstract: The project aims to boost economic activity in the event, cultural and sports sectors, around major Olympic sites in France where Orange and its partners offer increased 5G coverage, technological platforms and appropriate support allowing companies to appropriate these technologies and incubate innovations in the field of services to spectators and organizers.

ANR PARFAIT

Participants: Eitan Altman, Girik Maskara, Samir Medina Perlaza, Xinying Zou.

Project Acronym: PARFAIT

Project Title: Planning And leaRning For AI-Edge compuTing

Coordinator: Avignon Univ.

Duration: October 2021 – September 2025

Other Partners: Conservatoire National des Arts et Métiers (CNAM), Univ. Savoie Mont Blanc (USMB)

Abstract: The PARFAIT project develops theoretical foundations for distributed and scalable resource allocation schemes on edge computing infrastructures tailored for AI-based processing tasks. Algorithmic solutions will be developed based on the theory of constrained, delayed, and distributed Markov decision processes to account for edge service orchestration actions and quantify the effect of orchestration policies. Furthermore, using both game and team formulations, the project will pave the way for a theory of decentralized orchestration, a missing building block necessary to match the application quest for data proximity and the synchronization problems that arise when multiple edge orchestrators cooperate under local or partial system view. Finally, to achieve efficient online edge service orchestration, such solutions will be empowered with reinforcement learning techniques to define a suit of orchestration algorithms able to at once adapt over time to the applications' load and cope with the uncertain information available from AI-based applications' footprints.

ANR MAESTRO5G

Participant: Eitan Altman.

Project Acronym: MAESTRO5G

Project Title: MAnagEment of Slices in The Radio access Of 5G networks

Coordinator: Orange Labs

Duration: February 2019 – January 2022

Other Partners: Nokia Bell Labs, U. Avignon, Inria Project-Team AGORA, Sorbonne U., Telecom SudParis, CentraleSupélec.

Abstract: The project develops enablers for implementing and managing slices in the 5G radio access network, not only for the purpose of serving heterogeneous services, but also for dynamic sharing of infrastructure between operators. MAESTRO-5G develops a framework for resource allocation between slices and a business layer for multi-tenant slicing. It provides an orchestration framework based on Software Define Networking that manages resources and virtual functions for slices. A hardware demonstrator brings the slicing concept to reality and showcases the project's innovations.

Inria Challenge FedMalin

Participants: Othmane Marfoq, Giovanni Neglia, Angelo Rodio.

Project Acronym: FedMalin

Project Title: FEDerated MAchine Learning over the INternet

Coordinator: Giovanni Neglia and Aurélien Bellet (Inria team MAGNET)

Duration: November 2022 - November 2026

Abstract: In many use-cases of Machine Learning (ML), data is naturally decentralized: medical data is collected and stored by different hospitals, crowdsensed data is generated by personal devices, etc. Federated Learning (FL) has recently emerged as a novel paradigm where a set of entities with local datasets collaboratively train ML models while keeping their data decentralized.

FedMalin is a research project that spans 10 Inria research teams and aims to push FL research and concrete use-cases through a multidisciplinary consortium involving expertise in ML, distributed systems, privacy and security, networks, and medicine. We propose to address a number of challenges that arise when FL is deployed over the Internet, including privacy and fairness, energy consumption, personalization, and location/time dependencies. FedMalin will also contribute to the development of open-source tools for FL experimentation and real-world deployments, and use them for concrete applications in medicine and crowdsensing. The FedMalin Inria Challenge is supported by Groupe La Poste, sponsor of the Inria Foundation.

Exploratory action Inria MAMMALS

Participants: Francescomaria Faticanti, Giovanni Neglia.

Project Acronym: MAMMALS

Project Title: Memory-augmented Models for low-latency Machine-learning Serving

Coordinator: Giovanni Neglia

Duration: November 2020 - June 2023

Other Partners: Univ. Turin, Polytechnic Turin, Univ. Verona, Univ. of Massachusetts, Northeastern Univ.

Abstract: A machine learning model is often trained for inference's purposes. Inference does not involve complex iterative algorithms and is therefore generally presumed to be easy. Nevertheless, it presents fundamental challenges that are likely to become dominant as machine learning adoption increases and machine learning systems are ubiquitously deployed and need to make timely and safe decisions in unpredictable environments. MAMMALS aims to provide low-latency inferences by running—close to the end user—simple machine learning models that can also take advantage of a (small) local data store of examples. The focus is on algorithms to learn online what to store locally to improve inference quality and achieve domain adaptation.

