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2020

ACTIVITY REPORT

Project-Team

COATI

Combinatorics, Optimization and Algorithms for Telecommunications

IN COLLABORATION WITH: Laboratoire informatique, signaux systèmes
de Sophia Antipolis (I3S)

DOMAIN

Networks, Systems and Services,
Distributed Computing

THEME

Networks and Telecommunications

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Project-Team COATI

Creation of the Team: 2013 January 01, updated into Project-Team: 2013 January 01

Keywords

Computer sciences and digital sciences

- A1.2.1. – Dynamic reconfiguration
- A1.2.3. – Routing
- A1.2.5. – Internet of things
- A1.2.9. – Social Networks
- A1.6. – Green Computing
- A3.5.1. – Analysis of large graphs
- A7.1. – Algorithms
 - A7.1.1. – Distributed algorithms
 - A7.1.3. – Graph algorithms
- A8.1. – Discrete mathematics, combinatorics
- A8.2. – Optimization
 - A8.2.1. – Operations research
- A8.7. – Graph theory
- A8.8. – Network science

Other research topics and application domains

- B1.1.1. – Structural biology
- B6.3.3. – Network Management
- B6.3.4. – Social Networks
- B7.2. – Smart travel

1 Team members, visitors, external collaborators

Research Scientists

- David Coudert [Team leader, Inria, Senior Researcher, HDR]
- Ramon Aparicio Pardo [Université Côte d'Azur, Researcher, from Sep 2020]
- Jean-Claude Bermond [CNRS, Emeritus, HDR]
- Frédéric Giroire [CNRS, Senior Researcher, HDR]
- Frédéric Havet [CNRS, Senior Researcher, HDR]
- Emanuele Natale [CNRS, Researcher]
- Nicolas Nisse [Inria, Researcher, HDR]
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Faculty Members

- Julien Bensmail [Université Côte d'Azur, Associate Professor, HDR]
- Christelle Caillouet [Université Côte d'Azur, Associate Professor]
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Post-Doctoral Fellows

- Emilio Cruciani [Université Côte d'Azur, until Oct 2020]
- François Pirot [Inria, from Nov 2020]
- Malgorzata Sulkowska [Université Côte d'Azur, from Sep 2020]

PhD Students

- Ali Al Zoobi [Inria]
- Arthur Carvalho Walraven Da Cunha [Inria, from Oct 2020]
- Francesco D'amore [Inria]
- Igor Dias Da Silva [Inria, from Oct 2020]
- Thomas Dissaux [Université Côte d'Azur, from Oct 2020]
- Foivos Fioravantes [Université Côte d'Azur]
- Adrien Gausseran [Université Côte d'Azur, from Oct 2018]
- Hicham Lesfari [Université Côte d'Azur]
- Zhejiayu Ma [Easybroadcast, CIFRE]
- Thi Viet Ha Nguyen [Inria]
- Thibaud Trolliet [Inria, Université Côte d'Azur, ATER, from Oct 2017]

Technical Staff

- Luc Hogie [CNRS, Engineer]

Interns and Apprentices

- Anthony Choquard [Université Côte d'Azur, Intern, from Nov 2020]
- Lucas De Meyer [École normale supérieure de Rennes, Intern, from May 2020 until Jul 2020]
- Igor Dias Da Silva [Université Côte d'Azur, Intern, until Jan 2020]
- Igor Dias Da Silva [Inria, Intern, from Mar 2020 until Aug 2020]
- Haoran Ding [Université Côte d'Azur, Intern, until Jan 2020]
- Thomas Dissaux [Inria, Intern, from Mar 2020 until Aug 2020]
- Abdelkrim El Merss [Université Côte d'Azur, Intern, until Jan 2020]
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- Gregory Hoareau [Université Côte d'Azur, Intern, from Nov 2020]
- Noueman Khalikine [Noueman Khalikine, Intern, until Jan 2020]
- Guillaume Naffrichoux [Engie, Intern, until Feb 2020]
- Artem Panchenko [Inria, Intern, from Mar 2020 until Aug 2020]
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Administrative Assistant

- Patricia Riveill [Inria]

Visiting Scientists

- Redha Abderrahmane Alliche [Université Côte d'Azur, from Oct 2020]
- Jorgen Bang-Jensen [University Southern Denmark de Odense, from Feb 2020 until Jun 2020]
- Jonas Costa Ferreira Da Silva [Universidade Federal do Ceará de Fortaleza - Brazil]
- Michal Lason [Polish Academy of Sciences, Oct 2020]
- Fabricio Siqueira Benevides [Universidade Federal do Ceará de Fortaleza - Brazil, until Jul 2020]
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External Collaborator

- Michel Cosnard [Université Côte d'Azur, from Nov. 2019, emeritus Professor]

2 Overall objectives

COATI is a joint team between INRIA Sophia Antipolis - Méditerranée and the I3S laboratory (Informatique Signaux et Systèmes de Sophia Antipolis) which itself belongs to CNRS (Centre National de la Recherche Scientifique) and Univ. Côte d'Azur. Its research fields are Algorithmics, Discrete Mathematics, and Combinatorial Optimization, with applications mainly in telecommunication networks.

The main objectives of the COATI project-team are to design networks and communication algorithms. In order to meet these objectives, the team studies various theoretical problems in Discrete Mathematics, Graph Theory, Algorithmics, and Operations Research and develops applied techniques and tools, especially for Combinatorial Optimization and Computer Simulation. In particular, COATI used in the last years both these theoretical and applied tools for the design of various networks, such as SDN (software defined networks), WDM, wireless (radio), satellite, and peer-to-peer networks. This research has been done within various industrial and international collaborations.

COATI also investigates other application areas such as bio-informatics and transportation networks.

The research done in COATI results in the production of prototype and more advanced software, and in the contribution to large open source software such as [Sagemath](#).

3 Research program

Since its creation in 2013, the objectives of COATI are to conduct fundamental research in Discrete Mathematics, Graph Theory, Digraph Theory, Algorithms and Operations Research, and to use these tools for studying specific network optimization problems. Notice that we are mostly interested in telecommunications networks. However, our expertise can be applied to solve many other problems in various areas (transport, biology, resource allocation, social sciences, smart-grids, speleology, etc.) and we collaborate with teams of these other domains. COATI also contributes to the development of software components in order to validate proposed algorithms and to boost their dissemination.

The research program of COATI is therefore structured as follows.

- We conduct fundamental research in graph and digraph theory. Our goal is to better understand the structure of (di)graphs and which particular (sub)structures make an optimization problem on (di)graphs difficult. We are particularly interested in digraphs which are less investigated than (undirected) graphs, although most optimization problems are naturally modeled using digraphs. This is certainly due to the fact that several problems that can be solved in polynomial time on graphs are hard to solve on digraphs.
- We use this knowledge to design algorithms on (di)graphs (exact, sub-exponential, parameterized, approximation, heuristics) in order to solve various optimization problems. We also investigate games on graphs as an algorithmic counter part of some (di)graph theory studies to get more insight on problems and (di)graphs properties. One of the challenges we have to face in the design of algorithms is the increase in size of practical instances. It is difficult, if not impossible, to solve practical instances optimally using existing tools. Therefore, we have to find new ways to address problems using reduction and decomposition methods, characterization of polynomial instances (which are sometimes the practical ones), or design of algorithms with acceptable practical performances independently of the worst case time complexity.
- We study specific network optimization problems at both design and management levels such as energy efficiency in networks, routing reconfiguration of optical and software defined networks (SDN), reconfiguration of network slices without interruption, placement and migration of chains of virtual functions (NFV), compact routing in large-scale networks, deployment and management of fleet of drones, design of reliable wireless networks, evolution of the routing in case of any kind of topological modifications (maintenance operations, failures, capacity variations, etc.), survivability to single and multiple failures, etc. These specific problems often come from questions of our industrial partners (CIENA, Huawei, Orange labs). We first contribute to the modeling of these problems; then we either use existing tools or develop new tools in Operation Research and (Di)Graph Theory to solve them.

- We also investigate optimization problems in other application fields such as structural biology, transportation networks, economy, sociology, etc. On the one side, these collaborations benefit to the considered domains via the dissemination of our tools. On the other side, they give rise to new problems of interest for our community, and help us to improve our knowledge and to test our algorithms on specific instances.
- We have recently started investigating how tools from multi-agents based systems and machine learning theory could help solving some optimization problems in networks. The arrival of Emanuele Natale as a CNRS researcher in the team, of Ramon Aparicio-Pardo for a one year "délégation", and the recruitment of several new PhD students (Francesco D'Amore, Arthur Carvalho Walraven da Cunha and Hicham Lesfari) will foster these investigations.
- Last but not the least, the research done in COATI results in the production of prototype and advanced software (FastGRACE, GRPH, BigGrph, etc.), and in the contribution to large open source software such as [Sagemath](#).

Note also that beside our research activity, we are deeply involved in the dissemination of our domain towards a general public.

4 Application domains

4.1 Telecommunication Networks

COATI is mostly interested in telecommunications networks but also in the network structure appearing in social, molecular and transportation networks.

We focus on the design and management of heterogeneous physical and logical networks. The project has kept working on the design of backbone networks (optical networks, radio networks, IP networks). However, the fields of Software Defined Networks and Network Function Virtualization are growing in importance in our studies. In all these networks, we study routing algorithms and the evolution of the routing in case of any kind of topological modifications (maintenance operations, failures, capacity variations, etc.).

4.2 Other Domains

Our combinatorial tools may be well applied to solve many other problems in various areas (transport, biology, resource allocation, chemistry, smart-grids, speleology, etc.) and we collaborate with experts of some of these domains.

For instance, we collaborate with project-team ABS (Algorithms Biology Structure) from Sophia Antipolis on problems from Structural Biology (co-supervision of a PhD student). In the area of transportation networks, we collaborate with SMEs Benomad and Instant-System on dynamic car-pooling combined with multi-modal transportation systems in the context of ANR project Multimod started in January 2018. We collaborate with SME MillionRoads since October 2019 on the modeling and exploration of the HumanRoads database that gathers more than 100 million curriculums (studies and career paths of persons). Last, we have started a collaboration with GREDEG (Groupe de Recherche en Droit, Economie et Gestion, Université Côte d'Azur) and the SKEMA business school on the analysis of the impact of competitive funding on the evolution of scientific collaboration networks.

5 Highlights of the year

- Adrien Gausseran, 1st prize of the jury for the "*Ma Thèse en 180 secondes*" (MT180) final at Université Côte d'Azur, edition 2020.
- The software FastGrace has been transferred to SME MillionRoads (see description of the software Section [6.1](#)).

6 New software and platforms

6.1 New software

6.1.1 k shortest simple paths

Name: k shortest simple paths

Keywords: Graph, Graph algorithmics

Functional Description: Implementation in C++ of algorithms for computing the k shortest simple paths from a source to a destination in a weighted directed graph.

Release Contributions: This version implements the standard algorithm proposed by Yen (Yen), Node Classification algorithm proposed by Feng (NC), the Sidetrack Based algorithm proposed by Kurz and Mutzel (SB), and variants of SB proposed by Ali Zoobi, Coudert and Nisse to reduce running time (SB*) and memory usage (PSB).

URL: <https://gitlab.inria.fr/dcoudert/k-shortest-simple-paths>

Publication: hal-02865918

Contact: David Coudert

Participants: David Coudert, Nicolas Nisse, Ali Al Zoobi

6.1.2 FastGRACE

Keywords: Graph algorithmics, Java, Data Exploration, Data base

Functional Description: Modeling of a database linking users to their studies and careers in the form of a graph. Algorithms for graphs associated with the queries made (of the type: number of users who have completed a given curriculum, distribution of careers following a given curriculum, distribution of curriculums preceding a given career, etc.). Scaling for a database of >100 million users.

In addition, Neo4j implemetations of various algorithms tested on the HumanRoads data.

Authors: Nicolas Chleq, Frédéric Giroire, Luc Hogie, Nicolas Nisse

Contacts: Nicolas Nisse, Frédéric Giroire

Participants: Nicolas Chleq, Frédéric Giroire, Luc Hogie, Nicolas Nisse

6.1.3 Sagemath

Name: SageMath

Keywords: Graph algorithmics, Graph, Combinatorics, Probability, Matroids, Geometry, Numerical optimization

Scientific Description: SageMath is a free open-source mathematics software system. It builds on top of many existing open-source packages: NumPy, SciPy, matplotlib, Sympy, Maxima, GAP, FLINT, R and many more. Access their combined power through a common, Python-based language or directly via interfaces or wrappers.

Functional Description: SageMath is an open-source mathematics software initially created by William Stein (Professor of mathematics at Washington University). We contribute the addition of new graph algorithms along with their documentations and the improvement of underlying data structures.

Release Contributions: See <http://www.sagemath.org/changelogs/>

News of the Year: 1) Improvement of methods related to distances (shortest paths, radius, diameter, eccentricities). Done in the context of Google Summer of Code 2020. 2) Implementation of various algorithms such as linear time Lex-BFS, decomposition of a graph by clique minimal separators, Wiener index, distance distribution, Cheeger constants, etc.

URL: <http://www.sagemath.org/>

Contact: David Coudert

Participant: David Coudert

6.1.4 JMaxGraph

Keywords: Java, HPC, Graph algorithmics

Functional Description: JMaxGraph is a collection of techniques for the computation of large graphs on one single computer. The motivation for such a centralized computing platform originates in the constantly increasing efficiency of computers which now come with hundred gigabytes of RAM, tens of cores and fast drives. JMaxGraph implements a compact adjacency-table for the representation of the graph in memory. This data structure is designed to 1) be fed page by page, à-la GraphChi, 2) enable fast iteration, avoiding memory jumps as much as possible in order to benefit from hardware caches, 3) be tackled in parallel by multiple-threads. Also, JMaxGraph comes with a flexible and resilient batch-oriented middleware, which is suited to executing long computations on shared clusters. The first use-case of JMaxGraph allowed F. Giroire, T. Trollet and S. Pérennes to count K_{2,2}s, and various types of directed triangles in the Twitter graph of users (23G arcs, 400M vertices). The computation campaign took 4 days, using up to 400 cores in the NEF Inria cluster.

URL: <http://www.i3s.unice.fr/~hogie/software/?name=jmaxgraph>

Contacts: Luc Hogie, Michel Syska, Stéphane Pérennes

6.1.5 Idawi

Keywords: Java, Distributed, Distributed computing, Distributed Applications, Web Services, Parallel computing, Component models, Software Components, P2P, Dynamic components, Iot

Functional Description: Idawi is a middleware for the development and experimentation of distributed algorithms. It boasts a very general and flexible multi-hop component-oriented model that make it applicable in many contexts such as parallel and distributed computing, cloud, Internet of Things (IOT), P2P networks, etc. Idawi components can be deployed anywhere a SSH connection is possible. They exhibit services which communicate with each other via explicit messaging. Messages and be sent in either synchronously or asynchronously, and they can be handled in either procedural (with the optional use of futures) or reactive (event-driven) fashion. In the latter case, multi-threading is used to maximize both speed and number of components in the system. Idawi message transport is done via TCP, UDP, SSH or shared-memory.

Idawi is a synthesis of the past developments of the COATI Research group in the field of graph algorithms for big graphs, and it is designed to be useful to the current and future Research project of COATI and KAIROS groups.

URL: <https://github.com/lhogie/idawi>

Contact: Luc Hogie

7 New results

7.1 Network Design and Management

Participants Jean-Claude Bermond, Yann Busnel (*DIONYSOS*), Christelle Caillouet, David Coudert, Igor Dias da Silva, Giuseppe Di Lena (*COATI*, *DIANA*), Foivos Fioravantes, Adrien Gausseran, Frédéric Giroire, Dorian Mazauric (*ABS*), Joanna Moulierac, Philippe Nain (*DANTE*), Damien Saucez (*DIANA*), Géraldine Texier (*ADOPNET*), Thierry Turetletti (*DIANA*).

Network design is a very wide subject which concerns all kinds of networks. In telecommunications, networks can be either physical (backbone, access, wireless, ...) or virtual (logical). The objective is to design a network able to route a (given, estimated, dynamic, ...) traffic under some constraints (e.g. capacity) and with some quality-of-service (QoS) requirements. Usually the traffic is expressed as a family of requests with parameters attached to them. In order to satisfy these requests, we need to find one (or many) paths between their end nodes. The set of paths is chosen according to the technology, the protocol or the QoS constraints.

We mainly focus on the following topics: Firstly, we study Network Function Virtualization (NFV) and how to embed them in public clouds. We also study the reconfiguration of network slices within 5G networks. Secondly, we study the optimization of LoRa networks. We propose a new analytic model to better evaluate the capacity of a single LoRaWAN cell and an optimization model to maximize the minimum packet delivery rate of every IoT node in the network. Thirdly, we pursued our study of distributed link scheduling in wireless networks. Finally, we investigate on the placement of drones for maximizing the coverage of a landscape by drones in order to localize targets or collect data from sensors.

7.1.1 Network slicing and Network Function Virtualization

Recent advances in networks such as Software Defined Networking (SDN) and Network Function Virtualization (NFV) are changing the way network operators deploy and manage Internet services. On the one hand, SDN introduces a logically centralized controller with a global view of the network state. On the other hand, NFV enables the complete decoupling of network functions from proprietary appliances and runs them as software applications on general purpose servers. In such a way, network operators can dynamically deploy Virtual Network Functions (VNFs). SDN and NFV, both separately, bring to network operators new opportunities for reducing costs, enhancing network flexibility and scalability, and shortening the time-to-market of new applications and services. Moreover, the centralized routing model of SDN jointly with the possibility of instantiating VNFs on demand may open the way for an even more efficient operation and resource management of networks. For instance, an SDN/NFV-enabled network may simplify the Service Function Chain (SFC) deployment and provisioning by making the process easier and cheaper. We addressed several questions in this context.

In [63, 64, 65] we address a cost minimization problem encountered by network operators subscribing to public cloud offers to embed network functions. The diversity of offers, in terms of resource capacity and price, makes it difficult to find the optimal combination of offers that meets all needs at the lowest cost. We propose to solve this issue with an algorithm designed to help a network operator to select the best combination of offers (in terms of price) to reserve the virtual machines needed to support a set of network services. We analyze the computation time of our solution against various metrics, and estimate the cost savings compared to a traditional resource provision scheme or an unplanned resource rental strategy. Finally we evaluate the opportunity for a network operator to build its own datacenter, considering the existence of offers from public clouds.

In [56], we consider the problem of network slice reconfiguration without interruption. A network slice can be seen as a virtual network embedded on the physical topology, with some VNFs placed in specific nodes. As an example, a simplified network slice could be an SFC. Reconfiguring from time to time network slices allows to reduce the network operational costs and to increase the number of slices that can be managed within the network. However, it impacts users' Quality of Service during the

reconfiguration step. To solve this issue, we study solutions implementing a make-before-break scheme. We propose new models and scalable algorithms (relying on column generation techniques) that solve large data instances in few seconds.

In [62] we propose and implement a new placement module for distributed emulation of SDN/NFV emulation. To handle the ever growing demand of resource intensive experiments distributed, network emulation tools such as Mininet and Maxinet have been proposed. They automatically allocate experimental resources. However, we have shown that resources are poorly allocated, leading to resource overloading and hence to dubious experimental results. Our new algorithms take into account both link and node resources and minimize the number of physical hosts needed to carry out the emulation. Through extensive numerical evaluations, simulations, and actual experiments, we show that our placement methods outperform existing ones and allowing to re-establish trust in experimental results.

7.1.2 Optimization of LoRa networks for the IoT

Optimization of a LoRaWAN Cell In [48, 61], we consider the problem of evaluating the capacity of a LoRaWAN cell. Previous analytical studies investigated LoRaWAN performance in terms of the Packet Delivery Ratio (PDR) given a number of devices around a gateway and its range. We improve the model for PDR by taking into consideration that the following two events are dependent: successful capture during a collision and successful frame decoding despite ambient noise. We consider a realistic traffic model in which all devices generate packets with the same inter-transmission times corresponding to the duty cycle limitation at the highest SF, regardless of the distance to the gateway. Based on the developed model, we optimize the Spreading Factor (SF) boundaries to even out PDR throughout the cell. We validate the analytical results with simulations, compare our model with previous work, and experimentally validate the hypothesis of Rayleigh fading for the LoRa channel. The important conclusion from our results is that a LoRa cell can handle a relatively large number of devices. We also show that there is practically no inter-SF interference (cross interference between transmissions with different SFs): interference from higher SFs comes from nodes located farther away, so they face greater attenuation and thus, they do not interfere with lower SF nodes.

Bringing Fairness in LoRaWAN through SF Allocation Optimization In [47], we propose an optimization model for single-cell LoRaWAN planning which computes the limit range of each spreading factor (SF) in order to maximize the minimum packet delivery ratio (PDR) of every node in the network. It allows to balance the opposite effects of attenuation and collision of the transmissions and guarantee fairness among the nodes. We show that our optimization framework improves the worst PDR of the nodes by more than 13 percentage points compared to usual SF boundaries based on SNR threshold. A study of the tradeoff between precision and resolution time of the model shows its effectiveness even with a small number of possible distance limits, and its scalability when the node density increases.

7.1.3 Link scheduling in wireless networks

Distributed link scheduling in wireless networks In [29], we investigated distributed transmission scheduling in wireless networks. Due to interference constraints, “neighboring links” cannot be simultaneously activated, otherwise transmissions will fail. We consider any binary model of interference and use a model described by Bui, Sanghavi, and Srikant in [86, 92]. We assume that time is slotted and during each slot there are two phases: one control phase in which a link scheduling algorithm determines a set of non interfering links to be activated, and a data phase in which data is sent through these links. We assume random arrivals on each link during each slot, so that a queue is associated to each link. We design the first fully distributed local algorithm with the following properties: it works for any arbitrary binary interference model; it has a constant overhead (independent of the size of the network and the values of the queues), and it does not require any knowledge of the queue-lengths. We prove that this algorithm gives a maximal set of active links, where for any non-active link there exists at least one active link in its interference set. We also establish sufficient conditions for stability under general Markovian assumptions. Finally, the performance of our algorithm (throughput, stability) is investigated and compared via simulations to that of previously proposed schemes.

Gossiping with Interference Constraints in Radio Chain Networks In [28], we study the problem of gossiping with neighboring interference constraint in radio chain networks. Gossiping (also called total exchange information) is a protocol where each node in the network has a message and is expected to distribute its own message to every other node in the network. The gossiping problem consists in finding the minimum running time (makespan) of a gossiping protocol and efficient algorithms that attain this makespan. We focus on the case where the transmission network is a chain (directed path or line) network. We consider synchronous protocols where it takes one unit of time (step) to transmit a unit-length message. During one step, a node receives at most one message only through one of its two neighbors. We assume that during one step, a node cannot be both a sender and a receiver (half duplex model). Moreover we have neighboring interference constraints under which a node cannot receive a message if one of its neighbors is sending. A round consists of a set of non-interfering (or compatible) calls and uses one step. We completely solve the gossiping problem for P_n , the chain network on n nodes, and give an algorithm that completes the gossiping in $3n - 5$ rounds (for $n > 3$), which is exactly the makespan.

7.1.4 Optimizing drone coverage

The use of autonomous unmanned aerial vehicles (UAVs) or drones has emerged to efficiently collect data from mobile sensors when there is no infrastructure available. The drones can form a flying ad-hoc network through which the sensors can send their data to a base station at any time.

In [54], we present a mixed integer linear program to find the drones' optimal trajectories to form and maintain this network through time while minimizing their movements and energy consumption. Furthermore we analyze the trade-off between distance and energy, where increasing the drones' mobility can reduce their energy consumption, and derive a fair trade-off optimal solution to balance the two opposite objectives.

In [46], we propose VESPA, a distributed algorithm using only one-hop information of the drones, to discover targets with unknown location and auto-organize themselves to ensure connectivity between them and the sink in a multi-hop aerial wireless network. We prove that connectivity, termination and coverage are preserved during all stages of our algorithm, and we evaluate the algorithm performances through simulations. Comparison with a prior work shows the efficiency of VESPA both in terms of discovered targets and number of used drones.

7.2 Graph Algorithms

Participants Ali Al Zoobi, Julien Bensmail, Jean-Claude Bermond, David Coudert, Emilio Cruciani, Francesco d'Amore, Thomas Dissaux, Foivos Fioravantes, Frédéric Giroire, Frédéric Havet, Luc Hogue, Dorian Mazaruric (ABS), Emanuele Natale, Thi Viet Ha Nguyen, Nicolas Nisse, Stéphane Pérennes, Thibaud Trollet.

COATI is interested in the algorithmic aspects of Graph Theory. In general we try to find the most efficient algorithms to solve various problems of Graph Theory and telecommunication networks. We use Graph Theory to model various network problems. We study their complexity and then we investigate the structural properties of graphs that make these problems hard or easy.

7.2.1 Complexity of graph problems

On the Complexity of Computing Treebreadth During the last decade, metric properties of the bags of tree decompositions of graphs have been studied. Roughly, the length and the breadth of a tree decomposition are the maximum diameter and radius of its bags respectively. The treelength and the treebreadth of a graph are the minimum length and breadth of its tree decompositions respectively. Pathlength and pathbreadth are defined similarly for path decompositions. In [32], we answer open questions of Dragan *et al.* [87, 88] about the computational complexity of treebreadth, pathbreadth and pathlength. Namely, we prove that computing these graph invariants is NP-hard. We further

investigate graphs with treebreadth one, i.e., graphs that admit a tree decomposition where each bag has a dominating vertex. We show that it is NP-complete to decide whether a graph belongs to this class. We then prove some structural properties of such graphs which allows us to design polynomial-time algorithms to decide whether a bipartite graph, resp., a planar graph (or more generally, a triangle-free graph, resp., a $K_{3,3}$ -minor-free graph), has treebreadth one.

Treelength of Series-parallel graphs The *length* of a *tree-decomposition* of a graph is the maximum distance between two vertices of a same bag of the decomposition. The *treelength* of a graph is the minimum length among its tree-decompositions. Treelength of graphs has been studied for its algorithmic applications in classical metric problems such as Traveling Salesman Problem or metric dimension of graphs and also, in compact routing in the context of distributed computing. Deciding whether the treelength of a general graph is at most 2 is NP-complete (graphs of treelength one are precisely the chordal graphs), and it is known that the treelength of a graph cannot be approximated up to a factor less than $\frac{3}{2}$ (the best known approximation algorithm for treelength has an approximation ratio of 3). However, nothing is known on the computational complexity of treelength in planar graphs, except that the treelength of any outerplanar graph is equal to the third of the maximum size of its isometric cycles. This work initiates the study of treelength in planar graphs by considering its next natural subclass, namely the one of series-parallel graphs.

In [81], we first fully describe the treelength of melon graphs (set of pairwise internally disjoint paths linking two vertices), showing that, even in such a restricted graph class, the expression of the treelength is not trivial. Then, we show that treelength can be approximated up to a factor $\frac{3}{2}$ in series-parallel graphs. Our main result is a polynomial-time algorithm for deciding whether a series-parallel graph has treelength at most 2. Our latter result relies on a characterization of series-parallel graphs with treelength 2 in terms of infinite families of forbidden isometric subgraphs.

7.2.2 Combinatorial games in graphs

Eternal domination game on graphs In the eternal domination game played on graphs, an attacker attacks a vertex at each turn and a team of guards must move a guard to the attacked vertex to defend it. The guards may only move to adjacent vertices on their turn. The goal is to determine the eternal domination number γ_{all}^∞ of a graph, which is the minimum number of guards required to defend against an infinite sequence of attacks.