Exploratory action Inria IDEM

Participants: Alain Jean-Marie, Samir Medina Perlaza, Ke Sun.

Project Acronym: IDEM

Project Title: Information and Decision Making

Coordinators: Samir Medina Perlaza, Alain Jean-Marie

Duration: November 2021 - November 2023

Other Partners: Univ. of Sheffield, the National Chiao Tung Univ. in Taiwan, Princeton Univ.

Abstract: IDEM aims to characterize the interplay between data acquisition and information processing in decentralized decision making by bringing together tools from information theory and game theory. This characterization is central in the comprehension of problems including decentralized optimization and Machine Learning subject to local information constraints.

10 Dissemination

Participants: Sara Alouf, Eitan Altman, Konstantin Avrachenkov, Younes Ben Mazziane, Francescomaria Faticanti, Alain Jean-Marie, Othmane Marfoq, Giovanni Neglia, Samir Medina Perlaza, Angelo Rodio.

10.1 Promoting scientific activities

10.1.1 Scientific events: organisation

General chair, scientific chair

- G. Neglia chaired, together with Lorenzo Valerio from IIT-CNR, Italy, the "Big Data and AI" track of the 18th International Conference on Mobility, Sensing and Networking (MSN 2022), online, 14-16/12/2022.
- S. Perlaza chaired, together with Samson Lasaulce (CNRS, France), Alessio Zappone (Univ. of Cassino and Southern Lazio, Italy), and Chao Zhang, (Central South Univ., China), the "International Workshop on Resource Allocation and Cooperation in Wireless Networks (RAWNET)" collocated with WiOpt 2022 in Turin, Italy, on September 19th, 2022.

Steering committee

- E. Altman is a member of the steering committee of WiOpt: Workshop on Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks.

Member of the organizing committees

- S. Alouf is a Student Activities co-chair at ACM SIGMETRICS 2023 (Orlando, Florida, USA)
- S. Perlaza is a publicity chair of the International Symposium on Modeling and Optimization in Mobile, Ad hoc, and Wireless Networks (WiOpt) to held in Singapore in 2023.

10.1.2 Scientific events: selection

Chair of conference program committees

- K. Avrachenkov is a Technical Programme Committee Co-Chair at ACM SIGMETRICS 2023 (Orlando, Florida, USA)

Member of the conference program committees

- ACM SIGMETRICS 2023, Summer and Fall TPCs (Orlando, Florida, USA) (S. Alouf, K. Avrachenkov);
- ACM SIGMETRICS/IFIP Performance 2022, Winter TPC (Mumbai, India) (S. Alouf, K. Avrachenkov);
- 15th EAI International Conference on Performance Evaluation Methodologies and Tools, Valuetools 2022 (online) (K. Avrachenkov, S. M. Perlaza);
- 18th European Performance Evaluation Workshop, EPEW 2022 (Santa Pola, Alicante, Spain) (A. Jean-Marie);
- IEEE INFOCOM 2023 (Hoboken, NJ) (G. Neglia);
- IEEE International Conference on Communications, ICC 2022 (Seul, South Korea) (S. Perlaza);
- IEEE International Conference on Mobility, Sensing and Networking, MSN 2022 (online) (F. Faticanti, G. Neglia);
- IEEE International Conference on Sensing, Communication, and Networking, SECON 2022 (online) (F. Faticanti, G. Neglia);
- IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, PIMRC 2022 (online) (S. Perlaza);
- IEEE International Symposium on Information Theory, ISIT 2023 (Taiwan) (S. Perlaza);
- IEEE NetSoft Workshop on Edge Network Softwarization, ENS 2022 (Milan, Italy) (F. Faticanti);