We have continued the study of the eternal domination game on strong grids. Cartesian grids have been vastly studied with tight bounds for small grids such as $2 \times n$, $3 \times n$, $4 \times n$, and $5 \times n$ grids, and it was proven in [90] that the eternal domination number of these grids in general is within $O(m+n)$ of their domination number which lower bounds the eternal domination number. Furthermore, it has been proved in [89] that the eternal domination number of strong grids is upper bounded by $\frac{mn}{6} + O(m+n)$.

In [33], we adapt the techniques of [90] to prove that the eternal domination number of strong grids is upper bounded by $\frac{mn}{7} + O(m+n)$. While this does not improve upon a recently announced bound of $\lceil m/3 \rceil \times \lceil n/3 \rceil + O(m\sqrt{n})$ [91] in the general case, we show that our bound is an improvement in the case where the smaller of the two dimensions is at most 6179.

In [35], we prove that, for all $n, m \in \mathbb{N}^*$ such that $m \geq n$, $\lfloor \frac{n}{3} \rfloor \lfloor \frac{m}{3} \rfloor + \Omega(n+m) = \gamma_{all}^\infty(P_n \boxtimes P_m) = \lceil \frac{n}{3} \rceil \lceil \frac{m}{3} \rceil + O(m\sqrt{n})$ (note that $\lceil \frac{n}{3} \rceil \lceil \frac{m}{3} \rceil$ is the domination number of $P_n \boxtimes P_m$). We then generalize our technique to prove that $\gamma_{all}^\infty(G) = \gamma(G) + o(\gamma(G))$ for all graphs $G \in \mathcal{F}$, where \mathcal{F} is a large family of D -dimensional grids which are supergraphs of the D -dimensional Cartesian grid and subgraphs of the D -dimensional strong grid. In particular, \mathcal{F} includes both the D -dimensional Cartesian grid and the D -dimensional strong grid.

Study of a Combinatorial Game in Graphs Through Linear Programming In the Spy game played on a graph G , a single spy travels the vertices of G at speed s , while multiple slow guards strive to have, at all times, one of them within distance d of that spy. In [30], we analyze the game through a Linear Programming formulation and the fractional strategies it yields for the guards in order to determine the smallest number of guards necessary for this task. We then show the equivalence of fractional and integral strategies in trees. This allows us to design a polynomial-time algorithm for computing an optimal strategy in this class of graphs. Using duality in Linear Programming, we also provide non-trivial

bounds on the fractional guard-number of grids and tori, which gives a lower bound for the integral guard-number in these graphs. We believe that the approach using fractional relaxation and Linear Programming is promising to obtain new results in the field of combinatorial games.

Sequential Metric Dimension In the localization game, introduced by Seager in 2013, an invisible and immobile target is hidden at some vertex of a graph G . At every step, one vertex v of G can be probed which results in the knowledge of the distance between v and the secret location of the target. The objective of the game is to minimize the number of steps needed to locate the target whatever be its location.

In [24], we address the generalization of this game where $k \geq 1$ vertices can be probed at every step. Our game also generalizes the notion of the *metric dimension* of a graph. Precisely, given a graph G and two integers $k, \ell \geq 1$, the LOCALIZATION problem asks whether there exists a strategy to locate a target hidden in G in at most ℓ steps and probing at most k vertices per step. We first show that, in general, this problem is NP-complete for every fixed $k \geq 1$ (resp., $\ell \geq 1$). We then focus on the class of trees. On the negative side, we prove that the LOCALIZATION problem is NP-complete in trees when k and ℓ are part of the input. On the positive side, we design a (+1)-approximation algorithm for the problem in n -node trees, *i.e.*, an algorithm that computes in time $O(n \log n)$ (independent of k) a strategy to locate the target in at most one more step than an optimal strategy. This algorithm can be used to solve the LOCALIZATION problem in trees in polynomial time if k is fixed.

We also consider some of these questions in the context where, upon probing the vertices, the relative distances to the target are retrieved. This variant of the problem generalizes the notion of the *centroidal dimension* of a graph.

Complexity of Games Compendium Since games and puzzles have been studied under a computational lens, researchers unearthed a rich landscape of complexity results showing deep connections between games and fundamental problems and models in computer science. Complexity of Games (CoG, <https://steven3k.gitlab.io/isnphard-test/>) is a compendium of complexity results on games and puzzles. It aims to serve as a reference guide for enthusiasts and researchers on the topic and is a collaborative and open source project that welcomes contributions from the community.

NP-completeness of the Kingdomino game Kingdomino is a board game designed by Bruno Cathala and edited by Blue Orange since 2016. The goal is to place 2×1 dominoes on a grid layout, and get a better score than other players. Each 1×1 domino cell has a color that must match at least one adjacent cell, and an integer number of crowns (possibly none) used to compute the score. In [36], we prove that even with full knowledge of the future of the game, in order to maximize their score at Kingdomino, players are faced with an NP-complete optimization problem.

7.2.3 Algorithms engineering

Space and Time Trade-Off for the k Shortest Simple Paths Problem The k shortest simple path problem (k SSP) asks to compute a set of top- k shortest simple paths from a vertex s to a vertex t in a digraph. Yen (1971) proposed the first algorithm with the best known theoretical complexity of $O(kn(m + n \log n))$ for a digraph with n vertices and m arcs. Since then, the problem has been widely studied from an algorithm engineering perspective, and impressive improvements have been achieved. In particular, Kurz and Mutzel (2016) proposed a *sidetracks-based* (SB) algorithm which is currently the fastest solution. In this work, we propose two improvements of this algorithm. In [39, 40, 70], we first show how to speed up the SB algorithm using dynamic updates of shortest path trees. We did experiments on some road networks of the 9th DIMAC'S challenge with up to about half a million nodes and one million arcs. Our computational results show an average speed up by a factor of 1.5 to 2 with a similar working memory consumption as SB. We then propose a second algorithm enabling to significantly reduce the working memory at the cost of an increase of the running time (up to two times slower). Our experiments on the same data set show, on average, a reduction by a factor of 1.5 to 2 of the working memory.

7.2.4 Algorithms for social networks

A Random Growth Model with any Real or Theoretical Degree Distribution The degree distributions of complex networks are usually considered to be power law. However, it is not the case for a large number of them. We thus propose in [55, 57] a new model able to build random growing networks with (almost) any wanted degree distribution. The degree distribution can either be theoretical or extracted from a real-world network. The main idea is to invert the recurrence equation commonly used to compute the degree distribution in order to find a convenient attachment function for node connections—commonly chosen as linear. We compute this attachment function for some classical distributions, as the power-law, broken power-law, geometric and Poisson distributions. We also use the model on an undirected version of the Twitter network, for which the degree distribution has an unusual shape.

Interest Clustering Coefficient: a New Metric for Directed Networks like Twitter In [66, 67], we study the clustering of directed social graphs. The clustering coefficient has been introduced to capture the social phenomena that a friend of a friend tends to be my friend. This metric has been widely studied and has shown to be of great interest to describe the characteristics of a social graph. In fact, the clustering coefficient is adapted for a graph in which the links are undirected, such as friendship links (Facebook) or professional links (LinkedIn). For a graph in which links are directed from a source of information to a consumer of information, it is no longer adequate. We show that former studies have missed much of the information contained in the directed part of such graphs. We thus introduce a new metric to measure the clustering of a directed social graph with interest links, namely the interest clustering coefficient. We compute it (exactly and using sampling methods) on a very large social graph, a Twitter snapshot with 505 million users and 23 billion links. We additionally provide the values of the formerly introduced directed and undirected metrics, a first on such a large snapshot. We exhibit that the interest clustering coefficient is larger than classic directed clustering coefficients introduced in the literature. This shows the relevancy of the metric to capture the informational aspects of directed graphs.

Step-by-step community detection in volume-regular graphs Spectral techniques have proved amongst the most effective approaches to graph clustering. However, in general they require explicit computation of the main eigenvectors of a suitable matrix (usually the Laplacian matrix of the graph). Recent work (e.g., Becchetti et al., SODA 2017 [84]) suggests that observing the temporal evolution of the power method applied to an initial random vector may, at least in some cases, provide enough information on the space spanned by the first two eigenvectors, so as to allow recovery of a hidden partition without explicit eigenvector computations. While the results of Becchetti et al. apply to perfectly balanced partitions and/or graphs that exhibit very strong forms of regularity, we extend their approach to graphs containing a hidden k -partition and characterized by a milder form of volume-regularity. In [19], we show that the class of k -volume-regular graphs is the largest class of undirected (possibly weighted) graphs whose transition matrix admits k “stepwise” eigenvectors (i.e., vectors that are constant over each set of the hidden partition). To obtain this result, we highlight a connection between volume regularity and lumpability of Markov chains. Moreover, we prove that if the stepwise eigenvectors are those associated to the first k eigenvalues and the gap between the k -th and the $(k + 1)$ -th eigenvalues is sufficiently large, the Averaging dynamics of Becchetti et al. recovers the underlying community structure of the graph in logarithmic time, with high probability.

Biased Opinion Dynamics: When the Devil is in the Details In [41], we investigate opinion dynamics in multi-agent networks when a bias toward one of two possible opinions exists; for example, reflecting a status quo vs a superior alternative. Starting with all agents sharing an initial opinion representing the status quo, the system evolves in steps. In each step, one agent selected uniformly at random adopts the superior opinion with some probability α , and with probability $1 - \alpha$ it follows an underlying update rule to revise its opinion on the basis of those held by its neighbors. We analyze convergence of the resulting process under two well-known update rules, namely majority and voter. The framework we propose exhibits a rich structure, with a non-obvious interplay between topology and underlying update rule. For example, for the voter rule we show that the speed of convergence bears no significant dependence on the underlying topology, whereas the picture changes completely under the majority rule, where network density negatively affects convergence. We believe that the model we propose is at the same time simple,

rich, and modular, affording mathematical characterization of the interplay between bias, underlying opinion dynamics, and social structure in a unified setting.

Election Control Through Social Influence with Unknown Preferences The election control problem through social influence asks to find a set of nodes in a social network of voters to be the starters of a political campaign aiming at supporting a given target candidate. Voters reached by the campaign change their opinions on the candidates. The goal is to shape the diffusion of the campaign in such a way that the chances of victory of the target candidate are maximized. Previous work shows that the problem can be approximated within a constant factor in several models of information diffusion and voting systems, assuming that the controller, i.e., the external agent that starts the campaign, has full knowledge of the preferences of voters. However this information is not always available since some voters might not reveal it. In [38], we relax this assumption by considering that each voter is associated with a probability distribution over the candidates. We then propose two models in which, when an electoral campaign reaches a voter, this latter modifies its probability distribution according to the amount of influence it received from its neighbors in the network. We then study the election control problem through social influence on the new models: In the first model, under the Gap-ETH, election control cannot be approximated within a factor better than $1/n^{o(1)}$, where n is the number of voters; in the second model, which is a slight relaxation of the first one, the problem admits a constant factor approximation algorithm.

7.2.5 Distributed algorithms

Find Your Place: Simple Distributed Algorithms for Community Detection Given an underlying graph, we consider the following dynamics: Initially, each node locally chooses a value in $\{-1, 1\}$, uniformly at random and independently of other nodes. Then, in each consecutive round, every node updates its local value to the average of the values held by its neighbors, at the same time applying an elementary, local clustering rule that only depends on the current and the previous values held by the node. We prove in [18] that the process resulting from this dynamics produces a clustering that exactly or approximately (depending on the graph) reflects the underlying cut in logarithmic time, under various graph models that exhibit a sparse balanced cut, including the stochastic block model. We also prove that a natural extension of this dynamics performs community detection on a regularized version of the stochastic block model with multiple communities. Our results provide rigorous evidence for the ability of an extremely simple and natural dynamics which is non-trivial even in a centralized setting.

Consensus Dynamics: An Overview The survey [17] provides an in-depth algorithmic perspective on emergent complexity. Roughly, this area aims to characterize non-trivial emergent properties of complex systems, composed of large numbers of relatively simple agents, which can cooperate to express complex global behaviours. Interestingly, over the past two decades, fundamental processes such as consensus or opinion-formation dynamics have been studied independently by different research communities: for instance, in the Distributed Computing community, these dynamics have been studied in the context of population protocols via discrete-time analysis, whereas, in the Control and Optimization community, similar (or even identical) dynamics have been analyzed via continuous-time processes. This survey provides a unified view of these results, along with the mathematical background to understand and differentiate the underlying results.

Consensus vs Broadcast, with and without Noise Consensus and Broadcast are two fundamental problems in distributed computing, whose solutions have several applications. Intuitively, Consensus should be no harder than Broadcast, and this can be rigorously established in several models. Can Consensus be easier than Broadcast? In models that allow noiseless communication, we prove in [49] a reduction of (a suitable variant of) Broadcast to binary Consensus, that preserves the communication model and all complexity parameters such as randomness, number of rounds, communication per round, etc., while there is a loss in the success probability of the protocol. Using this reduction, we get, among other applications, the first logarithmic lower bound on the number of rounds needed to achieve Consensus in the uniform GOSSIP model on the complete graph. The lower bound is tight and, in this model, Consensus and Broadcast are equivalent. We then turn to distributed models with

noisy communication channels that have been studied in the context of some bio-inspired systems. In such models, only one noisy bit is exchanged when a communication channel is established between two nodes, and so one cannot easily simulate a noiseless protocol by using error-correcting codes. An $\Omega(\varepsilon^{-2}n)$ lower bound on the number of rounds needed for Broadcast is proved by Boczkowski et al. [85] in one such model (noisy uniform PULL, where ε is a parameter that measures the amount of noise). We prove an $O(\varepsilon^{-2} \log n)$ upper bound for binary Consensus in such model, thus establishing an exponential gap between the number of rounds necessary for Consensus versus Broadcast. We also prove a new $O(\varepsilon^{-2} \log n)$ upper bound for Broadcast in this model.

Phase Transitions of the k -Majority Dynamics in a Biased Communication Model We analyze in [52] the binary-state (either R or B) k -majority dynamics in a biased communication model where nodes have some fixed probability p , independent of the dynamics, of being seen in state B by their neighbors. In this setting we study how p , as well as the initial unbalance between the two states, impact on the speed of convergence of the process, identifying sharp phase transitions.

Phase Transition of a Non-Linear Opinion Dynamics with Noisy Interactions In several real *Multi-Agent Systems* (MAS), it has been observed that only weaker forms of *metastable consensus* are achieved, in which a large majority of agents agree on some opinion while other opinions continue to be supported by a (small) minority of agents. In [53], we take a step towards the investigation of metastable consensus for complex (non-linear) *opinion dynamics* by considering the famous Undecided dynamics in the binary setting, which is known to reach consensus exponentially faster than the Voter dynamics. We propose a simple form of uniform noise in which each message can change to another one with probability p and we prove that the persistence of a *metastable consensus* undergoes a *phase transition* for $p = 1/6$. In detail, below this threshold, we prove the system reaches with high probability a metastable regime where a large majority of agents keeps supporting the same opinion for polynomial time. Moreover, this opinion turns out to be the initial majority opinion, whenever the initial bias is slightly larger than its standard deviation. On the contrary, above the threshold, we show that the information about the initial majority opinion is “lost” within logarithmic time even when the initial bias is maximum. Interestingly, using a simple coupling argument, we show the equivalence between our noisy model above and the model where a subset of agents behave in a *stubborn* way.

Finding a Bounded-Degree Expander Inside a Dense One It follows from the Marcus-Spielman-Srivastava proof of the Kadison-Singer conjecture that if $G = (V, E)$ is a Δ -regular dense expander then there is an edge-induced subgraph $H = (V, EH)$ of G of constant maximum degree which is also an expander. As with other consequences of the MSS theorem, it is not clear how one would explicitly construct such a subgraph. We show in [44] that such a subgraph (although with quantitatively weaker expansion and near-regularity properties than those predicted by MSS) can be constructed with high probability in linear time, via a simple algorithm. Our algorithm allows a distributed implementation that runs in $O(\log n)$ rounds and does $O(n)$ total work with high probability. The analysis of the algorithm is complicated by the complex dependencies that arise between edges and between choices made in different rounds. We sidestep these difficulties by following the combinatorial approach of counting the number of possible random choices of the algorithm which lead to failure. We do so by a compression argument showing that such random choices can be encoded with a non-trivial compression. Our algorithm bears some similarity to the way agents construct a communication graph in a peer-to-peer network, and, in the bipartite case, to the way agents select servers in blockchain protocols.

Parallel Load Balancing on Constrained Client-Server Topologies In [50], we study parallel *Load Balancing* protocols for a client-server distributed model defined as follows. There is a set C of n clients and a set S of n servers where each client has (at most) a constant number $d \geq 1$ of requests that must be assigned to some server. The client set and the server one are connected to each other via a fixed bipartite graph: the requests of client v can only be sent to the servers in its neighborhood $N(v)$. The goal is to assign every client request so as to minimize the maximum load of the servers. In this setting, efficient parallel protocols are available only for dense topologies. In particular, a simple symmetric, non-adaptive protocol achieving constant maximum load has been recently introduced by Becchetti et

al [44] for regular dense bipartite graphs. The parallel completion time is $O(\log n)$ and the overall work is $O(n)$, w.h.p. Motivated by proximity constraints arising in some client-server systems, we devise a simple variant of Becchetti et al's protocol [44] and we analyze it over almost-regular bipartite graphs where nodes may have neighborhoods of small size. In detail, we prove that, w.h.p., this new version has a cost equivalent to that of Becchetti et al's protocol (in terms of maximum load, completion time, and work complexity, respectively) on every almost-regular bipartite graph with degree $\Omega(\log^2 n)$. Our analysis significantly departs from that in [44] for the original protocol and requires to cope with non-trivial stochastic-dependence issues on the random choices of the algorithmic process which are due to the worst-case, sparse topology of the underlying graph.

On the Search Efficiency of Parallel Lévy Walks on \mathbb{Z}^2 Motivated by the *Lévy flight foraging hypothesis* – the premise that the movement of various animal species searching for food resembles a *Lévy walk* – we study the search efficiency of parallel Lévy walks on the infinite 2-dimensional grid. We assume that k independent identical discrete-time Lévy walks, with exponent parameter $\alpha \in (1, +\infty)$, start simultaneously at the origin, and we are interested in the time $h_{\alpha,k,\ell}$ until some walk visits a given target node at distance ℓ from the origin. In [79], we first observe that the total work, i.e., the product $k \cdot h_{\alpha,k,\ell}$ is at least $\Omega(\ell^2)$, for any combination of the parameters α , k and ℓ . Then we provide a comprehensive analysis of the time and work, for the complete range of these parameters. Our main finding is that for any α , there is a specific choice of k that achieves optimal work, $\tilde{O}(\ell^2)$, whereas all other choices of k result in sub-optimal work. In particular, in the interesting super-diffusive regime of $2 < \alpha < 3$, the optimal value for k is $\tilde{\Theta}(\ell^{-1-\alpha})$. Our results should be contrasted with several previous works showing that the exponent $\alpha = 2$ is optimal for a wide range of related search problems on the plane. On the contrary, in our setting of multiple walks which measures efficiency in terms of the natural notion of work, no single exponent is optimal: for each α (and ℓ) there is a specific choice of k that yields optimal efficiency.

7.3 Graph and digraph theory

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COATI studies theoretical problems in graph theory. If some of them are directly motivated by applications, others are more fundamental.

We are putting an effort on understanding better directed graphs (also called *digraphs*) and partitioning problems, and in particular colouring problems. We also try to better understand the many relations between orientations and colourings. We study various substructures and partitions in (di)graphs. For each of them, we aim at giving sufficient conditions that guarantee its existence and at determining the complexity of finding it.

7.3.1 Distinguishing labelling problems

In distinguishing labelling problems, the general goal is, given a graph, to label some of its elements so that some pairs of elements can be distinguished accordingly to some parameter computed from the labelling. Note that this description involves many parameters that can be played with, such as the set of elements to be labelled, the set of labels to be assigned, the set of elements to be distinguished, and the distinguishing parameter computed from the labelling. A notable example is the so-called 1-2-3 Conjecture, which asks whether almost all graphs can have their edges labelled with 1,2,3 so that every two adjacent vertices are distinguished accordingly to their sums of incident labels.

We have recently obtained a number of results, related both to the 1-2-3 Conjecture and related problems. These results stand both as notable progress towards some open questions, and as new problems of independent interest.

- In a series of works, namely [45, 74, 76, 77], we have introduced and studied optimisation variants of the 1-2-3 Conjecture, our main intent being to understand better some of the core mechanisms and motivations behind the conjecture.

Namely, the 1-2-3 Conjecture is related to an optimisation problem where one aims at making any graph G locally irregular by multiplying its edges, resulting in a locally irregular multigraph M with essentially the same structure. The conjecture, if true, would imply that such a multigraph M with size $|E(M)|$ at most $3|E(G)|$ always exists. In [45, 76], we studied this very problem as a more general optimisation problem: Given a graph, what is the smallest (in terms of size) locally irregular multigraph that can be obtained through multiplying edges? In the language of labellings, this translates to: Given a graph, what is the smallest label sum assigned by a proper labelling, i.e., a labelling of its edges distinguishing adjacent vertices accordingly to their incident sums of labels? Regarding this question, we raised a few questions, which we have studied in general and for particular classes.

One such side question is about proper labellings assigning only a few large labels. In particular, regarding the 1-2-3 Conjecture, an interesting question is about the importance of label 3, in the sense that, perhaps, in general labels 1 and 2 are almost enough to label any graph. Note that previous works on the topic have highlighted that graphs requiring all labels 1, 2, 3 do exist, but such ones do not need lots of 3's. In [74], we have consequently studied proper 3-labellings assigning a few 3's only, our goal being to study formally whether, indeed, graphs in general need a few 3's only. Our feeling is that no graph should require more than a third of its edges labelled 3 in a proper 3-labelling. We have verified this feeling for a few graph classes. We also proved that, for a few classes of simple graphs, a constant number of 3's is not sufficient for a proper 3-labelling to be designed.

- In two works, namely [23, 25], we have studied two generalisations of distinguishing labelling problems to directed graphs (digraphs). In [23], we completely solved a peculiar variant of the 1-2-3 Conjecture in digraphs, where one is asked to design 3-labellings where, for every arc uv , the sum of labels incoming to u is different from the sum of labels outgoing from v . This is the concluding point of some recent attempts to generalise the 1-2-3 Conjecture to digraphs, as none of the variants that has been introduced earlier remains open to date. Surprisingly, the 1-2-3 Conjecture seems to be one of those problems that hardly generalise to digraphs.

In [25], we have studied directed variants of a related problem, called the AVD Conjecture, which is, in essence, a kind of 1-2-3 Conjecture where the labels assigned to the edges must form a proper edge-colouring (i.e., no two adjacent edges must be assigned a same label). Inspired from the existing directed variants of the 1-2-3 Conjecture, we have introduced a few directed variants of the AVD Conjecture, leading to interesting conjectures that we have partly solved.

- In [72, 77], we have provided results on two other problems related to the 1-2-3 Conjecture. In [77], we have provided results that get very close to its multiplicative variant, where adjacent vertices, by a labelling, must be distinguished accordingly to their products of incident labels. We proved the Multiplicative 1-2-3 Conjecture for 4-chromatic graphs, which is usually a hard barrier to overcome for this type of problems. We also showed a way to design 3-labellings that are very close to what is desired. In [72], we gave results related to a close problem, which is about distinguishing adjacent vertices by coloured sums by a labelling coloured labels. This formalism was introduced earlier as a way to generalise several existing problems of the field.

In [31], we considered a variant in which we both orient and give weight to the edges of a graph. A *weighted orientation* of a graph G is a pair (D, w) where D is an orientation of G and w is an *arc-weighting* of D , that is an application $A(D) \rightarrow \mathbb{N} \setminus \{0\}$. The *in-weight* of a vertex v in a weighted orientation (D, w) , denoted by $S_{(D,w)}(v)$, is the sum of the weights of arcs with head v in D . A *semi-proper orientation* is a weighted orientation such that two adjacent vertices have different in-weights. The *semi-proper orientation number* of a graph G , denoted by $\vec{\chi}_s(G)$, is $\min_{(D,w) \in \Gamma} \max_{v \in V(G)} S_{(D,w)}(v)$, where Γ is the set of all semi-proper orientations of G . A semi-proper orientation (D, w) of a graph G is *optimal* if $\max_{v \in V(G)} S_{(D,w)}(v) = \vec{\chi}_s(G)$. In this work, we show that every graph G has an optimal semi-proper orientation (D, w) such that the weight of each arc is 1 or 2. We then give some bounds on the semi-proper orientation number: we show $\lceil \frac{\text{Mad}(G)}{2} \rceil \leq \vec{\chi}_s(G) \leq \lceil \frac{\text{Mad}(G)}{2} \rceil + \chi(G) - 1$ and $\lceil \frac{\delta^*(G)+1}{2} \rceil \leq \vec{\chi}_s(G) \leq 2\delta^*(G)$ for all graph G , where $\text{Mad}(G)$ and $\delta^*(G)$ are the maximum average degree and the degeneracy of G , respectively. We then deduce that the maximum semi-proper orientation number of a tree is 2, of a

cactus is 3, of an outerplanar graph is 4, and of a planar graph is 6. Finally, we consider the computational complexity of associated problems: we show that determining whether $\vec{\chi}_s(G) = \vec{\chi}(G)$ is NP-complete for planar graphs G with $\vec{\chi}_s(G) = 2$; we also show that deciding whether $\vec{\chi}_s(G) \leq 2$ is NP-complete for planar bipartite graphs G .

7.3.2 Graph and digraph colourings

Cooperative colourings of trees and of bipartite graphs Given a system (G_1, \dots, G_m) of graphs on the same vertex set V , a cooperative colouring is a choice of vertex sets I_1, \dots, I_m , such that I_j is independent in G_j and $\cup_{j=1}^m I_j = V$. For a class \mathcal{G} of graphs, let $m_{\mathcal{G}}(d)$ be the minimal m such that every m graphs from \mathcal{G} with maximum degree d have a cooperative colouring. In [16], we prove that $\Omega(\log \log d) \leq m_{\mathcal{T}}(d) \leq O(\log d)$ and $\Omega(\log d) \leq m_{\mathcal{B}}(d) \leq O(d/\log d)$, where \mathcal{T} is the class of trees and \mathcal{B} is the class of bipartite graphs.

From light edges to strong edge-colouring of 1-planar graphs A strong edge-colouring of an undirected graph G is an edge-colouring where every two edges at distance at most 2 receive distinct colours. The strong chromatic index of G is the least number of colours in a strong edge-colouring of G . A conjecture of Erdős and Nešetřil, stated back in the 80's, asserts that every graph with maximum degree Δ should have strong chromatic index at most roughly $1.25\Delta^2$. Several works in the last decades have confirmed this conjecture for various graph classes. In particular, lots of attention have been dedicated to planar graphs, for which the strong chromatic index decreases to roughly 4Δ , and even to smaller values under additional structural requirements.

In [20], we initiate the study of the strong chromatic index of 1-planar graphs, which are those graphs that can be drawn on the plane in such a way that every edge is crossed at most once. We provide constructions of 1-planar graphs with maximum degree Δ and strong chromatic index roughly 6Δ . As an upper bound, we prove that the strong chromatic index of a 1-planar graph with maximum degree Δ is at most roughly 24Δ (thus linear in Δ). The proof of this result is based on the existence of light edges in 1-planar graphs with minimum degree at least 3.

On the signed chromatic number of some classes of graphs A signed graph (G, σ) is a graph G along with a function $\sigma : E(G) \rightarrow \{+, -\}$. A closed walk of a signed graph is positive (resp., negative) if it has an even (resp., odd) number of negative edges, counting repetitions. A homomorphism of a (simple) signed graph to another signed graph is a vertex-mapping that preserves adjacencies and signs of closed walks. The signed chromatic number of a signed graph (G, σ) is the minimum number of vertices $|V(H)|$ of a signed graph (H, π) to which (G, σ) admits a homomorphism.