- IEEE Wireless Communications and Networking Conference, WCNC 2022 (Austin, TX, USA) (S. Perlaza)
- International Conference on Computer Communications and Networks, ICCCN 2022, Social Networks and Computing Track (K. Avrachenkov);
- 20th International Symposium on Modeling and Optimization in Mobile, Ad hoc, and Wireless Networks, WiOpt 2022 (Turin, Italy) (S. Alouf, K. Avrachenkov, G. Neglia);
- 30th International Symposium on the Modeling, Analysis, and Simulation of Computer and Telecommunication Systems, MASCOTS 2022 (Nice, France) (S. Alouf, K. Avrachenkov, A. Jean-Marie);
- 34th International Teletraffic Congress, ITC 34 (Shenzhen, China) (K. Avrachenkov, A. Jean-Marie);
- International Workshop on Federated Learning: Recent Advances and New Challenges, FL-NeurIPS 2022 (New Orleans, USA) (G. Neglia);
- International Workshop on Smart Antennas, WSA 2023 (Braunschweig, Germany) (S. Perlaza);
- SIAM International Conference on Data Mining, SDM 2022 (K. Avrachenkov);
- 24th Workshop on MAthematical performance Modeling and Analysis, MAMA 2022 (Mumbai, India, hybrid) (A. Jean-Marie, P. Nain);
- Workshop on Pervasive and Resource-constrained AI, PeRConAI 2022 (online) (G. Neglia).

Reviewer (outside program committee duties)

- IEEE International Conference on Distributed Computing Systems, ICDCS 2022, (Bologna, Italy) (F. Faticanti);
- 39th International Conference on Machine Learning, ICML 2022 (Baltimore, USA) (O. Marfoq, G. Neglia, S. Perlaza);
- Conference on Neural Information Processing Systems, NeurIPS 2022 (New Orleans, USA) (O. Marfoq);
- International Conference on Learning Representations, ICLR 2023 (Kigali, Rwanda) (O. Marfoq);
- IEEE Global Communications Conference, Globecom 2022 (Rio de Janeiro, Brazil) (S. Perlaza);
- IEEE International Symposium on Information Theory, ISIT 2022 (Aalto, Finland) (S. Perlaza);
- International Conference on Artificial Intelligence and Statistics, AISTATS 2022 (online) (O. Marfoq, S. Perlaza);
- International Conference on Artificial Intelligence and Statistics, AISTATS 2023 (Valencia, Spain) (O. Marfoq, S. Perlaza).

10.1.3 Journal

Member of the editorial boards

- Elsevier Computer Communications journal (S. Alouf since May 2021, G. Neglia since 2014);
- IEEE Transactions on Mobile Computing (G. Neglia 2019-2022);
- Elsevier International Journal of Performance Evaluation (K. Avrachenkov, since 2009);
- Probability in the Engineering and Informational Sciences (K. Avrachenkov, since 2018);
- Stochastic Models (K. Avrachenkov, since 2019);

- IEEE Network Magazine (K. Avrachenkov, since 2020);
- IEEE Transactions on Communications (S. Perlaza, since 2019);
- ACM Transactions on Modeling and Performance Evaluation of Computing Systems (ACM ToMPECS) (K. Avrachenkov, since 2016).

Reviewer - reviewing activities NEO members regularly perform reviews for journals such as IEEE/ACM Transactions on Networking, IEEE Transactions on Mobile Computing, IEEE Transactions on Network Science and Engineering, IEEE Transactions on Information Theory, IEEE Transactions on Wireless Communications, IEEE on Communications, IEEE Journal on Selected Areas in Communications, IEEE Transactions on Network and Service Management.

10.1.4 Invited talks

S. Alouf has delivered the following talks:

- "Analyzing Count-Min Sketch with Conservative Updates" at
  - WIOPT 2022, Turin, Italy on September 20th
  - 12ème Atelier d'Evaluation de Performances, Grenoble, France, on July 4th

K. Avrachenkov has delivered the following talks:

- “Quantum (random) walks” at
  - Workshop “Mathematics for Quantum Technologies”, Nice, March 4
  - UCA QuantAzur days, Nice, June 16-17

A. Jean-Marie delivered the talk “Préchargement dans un monde dynamique”, 12ème Atelier d'Evaluation de Performances, Grenoble, France, on July 5th

P. Nain has delivered the following talks:

- “Modeling and Performance Evaluation of a Quantum Switch”
  - as a keynote lecture at Mascots 2022, Nice, Oct. 18-20
  - as a talk at QuantAzur Days, Nice July 16-17
  - 12ème Atelier d'Evaluation de Performances, Grenoble, France, on July 4th

G. Neglia delivered a talk on "Addressing Heterogeneity in Federated Learning", IMT Webinaire Data&IA, online, 23/6/2022.