Homomorphisms of signed graphs have been attracting growing attention in the last decades, especially due to their strong connections to the theories of graph coloring and graph minors. These homomorphisms have been particularly studied through the scope of the signed chromatic number. In [73], we provide new results and bounds on the signed chromatic number of several families of signed graphs (planar graphs, triangle-free planar graphs, K_n -minor-free graphs, and bounded-degree graphs).

Classification of edge-critical underlying absolute planar cliques for signed graphs A simple signed graph (G, Σ) is a simple graph G having two different types of edges, positive edges and negative edges, where Σ denotes the set of negative edges of G . A closed walk of a signed graph is positive (negative) if it has an even (odd) number of negative edges, taking repeated edges into account. A homomorphism (resp., colored homomorphism) of a simple signed graph to another simple signed graph is a vertex-mapping that preserves adjacencies and signs of closed walks (resp., signs of edges). A simple signed graph (G, Σ) is a signed absolute clique (resp., $(0, 2)$ -absolute clique) if any homomorphism (resp., colored homomorphism) of it is an injective function, in which case G is called an underlying signed absolute clique (resp., underlying $(0, 2)$ -absolute clique). Moreover, G is edge-critical if $G - e$ is not an underlying signed absolute clique (resp., underlying $(0, 2)$ -absolute clique) for any edge e of G . In [27], we characterize all edge-critical outerplanar underlying $(0, 2)$ -absolute cliques and all edge-critical planar underlying signed absolute cliques. We also discuss the motivations and implications of obtaining these exhaustive lists.

7.3.3 Graph and digraph decompositions

More Aspects of Arbitrarily Partitionable Graphs A graph G of order n is arbitrarily partitionable (AP) if, for every sequence (n_1, \dots, n_p) partitioning n , there is a partition (V_1, \dots, V_p) of $V(G)$ such that $G[V_i]$ is a connected graph of order n_i for $i = 1, \dots, p$. The property of being AP is related to other well-known graph notions, such as perfect matchings and Hamiltonian cycles, with which it shares several properties. In [22], we study two aspects behind AP graphs.

On the one hand, we consider algorithmic aspects of AP graphs, which received some attention in previous works. We first establish the NP-hardness of the problem of partitioning a graph into connected subgraphs following a given sequence, for various new graph classes of interest. We then prove that the problem of deciding whether a graph is AP is in NP for several classes of graphs, confirming a conjecture of Barth and Fournier for these.

On the other hand, we consider the weakening to APness of sufficient conditions for Hamiltonicity. While previous works have suggested that such conditions can sometimes indeed be weakened, we here point out cases where this is not true. This is done by considering conditions for Hamiltonicity involving squares of graphs, and claw- and net-free graphs.

Decomposing degenerate graphs into locally irregular subgraphs A (undirected) graph is locally irregular if no two of its adjacent vertices have the same degree. A decomposition of a graph G into k locally irregular subgraphs is a partition E_1, \dots, E_k of $E(G)$ into k parts each of which induces a locally irregular subgraph. Not all graphs decompose into locally irregular subgraphs; however, it was conjectured that, whenever a graph does, it should admit such a decomposition into at most three locally irregular subgraphs. This conjecture was verified for a few graph classes in recent years.

In [21], we study the decomposability of degenerate graphs with low degeneracy. Our main result is that decomposable k -degenerate graphs decompose into at most $3k + 1$ locally irregular subgraphs, which improves on previous results whenever $k \leq 9$. We improve this result further for some specific classes of degenerate graphs, such as bipartite cacti, k -trees, and planar graphs. Although our results provide only little progress towards the leading conjecture above, the main contribution of this work is rather the decomposition schemes and methods we introduce to prove these results.

Extending Drawings of Graphs to Arrangements of Pseudolines In the recent study of crossing numbers, drawings of graphs that can be extended to an arrangement of pseudolines (pseudolinear drawings) have played an important role as they are a natural combinatorial extension of rectilinear (or straight-line) drawings. A characterization of the pseudolinear drawings of K_n was found recently. In [42], we extend this characterization to all graphs, by describing the set of minimal forbidden subdrawings for pseudolinear drawings. Our characterization also leads to a polynomial-time algorithm to recognize pseudolinear drawings and construct the pseudolines when it is possible.

7.3.4 Substructures in graphs and digraphs

A variant of the Erdős-Sós conjecture A well-known conjecture of Erdős and Sós states that every graph with average degree exceeding $m - 1$ contains every tree with m edges as a subgraph. In [34], we propose a variant of this conjecture, which states that every graph of maximum degree exceeding m and minimum degree at least $\lceil 2m/3 \rceil$ contains every tree with m edges. As evidence for our conjecture we show (i) for every m there is a $g(m)$ such that the weakening of the conjecture obtained by replacing the first m by $g(m)$ holds, and (ii) there is a $\gamma > 0$ such that the weakening of the conjecture obtained by replacing $\lceil 2m/3 \rceil$ by $(1 - \gamma)m$ holds.

Inversion number of an oriented graph Let D be an oriented graph. The *inversion* of a set X of vertices in D consists in reversing the direction of all arcs with both ends in X . The *inversion number* of D , denoted by $\text{inv}(D)$, is the minimum number of inversions needed to make D acyclic. Denoting by $\tau(D)$, $\tau'(D)$, and $\nu(D)$ the cycle transversal number (minimum size of a feedback vertex set), the cycle arc-transversal number (minimum size of a feedback arc set) and the cycle packing number of D respectively, we show in [43] that $\text{inv}(D) \leq \tau'(D)$, $\text{inv}(D) \leq 2\tau(D)$ and there exists a function g such that $\text{inv}(D) \leq g(\nu(D))$. We conjecture that for any two oriented graphs L and R , $\text{inv}(L \rightarrow R) = \text{inv}(L) + \text{inv}(R)$ where $L \rightarrow R$ is the

dijoin of L and R . This would imply that the first two inequalities are tight. We prove this conjecture when $\text{inv}(L) \leq 1$ and $\text{inv}(R) \leq 2$ and when $\text{inv}(L) = \text{inv}(R) = 2$ and L and R are strongly connected. We also show that the function g of the third inequality satisfies $g(1) \leq 4$.

We then consider the complexity of deciding whether $\text{inv}(D) \leq k$ for a given oriented graph D . We show that it is NP-complete for $k = 1$, which together with the above conjecture would imply that it is NP-complete for every k . This contrasts with a result of Belkhechine et al. which states that deciding whether $\text{inv}(T) \leq k$ for a given tournament T is polynomial-time solvable.

On the characterization of networks with multiple arc-disjoint branching flows An s -branching flow f in a network $N = (D, u)$, such that u is the capacity function, is a flow that reaches every vertex in $V(D) \setminus \{s\}$ from s while loosing exactly one unit of flow in each vertex other than s . It is known that the hardness of the problem of finding k arc-disjoint s -branching flows in a network N is linked to the capacity u of the arcs in N : for fixed c , the problem is solvable in polynomial time if every arc has capacity $n - c$ and, unless the Exponential Time Hypothesis (ETH) fails, there is no polynomial time algorithm for it for most other choices of the capacity function when every arc has the same capacity. The hardness of a few cases remains open. In [78], we further investigate a conjecture that aims to characterize networks admitting k arc-disjoint s -branching flows, generalizing a result that provides such characterization when all arcs have capacity $n - 1$, based on Edmonds' branching theorem. We show that, in general, the conjecture is false. However, it holds for some special classes of digraphs, as branchings and spindles with parallel arcs.

Metric Dimension: from Graphs to Oriented Graphs The metric dimension $\text{MD}(G)$ of an undirected graph G is the cardinality of a smallest set of vertices that allows, through their distances to all vertices, to distinguish any two vertices of G . Many aspects of this notion have been investigated since its introduction in the 70's, including its generalization to digraphs.

In [26], we study, for particular graph families, the maximum metric dimension over all strongly-connected orientations, by exhibiting lower and upper bounds on this value. We first exhibit general bounds for graphs with bounded maximum degree. In particular, we prove that, in the case of subcubic n -node graphs, all strongly-connected orientations asymptotically have metric dimension at most $\frac{n}{2}$, and that there are such orientations having metric dimension $\frac{2n}{5}$. We then consider strongly-connected orientations of grids. For a torus with n rows and m columns, we show that the maximum value of the metric dimension of a strongly-connected Eulerian orientation is asymptotically $\frac{nm}{2}$ (the equality holding when n, m are even, which is best possible). For a grid with n rows and m columns, we prove that all strongly-connected orientations asymptotically have metric dimension at most $\frac{2nm}{3}$, and that there are such orientations having metric dimension $\frac{nm}{2}$.

On finding the best and worst orientations for the metric dimension The (directed) metric dimension of a digraph D , denoted by $\text{MD}(D)$, is the size of a smallest subset S of vertices such that every two vertices of D are distinguished via their distances from the vertices in S . In [71], we investigate the graph parameters $\text{BOMD}(G)$ and $\text{WOMD}(G)$ which are respectively the smallest and largest metric dimension over all orientations of G . We show that those parameters are related to several classical notions of graph theory and investigate the complexity of determining those parameters. We show that $\text{BOMD}(G) = 1$ if and only if G is hypotractable (that is has a path spanning all vertices but one), and deduce that deciding whether $\text{BOMD}(G) \leq k$ is NP-complete for every positive integer k . We also show that $\text{WOMD}(G) \geq \alpha(G) - 1$, where $\alpha(G)$ is the stability number of G . We then deduce that for every fixed positive integer k , we can decide in polynomial time whether $\text{WOMD}(G) \leq k$. The most significant results deal with oriented forests. We provide a linear-time algorithm to compute the metric dimension of an oriented forest and a linear-time algorithm that, given a forest F , computes an orientation D^- with smallest metric dimension (i.e. such that $\text{MD}(D^-) = \text{BOMD}(F)$) and an orientation D^+ with largest metric dimension (i.e. such that $\text{MD}(D^+) = \text{WOMD}(F)$).

7.4 Other domains

We collaborate with experts in various areas (transport, bio-informatics, e-health, etc.). In this section, we present the results we have obtained in the context of these collaborations.

Overlaying a hypergraph with a graph with bounded maximum degree

Participants Frédéric Havet, Dorian Mazauric (*ABS*), Thi Viet Ha Nguyen.

A major problem in structural biology is the characterization of low resolution structures of macromolecular assemblies. One subproblem of this very difficult question is to determine the plausible contacts between the subunits (e.g. proteins) of an assembly, given the lists of subunits involved in all the complexes. This problem can be conveniently modelled by graphs and hypergraphs, and we collaborate with project-team ABS in order to better understand its computational complexity.

Let G and H be respectively a graph and a hypergraph defined on a same set of vertices, and let F be a fixed graph. We say that G F -overlays a hyperedge S of H if F is a spanning subgraph of the subgraph of G induced by S , and that it F -overlays H if it F -overlays every hyperedge of H . We study in [60, 59] the computational complexity of two problems. The first problem, $(\Delta \leq k) - F$ -Overlay, consists in deciding whether there is a graph with maximum degree at most k that F -overlays a given hypergraph H . It is a particular case of the second problem Max $(\Delta \leq k) - F$ -Overlay, which takes a hypergraph H and an integer s as input, and consists in deciding whether there is a graph with maximum degree at most k that F -overlays at least s hyperedges of H . We give a complete polynomial/NP-complete dichotomy for the Max $(\Delta \leq k) - F$ -Overlay problems depending on the pairs (F, k) , and establish the complexity of $(\Delta \leq k) - F$ -Overlay for many pairs (F, k) .

Network alignment and similarity reveal atlas-based topological differences in structural connectomes

Participants David Coudert, Emilio Cruciani, Rachid Deriche (*ATHENA*), Samuel Deslauriers-Gauthier (*ATHENA*), Matteo Frigo (*ATHENA*), Emanuele Natale.

Brain atlases are central objects in network neuroscience, where the interactions between different brain regions are modeled as a graph called connectome. In structural connectomes, nodes are parcels from a predefined cortical atlas and edges encode the strength of the axonal connectivity between regions measured via diffusion Magnetic Resonance Imaging (MRI) tractography. In collaboration with project-team ATHENA, we provided in [82] a novel perspective on the evaluation of brain atlases by modeling it as a network alignment problem, with the goal of tackling the following question: given an atlas, how robustly does it capture the network topology across different subjects? To answer such a question, we introduce two novel concepts arising as natural generalizations of previous ones. First, the graph Jaccard index (GJI), a graph similarity measure based on the well-established Jaccard index between sets; the GJI exhibits natural mathematical properties that are not satisfied by previous approaches. Second, we devise WL-align, a new technique for aligning connectomes obtained by adapting the Weisfeiler-Lehman (WL) graph-isomorphism test. We validated the GJI and WL-align on data from the Human Connectome Project database, inferring a strategy for choosing a suitable parcellation for structural connectivity studies. Code and data are publicly available.

Improving Mapping for Sparse Direct Solvers - A Trade-Off Between Data Locality and Load Balancing

Participants Ali Al Zoobi, Anne Benoit (*ROMA*), Mathieu Faverge (*ROMA*), Changjiang Gou (*ROMA*), Loris Marchal (*ROMA*), Grégoire Pichon (*ROMA*), Pierre Ramet (*ROMA*).

In order to express parallelism, parallel sparse direct solvers take advantage of the elimination tree to exhibit tree-shaped task graphs, where nodes represent computational tasks and edges represent data dependencies. One of the pre-processing stages of sparse direct solvers consists of mapping computational resources (processors) to these tasks. The objective is to minimize the factorization time by exhibiting good data locality and load balancing. The proportional mapping technique is a widely used approach to solve this resource-allocation problem. It achieves good data locality by assigning the same processors to large parts of the elimination tree. However, it may limit load balancing in some cases. In [58, 83], we propose a dynamic mapping algorithm based on proportional mapping. This new approach, named Steal, relaxes the data locality criterion to improve load balancing. In order to validate the newly introduced method, we perform extensive experiments on the PaStiX sparse direct solver. It demonstrates that our algorithm enables better static scheduling of the numerical factorization while keeping good data locality.

JTeC: A Large Collection of Java Test Classes for Test Code Analysis and Processing

Participants Emilio Cruciani.

The recent push towards test automation and test-driven development continues to scale up the dimensions of test code that needs to be maintained, analyzed, and processed side-by-side with production code. As a consequence, on the one side regression testing techniques, e.g., for test suite prioritization or test case selection, capable to handle such large-scale test suites become indispensable; on the other side, as test code exposes own characteristics, specific techniques for its analysis and refactoring are actively sought. In [51], we propose JTeC, a large-scale dataset of test cases that researchers can use for benchmarking the above techniques or any other type of tool expressly targeting test code. JTeC collects more than 2.5M test classes belonging to 31K+ GitHub projects and summing up to more than 430 Million SLOCs of ready-to-use real-world test code.

8 Bilateral contracts and grants with industry

8.1 Bilateral contracts with industry

MillionRoads, 2019-2020

Participants David Coudert, Frédéric Giroire, Luc Hogue, Nicolas Nisse, Michel Syska.

- **Duration:** October 2019 - April 2020
- **Project title:** HumanRoads
- **Coordinator:** Nicolas Nisse
- **Other partners:** SME MillionRoads; EP Zenith (Didier Parigot)
- **Summary:** HumanRoads uses a graph database, in the Neo4j environment, to store and structure its data. This database is already large and is regularly enriched with new data. However, to date, response times to queries are not satisfactory. This Project aims at identifying the limiting factors and to propose alternatives. More precisely, we will work on analyzing the data structure in the graph database to optimize queries, in the Neo4j environment, and on graph algorithms to speed up queries.

Orange, 2018-2021

Participants Frédéric Giroire, Giuseppe Di Lena.

- Collaboration with Orange and EP DIANA on the topic of Network Function Virtualization. The activity includes the CIFRE PhD thesis of Giuseppe Di Lena that started his PhD on resilient NFV/SDN environments on April 2018 under the co-supervision of Frédéric Giroire and Thierry Turletti (DIANA).

9 Partnerships and cooperations

9.1 International initiatives

9.1.1 Inria associate team not involved in an ILL

EfDyNet

Participants David Coudert, Adrien Gausseran, Frédéric Giroire, Joanna Moulierac.

- **Title:** Efficient Dynamic Resource Allocation in Networks
- **Duration:** 2019 - 2021
- **Coordinator:** Frédéric Giroire
- **Partners:** Department of Electrical Engineering, Concordia University (Canada)
- **Inria contact:** Frédéric Giroire
- **Summary:** Networks are evolving rapidly in two directions. On the one hand, new network technologies are developed for different layers, and in particular flexible optical technologies (enabling to allocate a fraction of the optical spectrum rather than a fixed wavelength), Software Defined Networks, and Network Function Virtualization. On the other hand, the traffic patterns evolve and become less predictable due to the increase of cloud and mobile traffic. In this context, there are new possibilities and needs for dynamic resource allocations. We will study this problem mainly in two directions: network reconfiguration and the allocation of virtualized resources. The associated team will build on an already fruitful collaboration between COATI and Concordia. The two teams address design and management optimization problems in networks (WDM, wireless, SDN) with complementary tools and expertise.
- **Web:** <https://team.inria.fr/coati/projects/efdynet/>

9.1.2 Inria international partners

Informal international partners Apart from formal collaboration COATI members maintain strong connections with the following international teams, with regular visits of both sides.

- Universidade Federal do Ceará (Fortaleza, Brazil), ParGO team;
- Universidade Estadual do Ceará (Fortaleza, Brazil), Prof. Leonardo Sampaio;
- Univ. of Southern Denmark (Odense, Denmark), Prof. Jørgen Bang-Jensen.

9.1.3 Participation in other international programs

GALOP

Participants Julien Bensmail, David Coudert, Foivos Fioravantes, Frédéric Giroire, Frédéric Havet, Nicolas Nisse.

- **Title:** Graphs ALgorithms for Optimization Problems
- **Duration:** 2019 - 2021
- **Coordinator:** Nicolas Nisse
- **Partners:**
 - Universidade Federal do Ceará, Fortaleza (Brazil)
 - Universidad Diego Portales, Santiago (Chile)
- **Inria contact:** Nicolas Nisse
- **Summary:** This project aims at studying the Computational Complexity of several important problems arising in networks. In particular, we will focus on the computation of metric or structural properties and parameters of large networks. We plan to design efficient exact algorithms for solving these problems or to theoretically prove that such algorithms cannot exist. In the latter case, we will then design approximation algorithms, or prove that none exists. In all cases, we aim at implementing our algorithms and use them on real-world instances such as large road networks or huge social networks.

IFCAM Program, Applications of Graph homomorphisms

Participants Julien Bensmail.

- **Program:** IFCAM 2018-2020 (<http://math.iisc.ac.in/~ifcam/>)
- **Project title:** Applications of graph homomorphisms on graph database
- **Duration:** Janvier 2018 - Décembre 2020
- **Coordinator:** Reza Naserasr (for France) - Sagnik Sen (for India)
- **Other partners:** complete list of participants on the [project website](#).
- **Summary:** In this project, we are going to study the graph homomorphism problems from a very general point of view. Apart from studying the usual graph homomorphism on undirected graphs, we will study it for different types of graphs such as, signed graphs, oriented graphs, edge-colored graphs, colored mixed graphs etc. We will apply the theories and techniques associated with graph homomorphism to solve practical problems. Our main application oriented work is studying graph homomorphism in the context of graph database, a type of database now a days used even by popular social medias. Graph homomorphism is equivalent to the query evaluation problem in graph database, and thus have exciting intersection with the theory. In our group we have experts of graph homomorphisms as well as graph database making this project a potential case for Indo-French interdisciplinary collaboration. We want to organize a workshop by the end of this project. We also consider a few other application oriented topics as auxiliary research tracks inside this project.

DESPROGES

Participants Julien Bensmail, Foivos Fioravantes, Nicolas Nisse.

- **Program:** Partenariats Hubert Curien (PHC) Xu Guangqi.
- **Project title:** Décompositions arborescentes et problèmes de graphes (DESPROGES).
- **Duration:** 2020 - 2021.
- **Coordinator:** Nicolas Nisse
- **Other partners:** Xidian University (Xi'an, Chine).
- **Summary:** This project aims at studying relationships between tree-decompositions and distinguishing labellings in graphs.

9.2 International research visitors

9.2.1 Visits of international scientists

- Jorgen Bang-Jensen, University Southern Denmark de Odense, from Feb 2020 until Jun 2020.
- Jonas Costa Ferreira Da Silva, Universidade Federal do Ceará de Fortaleza (Brazil), visting PhD student from Oct. 2019 until Nov 2020.
- Michał Lasoń, Polish Academy of Sciences, Warszawa, Poland. October 19-30, 2020.
- Fabricio Siqueira Benevides, Universidade Federal do Ceará de Fortaleza (Brazil), sabbatical until Jul 2020.
- Malgorzata Sulkowska, Université sciences et technologie de Wroclaw (Poland), from Feb 2020 until Mar 2020.

9.2.2 Visits to international teams

Research stays abroad

- Frédéric Giroire: Center for Mathematical Modeling (CMM), at Universidad de Chile, Santiago, Chili. February 05-14, 2020.

9.3 National initiatives

DGA/Inria Brainside, 2019-2023

Participants Francesco D'Amore, Arthur Carvalho Walraven Da Cunha, Emilio Cruciani, Emanuele Natale.

- **Program:** DGA/Inria
- **Project acronym:** Brainside
- **Project title:** Algorithms for simplifying neural networks
- **Duration:** October 2019 - March 2023
- **Coordinator:** Emanuele Natale
- **Other partners:** Inria Paris, EP GANG

- **Summary:** The widespread use of neural networks on devices with computationally-low capabilities, demands for lightweight and energy-efficient networks. Despite such need, and despite the strategies employed to prevent overfitting by removing a substantial part of their edges, the question of how to reduce their size in terms of the number of neurons appears largely unexplored. The aim of the project is to investigate algorithmic procedures to reduce the size of neural networks, in order to improve the speed with which they can be evaluated and to shed light on how much information about the computational problem at hand can be encoded within neural networks of small size.

ANR-17-CE22-0016 MultiMod, 2018-2023

Participants Ali Al Zoobi, David Coudert, Nicolas Nisse, Michel Syska.

- **Program:** ANR
- **Project acronym:** MultiMod
- **Project title:** Scalable routing in Multi Modal transportation networks
- **Duration:** January 2018 - December 2022
- **Coordinator:** David Coudert
- **Other partners:** Inria Paris, EP GANG; team CeP, I3S laboratory; SME Instant-System; SME Benomad
- **Summary:** The MultiMod project addresses key algorithmic challenges to enable the fast computation of personalized itineraries in large-scale multi-modal public transportation (PT) networks (bus, tram, metro, bicycle, etc.) combined with dynamic car-pooling. We will use real-time data to propose itineraries with close to real travel-time, and handle user-constraints to propose personalized itineraries. Our main challenge is to overcome the scalability of existing solutions in terms of query processing time and data-structures space requirements, while including unplanned transportation means (car-pooling), real-time data, and personalized user constraints. The combination of car-pooling and PT network will open-up areas with low PT coverage enable faster itineraries and so foster the adoption of car-pooling. We envision that the outcome of this project will dramatically enhanced the mobility and daily life of citizens in urban areas.
- **Web:** <https://project.inria.fr/multimod/>

ANR-19-CE48-0013-01 Digraphs, 2020-2023

Participants Julien Bensmail, David Coudert, Frédéric Havet, Nicolas Nisse, Stéphane Pérennes.

- **Program:** ANR
- **Project acronym:** Digraphs
- **Project title:** Digraphs
- **Duration:** January 2020 - December 2023
- **Coordinator:** Frédéric Havet
- **Other partners:** LIRMM, Montpellier; LIP, Lyon.

- **Summary:** The objectives of the project is to make some advances on digraph theory in order to get a better understanding of important aspects of digraphs and to have more insight on the differences and the similarities between graphs and digraphs. Our methodology is two-fold. On the one hand, we will focus on the tools. Indeed we believe that many proof techniques have been too rarely used or adapted to digraphs and can be developed to obtain many more results. On the second hand, we will consider many results on graphs, find their (possibly many) formulations in terms of digraphs and see if and how they can be extended. Studying such extensions has been occasionally done, but the point here is to do it in a kind of systematic way. Moreover we shall push even further the study by considering classes of digraphs: if a result does not extend to the whole class of digraphs, for which classes does it extend ? if a result extends, can we get better results for some restricted classes of digraphs ?
- **Web:** <https://project.inria.fr/anrdigraphs/>

PICS DISCO

Participants Frédéric Havet.

- **Program:** PICS
- **Project acronym:** DISCO
- **Project title:** Disjoint Structures and Coverings in Oriented graphs
- **Duration:** January 2018 - December 2020.
- **Coordinator:** Stéphane Bessy (LIRMM)
- **Other partners:** CNRS LIRMM (Montpellier), Syddansk universitet (Odense, Danemark)
- **Summary:** Directed graphs (digraphs) are much less understood than undirected graphs. Many, seemingly very simple questions remain unsolved for digraphs while the analogous problem for undirected graphs is trivial. At the same time digraphs are a very important modelling tool for practical applications and so a better understanding of their structure is important. The purpose of DISCO is to advance knowledge on fundamental problems on digraphs, including splitting a digraph into smaller pieces with given properties, problems regarding disjoint paths and trees, finding small certificates for given properties, such as strong spanning subdigraphs with few arcs. The later is important for speeding up certain algorithms.

Through a concerted effort we expect to obtain important results which will lead to a better understanding of fundamental questions about the structure of digraphs. The participants will meet regularly both in France and in Denmark to work on carefully selected problems.

9.3.1 GDR Actions

GDR RSD, ongoing (since 2006) Members of COATI are involved in the working group RESCOM (*Réseaux de communications*) of GDR RSD, CNRS (http://gdr-rsd.cnrs.fr/pole_rescom). In particular, David Coudert is co-chair of this working group since 2017.

We are also involved in the working group "Energy" of GDR RSD (http://gdr-rsd.cnrs.fr/acti_on_green). In particular, Frédéric Giroire is co-chair of this working group.

GDR IM, ongoing (since 2006) Members of COATI are involved in the working group "Graphes" of GDR IM, CNRS. (<http://gtgraphes.labri.fr/>). In particular, Frédéric Havet is member of the steering committee.

GDR MADICS, ongoing (since 2017) Members of COATI are involved in the working group GRAMINEES (GRaph data Mining in Natural, Ecological and Environnemental Sciences) of GDR MADICS (Masses de Données, Informations et Connaissances en Sciences). (<http://www.madics.fr/actions/actions-en-cours/graminees/>).

9.4 Regional initiatives

SNIF, 2018-2021

Participants David Coudert, Frédéric Giroire, Nicolas Nisse, Stéphane Pérennes, Malgorzata Sulkowska, Thibaud Trolliet.

- **Program:** Innovation project of IDEX UCA^{JEDI}.
- **Project acronym:** SNIF
- **Project title:** Scientific Networks and IDEX Funding
- **Duration:** September 2018 - August 2021
- **Coordinator:** Patrick Musso
- **Other partners:** GREDEG, SKEMA, I3S (SigNet) and Inria (COATI), all from UCA.
- **Summary:** Scientific collaboration networks play a crucial role in modern science. This simple idea underlies a variety of initiatives aiming to promote scientific collaborations between different research teams, universities, countries and disciplines. The recent French IDEX experience is one of them. By fostering competition between universities and granting few of them with a relatively small amount of additional resources (as compare to their global budget), public authorities aim to encourage them to deeply reshape the way academic activities are organized in order to significantly increase the quality of their research, educational programs and innovative activities. The development of new collaboration networks is one of the factors at the heart of this global reorganization. Promoting new international and/or interdisciplinary collaborations is supposed to increase researchers' productivity and industry partnerships. This project aims to question the validity of this line of thought.