S. Perlaza has delivered the following talks:

- “Empirical Risk Minimization and Zero-Sum Games with Noisy Observations” at
  - Conservatoire national des arts et métiers (CNAM), Paris, France, December 12 2022. Host: Prof. Stefano Secci.
  - Industrial Engineering and Operations Research Department. Indian Institute of Technology at Bombay (IITB), Mumbai, India, November 9 2022. Host: Prof. Manjesh Hanawal.
- “The Role of Relative Entropy in Supervised Machine Learning”
  - Electrical and Computer Engineering Department and Center for Statistics and Machine learning at Princeton Univ., Princeton NJ USA. July 28, 2022. Host: Prof. H. Vincent Poor
  - Electrical and Computer Engineering Department at Rensselaer Polytechnic Institute, Troy NY USA. July 26, 2022. Host: Prof. Ali Tajer.
  - Laboratoire Traitement et Communication de l'Information (LTCI), TelecomParis, Saclay, France. July 6, 2022. Host: Prof. Michèle Wigger.

10.1.5 Leadership within the scientific community

S. Alouf

- is an elected member at the Board of Directors of ACM SIGMETRICS (July 2019 - June 2023);
- is a member of the Equality and Diversity committee of ACM SIGMETRICS;
- is a member of the Conference Advisory committee of ACM SIGMETRICS;
- was a member of the Rising Star Award Committee for ACM SIGMETRICS 2022.

K. Avrachenkov

- is a member of Conseil Scientifique & Pédagogique EUR DS4H Univ. Côte d'Azur.

S. Perlaza

- is a member of the Digital Presence Committee of the IEEE Information Theory Society, from Jan 1, 2022 until Dec 31, 2023.
- is a member of the Sharing Teaching Resources Ad Hoc Committee of the IEEE Information Theory Society.

10.1.6 Research administration

S. Alouf

- is a member of NICE, the Invited Researchers Committee of Inria Sophia Antipolis Méditerranée, since June 2020;
- is member of CLF, the training committee of Inria Sophia Antipolis Méditerranée, since November 2014;
- is vice-head of project-team Neo since January 2017.

K. Avrachenkov

- is in charge of the Activity Report process for Inria Sophia Antipolis Méditerranée.

A. Jean-Marie

- is the scientific coordinator of Inria activities in Montpellier (since 2008); as part of this duty, he represents Inria at: the Scientific Council of the Doctoral School "Sciences and Agrosciences" of the Univ. of Avignon; at the Regional Conference of Research Organisms (CODOR); at the board of the Labex NUMEV.
- is Head of project-team NEO since January 2017

S. Perlaza

- was a reviewer for the selection committee of Ph.D. Grants for Labex DigiCosme. Université Paris-Saclay, Saclay, France.

10.2 Teaching - Supervision - Juries

10.2.1 Teaching

Note: UCA is the Univ Côte d'Azur.

PhD

- G. Neglia, "Federated Learning", 9H, Ph.D. Program in Information and Communication Technologies, Department of Engineering, Univ. of Palermo, Italy, 18-22/11/2023;

Master

- F. Faticanti, “Data Engineering”, 24H, M2 IAE, Univ. Savoie Mont Blanc, France
- S. Alouf, "Performance Evaluation of Networks", 21H, M2 Ubinet, UCA, France;
- O. Marfoq, G. Neglia, “Machine Learning: Theory and Algorithms", 24H, M2 Ubinet, UCA, France;
- O. Marfoq, G. Neglia, A. Rodio, “Optimization for Data Science”, 30H, M1 Data Science and Artificial Intelligence.

Bachelor

- Y. Ben Mazziane, “Introduction à l’informatique par le web", 36H, L1 UE INFO S1, UCA, France;

10.2.2 Supervision

PhD

- Mandar Datar, "Resource Allocation and Pricing in 5G Network Slicing" [50], Univ. Avignon, defense date 28 June 2022, advisor: Eitan Altman.
- Maximilien Dreveton, "Graph clustering and semi-supervised learning of non-binary, temporal and geometric networks" [51], UCA, defense date 6 Apr. 2022, advisor: Konstantin Avrachenkov.
- Mikhail Kamalov, "Scalable algorithms for graph-based semi-supervised learning with embedding", UCA, defense date 1 Dec. 2022, advisor: Konstantin Avrachenkov.
- Tareq Si Salem, "Online Learning for Network Resource Allocation" [53], UCA, defense date 17 Oct. 2022, advisor: Giovanni Neglia.

PhD in progress

- Younes Ben Mazziane, "Online learning for Caching at the Edge", UCA, 1 Oct. 2020, advisors: Sara Alouf and Giovanni Neglia.
- Olha Chuchuk, "Optimization of data access at CERN and in the World Large Hadron Collider Computing Grid (WLCG)", UCA, 1 Sept. 2020, advisor: Giovanni Neglia.
- Francisco Daunas, "Data Injection Attacks in Machine Learning Systems", Univ. of Sheffield, 1 Oct. 2020, co-advisor: S. M. Perlaza.
- Ibtihal El Mimouni, "Systèmes de recommandation automatisés et responsables pour le marketing digital", UCA, Thèse Cifre avec NSP SmartProfile, 1 Oct. 2022, advisor: Konstantin Avrachenkov.
- Caelin Kaplan, "Privacy and fairness for machine learning", UCA, 1 July 2021, advisors: Giovanni Neglia and Alain Jean-Marie.
- Othmane Marfoq, "Distributed machine learning for IoT applications", UCA, 1 December 2020, advisor: Giovanni Neglia.
- Angelo Rodio, "Sustainable distributed machine learning", UCA, 1 April 2021, advisors: Giovanni Neglia and Alain Jean-Marie.
- Xiuzhen Ye, "Data Injection Attacks in Smart Grids", Univ. of Sheffield, 1 Oct. 2019, co-advisor: S. M. Perlaza.
- Xinying Zou, "Classical and non-classical information patterns in distributed control with delayed sharing information", UCA, 1 Dec. 2022, advisors: E. Altman and S. M. Perlaza.

10.2.3 Juries

PhD

- Sicheng Dai, “Study of dynamical social networks of pre-school children using wearable wireless sensors”, ENS Lyon/ECNU, 23 May 2022 (S. Alouf, jury member);
- Francesco D’Amore, “On the Collective Behaviors of Bio-Inspired Distributed Systems”, UCA, 17 October 2022 (A. Jean-Marie, jury president);
- Mustapha Hamad, “Sharing resources for enhanced distributed hypothesis testing”, Institut polytechnique de Paris, 7 July 2022 (S. M. Perlaza, jury member);
- Hicham Lesfari, “Foundations of Networks towards AI”, UCA, 7 October 2022 (G. Neglia, jury member);
- Adeel Malik, “Stochastic Coded Caching Networks: A Study of Cache-Load Imbalance and Random User Activity”, Sorbonne Univ., 30 March 2022 (G. Neglia, reviewer);
- Thomas Tournaire, “Model-Based vs Model-Free Reinforcement Learning for large scale system in Telecommunication Area”, Institut Polytechnique de Paris, 2 May 2022 (S. Alouf, reviewer);

10.3 Popularization

10.3.1 Interventions

S. Alouf met and discussed with two classes at Jules Ferry High School in Cannes on 9 May 2022, in the context of the French national program « 1 Scientifique – 1 Classe, Chiche ! ».

11 Scientific production

11.1 Major publications

[1] D. Anade, J.-M. Gorce, P. Mary and S. M. Perlaza. ‘Saddlepoint Approximations of Cumulative Distribution Functions of Sums of Random Vectors’. In: ISIT 2021 - IEEE International Symposium on Information Theory. Melbourne / Virtual, Australia: IEEE, 12th July 2021, pp. 1–6. URL: https://hal.inria.fr/hal-03226009.

[2] K. Avrachenkov, A. Bobu and M. Dreveton. ‘Higher-Order Spectral Clustering for Geometric Graphs’. In: *Journal of Fourier Analysis and Applications* 27 (15th Mar. 2021). DOI: 10.1007/s00041-021-09825-2. URL: https://hal.inria.fr/hal-03169834.

[3] K. Avrachenkov and V. S. Borkar. ‘Whittle Index Policy for Crawling Ephemeral Content’. In: *IEEE Transactions on Control of Network Systems* 5.1 (Mar. 2018), pp. 446–455. DOI: 10.1109/TCNS.2016.2619066. URL: https://hal.inria.fr/hal-01937994.

[4] K. Avrachenkov, A. Y. Kondratev, V. V. Mazalov and D. Rubanov. ‘Network partitioning algorithms as cooperative games’. In: *Computational Social Networks* 5.11 (Oct. 2018). DOI: 10.1186/s40649-018-0059-5. URL: https://hal.inria.fr/hal-01935419.