10 Dissemination

10.1 Promoting scientific activities

10.1.1 Scientific events: organisation

Member of the organizing committees

- Foivos Fioravantes, Frédéric Havet, Luc Hogue, Thi-Viet-Ha N'Guyen, and Michel Syska,
 - JGA'20: Journées Graphes et Algorithmes, Sophia-Antipolis (on-line), France, November 16-18, 2020 (<http://www-sop.inria.fr/coati/events/JGA2020/>)

10.1.2 Scientific events: selection

Chair of conference program committees

- Frédéric Havet
 - JGA'20: Journées Graphes et Algorithmes, Sophia-Antipolis (on-line), France, November 16-18 2020

- Christelle Caillouet
 - MaDeLoRa Workshop of EWSN conference, Lyon, France, February 17 2020 (<http://www-sop.inria.fr/coati/events/madelora2020/>)

Member of the conference program committees

- Christelle Caillouet
 - IEEE WiSARN'20: International Workshop on Wireless Sensor, Robot and UAV Networks, Virtual event, July 6th 2020
- David Coudert
 - ROADEF'20: Congrès annuel de la société Française de Recherche Opérationnelle et d'Aide à la Décision, Montpellier, France, February 19-21, 2020 Co-chair of stream "Optimisation dans les réseaux, flots, et applications télécom".
 - ICNC'20: International Conference on Computing, Networking and Communications, Hawaii, USA, February 17-20, 2020
 - ONDM'20: 24th Conference on Optical Network Design and Management, Barcelona, Spain, May 18-21, 2020
 - IEEE ICC'20: IEEE International Conference on Communications, Virtual Conference, June 7-11, 2020
 - IEEE Globecom'20: IEEE Global Communications Conference, Virtual Conference, December 7-11, 2020
- Frédéric Havet
 - ALGOS'20: ALgebras, Graphs and Ordered Sets - August 26th to 28th 2020, Metz (on-line), France
- Joanna Moulhierac
 - CoRes'20: 5ème Rencontres Francophones sur la Conception de Protocoles, l'Evaluation de Performance et l'EXpérimentation des Réseaux de Communication - September 28th to October 2nd 2020, Lyon, France
- Emanuele Natale
 - IJCAI-PRICAI'20: 29th International Joint Conference on Artificial Intelligence and the 17th Pacific Rim International Conference on Artificial Intelligence - January 7-15 2021, virtual conference
- Nicolas Nisse
 - AlgoTel: 22ème Rencontres Francophones sur les Aspects Algorithmiques des Télécommunications, Lyon, France, September 28-October 2, 2020
 - CoRes: 5ème Rencontres Francophones sur la Conception de Protocoles, l'Evaluation de Performance et l'EXpérimentation des Réseaux de Communication, Lyon, France, September 28-October 2, 2020

Reviewer Members of COATI have reviewed numerous manuscripts submitted to national and international conferences, including:

AAMAS'20, ALGOS'20, AlgoTel'20, CoRes'20, ESA'20, EvoApplications'20, ICALP'20, ICNC'20, IEEE Globecom'20, IEEE ICC'20, IEEE WiSARN'20, IJCAI'20, IWOC'20, MFCS'20, MobiWis'20, ONDM'20, OPODIS'20, PODC'20, ROADEF'20, SPAA'20, WG'20.

10.1.3 Journal

Member of the editorial boards

- Jean-Claude Bermond
 - Computer Science Reviews
 - Discrete Applied Mathematics
 - Discrete Mathematics
 - Discrete Mathematics, Algorithms and Applications
 - Journal of Graph Theory
 - Journal of Interconnection Networks (Advisory Board)
 - Networks
 - Parallel Processing Letters
 - the SIAM book series on Discrete Mathematics
- Alexandre Caminada
 - IEEE Transactions on Mobile Computing
 - IEEE Transactions on Vehicular Technology
 - Journal of Traffic and Transportation Engineering (Elsevier)
 - Sensors — Open Access Journal (MDPI)
 - Soft Computing (Springer)
- David Coudert
 - Discrete Applied Mathematics (Elsevier)
 - Networks (Wiley)
- Frédéric Giroire
 - Journal of Interconnection Networks (World Scientific)
 - Telecom (MDPI)
- Frédéric Havet
 - Discrete Mathematics and Theoretical Computer Science

Associate Editors

- Ramon Aparicio-Pardo
 - Guest Editor: *Special Issue on Optical Network Automation* for MDPI Sensors (ISSN 1424-8220)
- Christelle Caillouet
 - Co-Editor with Nathalie Mitton (Inria Lille) of journal MDPI Sensors Special Issue on "Optimization and Communication in UAV Networks", ISBN 978-3-03943-311-7
- Emanuele Natale
 - WikiJournal of Science

Reviewer - reviewing activities Members of COATI have reviewed numerous manuscripts submitted to international journals, including:

ACM Transactions on Algorithms (TALG), Ad Hoc Networks, Advances in Combinatorics, Algorithmica, Applied Network Science, Computer Communications (ComCom) Computer Networks (COMNET), Computers & Operations Research (COR), Discrete Applied Mathematics (DAM), Discrete Mathematics and Theoretical Computer Sciences (DMTCS), Discussiones Mathematicae Graph Theory, Distributed Computing, European Journal of Combinatorics, European Journal of Operational Research (EJOR), IEEE Communication Letters, IEEE Journal of Intelligent Transport, IEEE Networking Letters, IEEE Transactions on Green Communications and Networking (TGCN), IEEE Transactions on Mobile Computing (TOMC), IEEE Transactions on Signal Processing, IEEE/ACM Transactions on Networking (ToN), IEEE/OSA Journal of Optical Communications and Networking (JOCN), INFORMS Journal on Computing, Journal of Advanced Transportation (Hindawi), Journal of Combinatorial Optimization, Journal of Graph Theory (JGT), MDPI Applied Sciences, PLOS One, The Computer Journal, Transactions on Mobile Computing.

10.1.4 Invited talks

- Julien Bensmail
 - *On the "quest" towards a directed variant of the 1-2-3 Conjecture*. Seminar of the "Graphes et Optimisation" team, LaBRI, Bordeaux, February 2020
- David Coudert
 - *On the Flinders Hamiltonian Cycle Problem Challenge*. Keynote speaker at "Global Virtual SageDays 110", online, October 29-30, 2020
- Emilio Cruciani
 - *Collective Intelligence: A Personal Point of View*. Cassini Junior Workshop 2020, Rome, Italy, June 12, 2020
- Francesco d'Amore
 - *On the Search Efficiency of Parallel Lévy Walks in \mathbb{Z}^2* , IRIF online seminar, Paris (FR), June 9, 2020
 - *On some Opinion Dynamics in Multi-Agent Systems*, poster at SophI.A Summit, Sophia Antipolis (FR), November 16-21, 2020
- Frédéric Havet
 - 8 ECM (8th European Congress of Mathematics) Mini-symposium Algorithmic Graph Theory, Portoroz, Slovenia, 5-11 July 2020 (postponed due to COVID)
 - Workshop on Spanning Subgraphs, Montreal, Canada, 20-24 July 2020 (postponed due to COVID)
- Nicolas Nisse
 - *Localization games in graphs*. Graph Searching Online Seminar (<https://sites.google.com/view/graphsearchingonline2020/home>), online, July 10th, 2020

10.1.5 Leadership within the scientific community

- David Coudert
 - Co-chair of *Pôle RESCOM of GDR RSD of CNRS* since 2017 and member of the steering committee since 2005
- Frédéric Giroire
 - Member of the steering committee of *GT Energy of the GDR RSD of CNRS*

- Frédéric Havet
 - Member of the steering committee of *GT Graphes of the GDR IM of CNRS*

10.1.6 Scientific expertise

- Jean-Claude Bermond
 - Expert for DRTT-MESR Crédit impôt recherche (CIR et agréments)
- Christelle Caillouet
 - Expert for ANR
- David Coudert
 - Expert for ANR
- Frédéric Havet
 - Expert for ANR and FNRS (Belgium)
- Nicolas Nisse
 - Expert for European Science Foundation
 - Natural Sciences and Engineering Research Council of Canada
- Michel Syska
 - Expert for DRTT-MESR Crédit impôt recherche (CIR et agréments)

10.1.7 Research administration

- Jean-Claude Bermond
 - Responsible for the cooperation between Inria and Greece
- Christelle Caillouet
 - Elected member of Conseil de Laboratoire I3S since 2017
 - Nominated member at the Commission Permanente de Ressources Humaines (CPRH) of Côte d’Azur University until August 2020
 - Member of selection committee MCE, INSA de Lyon, 2020
- Alexandre Caminada
 - Member of the executive board of the Sophia Interdisciplinary Institute of Artificial Intelligence started in 2019
 - Manager of the research committee for the Polytech network national academic Foundation
- David Coudert
 - Nominated member for Inria at the board of doctoral school STIC, since September 2017
 - Head (since December 2019) and member (since 2009) of the “Comité de Suivi Doctoral” of Inria
 - Nominated member for Inria at the steering committee of Academy 1 RISE (Networks, Information, Digital Society) of UCA^{JEDI} since February 2018
 - Nominated member for Inria at the steering committee of EUR DS4H since February 2018
 - Nominated member for Inria at the steering committee of Labex UCN@Sophia since February 2018

- Member of the steering committee of seminar Forum Numerica of Academy 1 RISE of UCA^{JEDI} since 2018
- Member of the “Bureau du comité des équipe-projets” of Inria research center Sophia Antipolis - Méditerranée since 2018
- Frédéric Giroire
 - In charge of the internships of stream UbiNet of Master 2 IFI, Université Côte d’Azur
- Frédéric Havet
 - Head of COMRED team of I3S laboratory
- Nicolas Nisse
 - Elected member for the "Comité de centre", Inria Sophia Antipolis - Méditerranée, since 2017
 - Nominated member for Inria at the CoSP of EUR DS4H until October 2020
 - Elected member for Inria at the CoSP of EUR DS4H since October 2020
 - Member of the CoSP Terra Numerica, since 2020
- Michel Syska
 - Elected member at the Commission Permanente de Ressources Humaines (CPRH) of Université Côte d’Azur until August 2020
 - Nominated deputy director of the computing science department of Université Côte d’Azur (Département Disciplinaire Informatique) since March 2020

10.2 Teaching - Supervision - Juries

10.2.1 Teaching Responsibilities

- Julien Bensmail
 - Since September 2019: Head of the Licence Professionnelle “Managements des Processus Logistiques” (MPL) of Univ Côte d’Azur
- Christelle Caillouet
 - Elected member of Conseil de département IUT Informatique since September 2017
- Alexandre Caminada
 - Head of the graduate school of engineering Polytech Nice Sophia (1500 master grade students, 100 faculty members, 50 staffs)
 - Member of the executive board of the Polytech network, national network of public graduate school of engineering
 - Member of the executive board of Université Côte d’Azur
- Joanna Moulhierac
 - “Directrice d’études” for the 1st-year students of “Département Informatique” of IUT Nice Côte d’Azur (since September 2017)
 - Head of the “Conseil de Département Informatique” of IUT Nice Côte d’Azur (since September 2017)

10.2.2 Teaching

Members of COATI have for more that 1320 hours (ETD) this year:

- DUT: Julien Bensmail, *Recherche opérationnelle*, 90h ETD, Level L2, Département QLIO of IUT, Université Côte d'Azur, France
- DUT: Julien Bensmail, *Systèmes de gestion de bases de données*, 70h ETD, Level L2, Département QLIO of IUT, Université Côte d'Azur, France
- DUT: Christelle Caillouet, *Object Oriented Programming*, 150h ETD, Level L1, IUT, Université Côte d'Azur, France
- DUT: Christelle Caillouet, *Introduction to Networks*, 21h ETD, Level L1, IUT, Université Côte d'Azur, France
- DUT: Christelle Caillouet, *Algorithmics*, 21h ETD, Level L2, IUT, Université Côte d'Azur, France
- DUT: Foivos Fioravantes, *Bases de la conception orienté objet*, 64h ETD, Level L1, Département Informatique of IUT, Université Côte d'Azur, France
- DUT: Adrien Gausseran, *Introduction à l'algorithmique et à la programmation*, 10h ETD, Level L1, IUT, Université Côte d'Azur, France
- DUT: Adrien Gausseran, *Architecture des réseaux*, 38h ETD, Level L1, IUT, Université Côte d'Azur, France
- DUT: Adrien Gausseran, *Compléments d'algorithmique*, 20h ETD, Level L2, IUT, Université Côte d'Azur, France
- DUT: Luc Hogie, *Distributed programming*, 28h ETD, Level L2, IUT, Université Côte d'Azur, France
- DUT: Hicham Lesfari, *Réseaux d'opérateurs et réseaux d'accès*, 48h ETD, Level L2, IUT, Université Côte d'Azur, France
- DUT: Joanna Moulierac, *Introduction à l'algorithmique*, 30h ETD, Level L1, IUT, Université Côte d'Azur, France
- DUT: Joanna Moulierac, *Introduction aux Réseaux*, 56h ETD, Level L1, IUT, Université Côte d'Azur, France
- DUT: Joanna Moulierac, *Réseaux avancés*, 60h ETD, Level L2, IUT, Université Côte d'Azur, France;
- IUT: Thi Viet Ha Nguyen, *Algorithmique*, 24h ETD, Level L1, Département QLIO of IUT, Université Côte d'Azur, France
- IUT: Thibaud Trolliet, *Introduction aux bases de données*, 64h ETD, Level L1, IUT, Université Côte d'Azur, France
- DUT: Michel Syska, *Tutored Project: Introduction*, Level L1, IUT, Université Côte d'Azur, France
- DUT: Michel Syska, *Data Structures and Algorithms*, 44h ETD, Level L2, IUT, Université Côte d'Azur, France
- DUT: Michel Syska, *Introduction to Artificial Intelligence*, 40h ETD, Level L2, IUT, Université Côte d'Azur, France
- DUT: Michel Syska, *Algorithmics*, 52h ETD, Level L2, IUT, Université Côte d'Azur, France
- DUT: Michel Syska, *Distributed programming*, 52h ETD, Level L2, IUT, Université Côte d'Azur, France