[5] K. Avrachenkov, A. Piunovskiy and Y. Zhang. ‘Hitting Times in Markov Chains with Restart and their Application to Network Centrality’. In: *Methodology and Computing in Applied Probability* 20.4 (Dec. 2018), pp. 1173–1188. DOI: 10.1007/s11009-017-9600-5. URL: https://hal.inria.fr/hal-01937983.

[6] V. Bucarey López, E. Della Vecchia, A. Jean-Marie and F. Ordoñez. ‘Stationary Strong Stackelberg Equilibrium in Discounted Stochastic Games’. In: *IEEE Transactions on Automatic Control* (2023). URL: https://hal.inria.fr/hal-03934114.

[7] E. Leonardi and G. Neglia. ‘Implicit Coordination of Caches in Small Cell Networks under Unknown Popularity Profiles’. In: *IEEE Journal on Selected Areas in Communications* 36.6 (June 2018), pp. 1276–1285. DOI: 10.1109/JSAC.2018.2844982. URL: https://hal.inria.fr/hal-01956307.

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[10] G. Neglia, D. Carra, M. Feng, V. Janardhan, P. Michiardi and D. Tsigkari. 'Access-Time-Aware Cache Algorithms'. In: *ACM Transactions on Modeling and Performance Evaluation of Computing Systems* 2.4 (Dec. 2017), pp. 1–29. DOI: 10.1145/3149001. URL: https://hal.inria.fr/hal-01956285.

[11] G. Neglia, D. Carra and P. Michiardi. 'Cache Policies for Linear Utility Maximization'. In: *IEEE/ACM Transactions on Networking* 26.1 (Feb. 2018), pp. 302–313. DOI: 10.1109/TNET.2017.2783623. URL: https://hal.inria.fr/hal-01956319.

[12] A. Tajer, S. M. Perlaza and H. V. Poor. *Advanced Data Analytics for Power Systems*. Cambridge University Press, 1st Jan. 2021. URL: https://hal.archives-ouvertes.fr/hal-03128425.

11.2 Publications of the year

International journals

[13] K. Avrachenkov. 'Stability and partial instability of multi-class retrial queues'. In: *Queueing Systems* 100.3-4 (Apr. 2022), pp. 177–179. DOI: 10.1007/s11134-022-09814-2. URL: https://hal.inria.fr/hal-03767703.

[14] K. Avrachenkov, V. S. Borkar, S. Moharir and S. M. Shah. 'Dynamic social learning under graph constraints'. In: *IEEE Transactions on Control of Network Systems* 9.3 (Sept. 2022), pp. 1435–1446. DOI: 10.1109/TCNS.2021.3114377. URL: https://hal.science/hal-03462479.

[15] K. Avrachenkov, P. Brown and N. Litvak. 'Red Light Green Light Method for Solving Large Markov Chains'. In: *Journal of Scientific Computing* 93.18 (30th Aug. 2022), p. 43. DOI: 10.1007/s10915-022-01976-8. URL: https://hal.inria.fr/hal-03770430.

[16] K. Avrachenkov, V. Gaitsgory and L. Gamertsfelder. 'LP Based Upper and Lower Bounds for Cesàro and Abel Limits of the Optimal Values in Problems of Control of Stochastic Discrete Time Systems'. In: *Journal of Mathematical Analysis and Applications* 512.1 (Aug. 2022), p. 126121. DOI: 10.1016/j.jmaa.2022.126121. URL: https://hal.inria.fr/hal-03601283.

[17] K. Avrachenkov, K. Patil and G. Thoppe. 'Online algorithms for estimating change rates of web pages'. In: *Performance Evaluation*. SI: ValueTools 2020 153 (Feb. 2022), p. 25. DOI: 10.1016/j.peva.2021.102261. URL: https://hal.inria.fr/hal-03461575.

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[22] S. Dhamal, T. Chahed, E. Altman, A. Sunny, S. Poojary and W. Ben-Ameur. 'Strategic investments in distributed computing: A stochastic game perspective'. In: *Journal of Parallel and Distributed Computing* 169 (Nov. 2022), pp. 317–333. DOI: 10.1016/j.jpdc.2022.07.012. URL: https://inria.hal.science/hal-03767272.

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