- MPSI: Nicolas Nisse, *Option informatique, MPSI*, 24h ETD, classe préparatoire MPSI, Lycée International de Valbonne, France
- LP: Julien Bensmail, *Sécurité des échanges de données inter-entreprises*, 30h ETD, Level L3, LP MPL of IUT, Université Côte d'Azur, France
- LP: Michel Syska, *Web Security*, 16h ETD, Level L3, IUT, Université Côte d'Azur, France
- Licence: Ali Al Zoobi, *Programmation et structures en C*, 24h ETD, Level L2, Faculté des sciences, Université Côte D'Azur, France
- Licence: Michel Syska, *Networks*, 33h ETD, Level L3, MIAGE - Université Côte d'Azur, France
- Master: Nicolas Nisse, *Graphs*, 36h ETD, M1 Informatique et Interaction, Université Côte d'Azur, France
- Master: Alexandre Caminada, *Radio location systems*, 20h ETD, Master 2 (in english), Polytech Nice Sophia, France
- Master: Alexandre Caminada, *Artificial intelligence*, 40h ETD, Master 2 (in english), Polytech Nice Sophia, France
- Master: Alexandre Caminada, Master grade student's internship supervision and assesment, 10h ETD, Master 2, Polytech Nice Sophia, France
- Master: Christelle Caillouet, *Data Mining for Networks*, 9h ETD, M2 Ubinet, Université Côte d'Azur, France
- Master: David Coudert, *Algorithms for Telecoms*, 36h ETD, M2 Ubinet, Université Nice Sophia Antipolis, France
- Master: Frédéric Giroire, *Graph Algorithms*, 18h ETD, Master 2, International Track Ubinet, Université Côte d'Azur, France
- Master: Frédéric Giroire, *Machine learning for networks*, 24h ETD, Master 2, International Track Ubinet, Université Côte d'Azur, France
- Master: Nicolas Nisse, *Algorithms for Telecoms*, 15h ETD, M2 Ubinet, Université Côte d'Azur, France
- Master: Nicolas Nisse, *Advanced Graphs*, 36h ETD, M2 Informatique et Interaction, Université Côte d'Azur, France
- Formation professeurs lycée : Nicolas Nisse, *Algorithms*, 15h ETD, DUI Algorithmique, Université Côte d'Azur, France

10.2.3 Supervision

PhD thesis

- PhD in progress: Redha Abderrahmane ALLICHE, *Artificial Intelligence-based cloud network control*, since October 2020. Co-supervisors: Ramon Aparicio and Lucile Sassatelli
- PhD in progress: Ali Al Zoobi, *Algorithms for shared on demand public transportation system in the city*, since October 2018. Co-supervisors: David Coudert and Nicolas Nisse
- PhD in progress: Francesco D'Amore, *Dynamics for multi-agent system coordination in noisy and stochastic environments*, since October 2019. Co-supervisors: Emanuele Natale and Nicolas Nisse
- PhD in progress: Giuseppe Di Lena, *Resilience of virtualized networks*, since April 2018. Co-supervisors: Thierry Turetletti (DIANA), Chidung Lac (Orange Labs Lannion) and Frédéric Giroire. CIFRE grant with Orange

- PhD in progress: Thomas Dissaux, *Graph decompositions and treelength*, since October 2020. Supervisors: Nicolas Nisse
- PhD in progress: Foivos Fioravantes, *Distinguishing labellings of graphs*, since October 2019. Co-supervisors: Julien Bensmail and Nicolas Nisse
- PhD in progress: Igor Dias da Silva, *Optimization of UAVs deployment and coordination for exploration and monitoring applications*, since October 2020. Co-supervisors: Christelle Caillouet and David Coudert
- PhD in progress: Adrien Gausseran, *Optimization Algorithms for Network Slicing for 5G*, since October 2018. Supervisors: Joanna Moulrierac and Nicolas Nisse
- PhD in progress: Hicham Lesfari, *Machine learning for dynamic network resource allocation*, since October 2019. Supervisor: Frédéric Giroire
- PhD in progress: Zhejiayu Ma, *Learning problem for the diffusion of multimedia contents*, since October 2018. Co-Supervisors: Guillaume Urvoy-Keller, Frédéric Giroire, Soufiane Rouiba (Easybroadcast, Nantes). CIFRE grant with Easybroadcast
- PhD in progress: Thi-Viet-Ha Nguyen, *Graph Algorithms techniques for (low and high) resolution model of large protein assemblies.*, since October 2018. Co-supervisors: Frédéric Havet and Dorian Mazaauric (ABS)
- PhD in progress: Thibaud Trolliet, *Exploring Trust on Twitter*, since October 2017. Co-supervisors: Arnaud Legout (DIANA) and Frédéric Giroire
- PhD in progress: Arthur Walraven, *Algorithmic Principles for Artificial Neural Network Compression*, since October 2020. Supervisor: Emanuele Natale. DGA grant
- PhD: Huy Duong, *Nested Column Generation for Optical Network Optimization*, Concordia University, July 27, 2020. Supervisors: David Coudert and Brigitte Jaumard (Concordia University, Montréal, Canada)
- HdR: Julien Bensmail, *A contribution to distinguishing labellings of graphs* [69], Université Côte d'Azur, December 15, 2020

Internships

- Licence: Clément Rambaud, *Coloration de graphes orientés plongés dans des surfaces*, ENS Paris, France, from 25 May 2020 until 10 August 2020. Supervisor: Frédéric Havet
- Licence: Valentin Madeleine *Jeu Web de coloration dans les graphes*, L3, from October 2020 to January 2021. Supervisors: Frédéric Havet, Dorian Mazaauric and Nicolas Nisse
- Licence: Lucas de Meyer, *Interferences in symmetric trees*, ENS Rennes, France, from 25 May 2020 until 10 July 2020. Co-supervisors: David Coudert and Frédéric Havet
- Google Summer of Code: Vigul Gupta, *Improvement of various methods related to distances computation in (weighted) (directed) graphs in Sagemath*, 3rd year student of dual degree (B.Tech + M.Tech) Mathematics and Computing course at IIT-BHU, India, from May until August 2020. Mentor: David Coudert
- Master 1 (tutorship): Valentin Lacomme, *Conception and implementation of a distributed platform for the experimentation of distributed computing in the IOT*, M1 Computer Science MIAGE, Digital Systems for Humans (DS4H) Graduate school - Université Côte d'Azur, France, from October 2020 until June 2021. Supervisor: Luc Hogie
- Master 1 (PFE): Yassine Jrad, Mael Delaby, Fabrice Simon, *Simple and Efficient Distributed Plotter*, M1 Computer Science Polytech Nice - Université Côte d'Azur, France, from October 2020 until January 2021. Supervisor: Luc Hogie and Julien Deantoni

- Master 2 (TER): , Anthony CHOquard, Romain Giuntini, and Gregory Hoareau *Jeu web des gendarmes et du voleur dans les graphes*, M2 IHM Polytech Nice Sophia, Université Côte d’Azur, France, from November 2020 until December 2020. Supervisors: Frédéric Havet, Nicolas Nisse and Michel Syska
- Master 2 (TER): Kostiantyn Ohulchanskyi and Sofii Shelest, *Evolution Over Time of the Structure of Social Graphs*, Master 2 IFI, international track Ubinet, Université Côte d’Azur, France, from November 2020 until December 2020. Supervisors: Frédéric Giroire, Nicolas Nisse, Małgorzata Sulkowska, and Thibaud Trolliet
- Master 2 (apprentissage): Théo Qui, *Implementation and study of Graphs’ decompositions*, M2 IFI, Université Côte d’Azur, France, from September 2019 until August 2020. Supervisor: Nicolas Nisse
- Master 2: Thomas Dissaux, *Treelength of Series-parallel graphs*, Master 2 Informatique et Interactions, Université Côte d’Azur, France, from March 2020 until August 2020. Supervisor: Nicolas Nisse
- Master 2: Igor Dias da Silva, *Analysis and optimization of drones trajectory in wireless flying ad-hoc networks*, Master 2 IFI, international track Ubinet, Université Côte d’Azur, France, from March 2020 until August 2020. Supervisor: Christelle Caillouet
- Master 2: Abdelkrim El Merss *Impact of Research Funding: Evolution of The Structure of Scientific Collaboration Networks*, Master 2 IFI, international track Ubinet, Université Côte d’Azur, France, from March 2020 until August 2020. Supervisors: Frédéric Giroire et Nicolas Nisse

10.2.4 Juries

- Christelle Caillouet
 - Member of PhD committee of Oana Hotescu, INP Toulouse, May 29, 2020
 - Member of PhD committee of Moisés Nunez, INP Grenoble and CEA, June 17, 2020
- David Coudert
 - President of the PhD committee of Imane Oussakel, Université Paul Sabatier, Toulouse, France, July 17, 2020
- Frédéric Giroire
 - Referee and member of PhD committe of Cédric Morin, Ecole nationale supérieure Mines-Telecom Atlantique Bretagne Pays de la Loire, IMT Atlantique , November 18, 2020
 - Referee and member of PhD committee of Omar Houidi, Institut Polytechnique de Paris, June 25, 2020
- Frédéric Havet
 - President of the PhD prize committee *prix de thèse Graphes “Charles Delorme”* <http://gtgraphes.labri.fr/pmwiki/pmwiki.php/PrixTheseDelorme/PrixTheseDelorme>
- Emanuele Natale
 - Member of PhD committee of Briec Guinard, IRIF (Paris), November 4, 2020

10.2.5 Internal or external Inria responsibilities

- Frédéric Havet is one of the heads of Terra Numerica. This project which brings together several popularization groups in order to create a museum of digital sciences. It creates popularization devices that are used in several places (in particular, Maison de l’Intelligence Artificielle), on several events (Fête de la Science, ...), and in schools. See <https://terra-nerica.org/>

- Frédéric Havet is vice-president and member of the scientific committee of the association Institut Esope 21 (<https://esope21.fr/>). In particular, he is in charge of the organization of the “Carrefour des Sciences” at Vinon-sur-Verdon secondary school
- Nicolas Nisse is head of Galejade projet (Graphes et ALgorithmes : Ensemble de Jeux À Destination des Ecoliers... (mais pas que)) <https://galejade.inria.fr/>

10.3 Popularization

10.3.1 Education

- Ali al Zoobi, Jean-Claude Bermond, Frédéric Giroire, Frédéric Havet, Joanna Moulierac, Emanuele Natale, Nicolas Nisse, and Michel Syska are involved in Terra Numerica (see above). They participate in the creation of popularization devices.
- Frédéric Havet, Joanna Moulierac and Nicolas Nisse (responsable) : Participation to Galejade projet (Graphes et ALgorithmes : Ensemble de Jeux À Destination des Ecoliers... (mais pas que)), <https://galejade.inria.fr/>
 - Design of pedagogical resources introducing graphs and algorithms to primary school students

10.3.2 Interventions

- Frédéric Havet and Nicolas Nisse
 - Animation of the Mathematical Fair at Guynemer School, Hyères, France, January 27, 2020
- Frédéric Havet
 - Conferences in 3 schools for 15 classes. (Lycée Raynouard, Brignoles, January 13 and March 9; Collège Rostand, Draguignan, January 20; Collège Daudet, Nice, March 10)
 - Organisation and animation of discovery internships of 12 pupils, February 10-14, 2020
 - 12 conferences at “Carrefour des Sciences”, Collège Yves Montand, Vinon-sur-Verdon, during Fête de la Science, October 5-9 2020
- Nicolas Nisse
 - Intervention Collège du Rouret, March 12, 2020
 - Intervention Lycée Jules Ferry, Cannes. September 25, 2020
- Michel Syska
 - Member of the organization of the code competition "*Game on Web*" (33 teams of students), September, 2020
 - Organization and supervision of the local site IUT - DS4H for the national code competition "*La nuit de l'info*", December 3-4, 2020

11 Scientific production

11.1 Major publications

- [1] D. Agarwal, C. Caillouet, D. Coudert and F. Cazals. ‘Unveiling Contacts within Macro-molecular assemblies by solving Minimum Weight Connectivity Inference Problems’. In: *Molecular and Cellular Proteomics* 14 (Apr. 2015), pp. 2274–2284. DOI: [10.1074/mcp.M114.047779](https://doi.org/10.1074/mcp.M114.047779). URL: <https://hal.inria.fr/hal-01245401>.

- [2] L. Becchetti, A. Clementi, E. Natale, F. Pasquale and L. Trevisan. 'Finding a Bounded-Degree Expander Inside a Dense One'. In: *Proceedings of the thirty-first Annual ACM-SIAM Symposium on Discrete Algorithms (SODA)*. Salt Lake City, United States, Jan. 2020. URL: <https://hal.archives-ouvertes.fr/hal-02002377>.
- [3] J. Bensmail, A. Harutyunyan, T.-N. Le and S. Thomassé. 'Edge-partitioning a graph into paths: beyond the Barát-Thomassen conjecture'. In: *Combinatorica* 39.2 (Apr. 2019), pp. 239–263. DOI: [10.1007/s00493-017-3661-5](https://hal.archives-ouvertes.fr/hal-01744515). URL: <https://hal.archives-ouvertes.fr/hal-01744515>.
- [4] C. Caillouet, F. Giroire and T. Razafindralambo. 'Efficient Data Collection and Tracking with Flying Drones'. In: *Ad Hoc Networks*. Ad Hoc Networks 89.C (2019), pp. 35–46. DOI: [10.1016/j.adhoc.2019.01.011](https://hal.inria.fr/hal-02043136). URL: <https://hal.inria.fr/hal-02043136>.
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