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Activity Report 2018

Project-Team COATI

Combinatorics, Optimization and Algorithms for Telecommunications

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

RESEARCH CENTER
Sophia Antipolis - Méditerranée

THEME
Networks and Telecommunications

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

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1. Team, Visitors, External Collaborators

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Frédéric Havet [CNRS, Senior Researcher, HDR]
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External Collaborators

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Nicolas Huin [Concordia University, till Aug 2018]

2. Overall Objectives

2.1. 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 UNS (Univ. Nice Sophia Antipolis). 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 advanced software such as GRPH, and in the contribution to large open source software such as Sagemath.

3. Research Program

3.1. Research Program

Members of COATI have a strong expertise in the design and management of wired and wireless backbone, backhaul, broadband, software defined and complex networks. On the one hand, we cope with specific problems such as energy efficiency in backhaul and backbone networks, routing reconfiguration in connection oriented networks (MPLS, WDM), traffic aggregation in SONET networks, compact routing in large-scale networks, survivability to single and multiple failures, etc. These specific problems often come from questions of our industrial partners. On the other hand, we study fundamental problems mainly related to routing and reliability that appear in many networks (not restricted to our main fields of applications) and that have been widely studied in the past. However, previous solutions do not take into account the constraints of current networks/traffic such as their huge size and their dynamics. COATI thus puts a significant research effort in the following directions:

- **Energy efficiency and Software-Defined Networks (SDN)** at both the design and management levels. We study the deployment of energy-efficient routing algorithm within SDN. We developed new algorithms in order to take into account the new constraints of SDN equipments and we evaluate their performance by simulation and by experimentation on a fat-tree architecture.
- **Service Function Chains (SFC):** we study the placement of Service Function Chains within the network considering the ordering constraints. Then, we focus firstly on energy efficiency and secondly on reliability and protection mechanisms. In a last step, we study reconfiguration of the SFCs in case of dynamic traffic with a make-before-break approach.
- **Larger networks:** Another challenge one has to face is the increase in size of practical instances. It is already difficult, if not impossible, to solve practical instances optimally using existing tools. Therefore, we have to find new ways to solve problems using reduction and decomposition methods, characterization of polynomial instances (which are surprisingly often the practical ones), or algorithms with acceptable practical performances.
- **Stochastic behaviors:** Larger topologies mean frequent changes due to traffic and radio fluctuations, failures, maintenance operations, growth, routing policy changes, etc. We aim at including these stochastic behaviors in our combinatorial optimization process to handle the dynamics of the system and to obtain robust designs of networks.

The methods and tools used in our studies come from discrete mathematics and combinatorial optimization, and COATI contributes to their improvements. Also, COATI works on graph-decomposition methods and various games on graphs which are essential for a better understanding of the structural and combinatorial properties of the problems, but also for the design of efficient exact or approximate algorithms. We contribute to the modelling of optimization problems in terms of graphs, study the complexity of the problems, and then we investigate the structural properties of graphs that make these problems hard or easy. We exploit these properties in the design of algorithms in order to find the most efficient ways for solving the problems.

COATI also focuses on the theory of *directed graphs*. Indeed, graph theory can be roughly partitioned into two branches: the areas of undirected graphs and directed graphs. Even though both areas have numerous important applications, for various reasons, undirected graphs have been studied much more extensively than directed graphs. It is worth noticing that many telecommunication problems are modelled with directed graphs. Therefore, a deeper understanding of the theory of directed graphs will benefit to the resolution of telecommunication networks problems. For instance, the problem of finding disjoint paths becomes much more difficult in directed graphs and understanding the underlying structures of actual directed networks would help us to propose solutions.

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 have started a collaboration with SME Instant-System on dynamic car-pooling combined with multi-modal transportation systems. This collaboration is now consolidated as an ANR project started in January 2018. Last, we have started a collaboration with GREDEG (Groupe de Recherche en Droit, Economie et Gestion, Univ. Nice Sophia Antipolis) on the analysis of collaboration networks.

5. Highlights of the Year

5.1. Highlights of the Year

5.1.1. Awards

Guillaume Ducoffe, former PhD student of COATI, is the recipient of the second PhD prize delivered jointly by GDR RSD and Association ACM SIGOPS France (ASF), edition 2018, for his PhD thesis entitled "Metric properties of large graphs".

5.1.2. Habilitation à Diriger des Recherches

Frédéric Giroire has defended his Habilitation à Diriger des Recherches, entitled "*Optimisation des infrastructures réseaux. Un peu de vert dans les réseaux et autres problèmes de placement et de gestion de ressources*" [1], at Univ. Côte d'Azur on October 23, 2018.

Abstract: Pushed by the new sensitivity of the society, politics, and companies to energy costs and global warming, he investigated the question of how to build green networks. He first studied some practical scenarios to answer the question: how much energy could be saved for Internet Service Providers by putting into practice energy efficient protocols? It led him to study fundamental problems of graph theory.

At the core of these energy efficient methods, there is a dynamic adaptation to the changes of demands, which is impossible to do in legacy networks which are mostly manually operated. The emergence of two new paradigms, software defined networking (SDN) and network function virtualization (NFV), leads to a finer control of networks and thus bears the promise to to put energy efficient solutions into practice. He thus studied how to use SDN to implement dynamic routing.

His approach has been to use theoretical tools to solve problems raised by the introduction of new technologies or new applications. His tools come mainly from combinatorics and in particular from graph theory, algorithmics, optimization and probabilities. When he was able to propose new methods of resolution, he then tried to evaluate their practical impact by numerical evaluation, simulation or experimentation with realistic scenarios.

5.1.3. New team members

- Alexandre Caminada has been recruited as a University Professor of Univ. Nice Sophia Antipolis since September 2018 and he is now a member of COATI. Since September 2017, he is the director of the Polytech'Nice engineering school of Univ. Nice Sophia Antipolis.
- Emanuele Natale has been recruited as a Junior researcher at CNRS in 2018. He will join COATI in January 2019.

6. New Software and Platforms

6.1. GRPH

The high performance graph library for Java
KEYWORDS: Graph - Graph algorithmics - Java
FUNCTIONAL DESCRIPTION: Grph is an open-source Java library for the manipulation of graphs. Its design objectives are to make it portable, simple to use/extend, computationally/memory efficient, and, according to its initial motivation: useful in the context of graph experimentation and network simulation. Grph also has the particularity to come with tools like an evolutionary computation engine, a bridge to linear programming solvers, a framework for distributed computing, etc.

Grph offers a very general model of graphs. Unlike other graph libraries which impose the user to first decide if he wants to deal with directed, undirected, hyper (or not) graphs, the model offered by Grph is unified in a general class that supports mixed graphs made of undirected and directed simple and hyper edges. Grph achieves great efficiency through the use of multiple code optimization techniques such as multi-core parallelism, caching, adequate data structures, use of primitive objects, exploitation of low-level processor caches, on-the-fly compilation of specific C/C++ code, etc. Grph attempts to access the Internet in order to check if a new version is available and to report who is using it (login name and hostname). This has no impact whatsoever on performance and security.

- Participants: Aurélien Lancin, David Coudert, Issam Tahiri, Luc Hogie and Nathann Cohen
- Contact: Luc Hogie
- URL: http://www.i3s.unice.fr/~hogie/grph/

6.2. BigGraphs

KEYWORDS: Graph algorithmics - Distributed computing - Java - Graph processing
FUNCTIONAL DESCRIPTION: The objective of BigGraphs is to provide a distributed platform for very large graphs processing. A typical data set for testing purpose is a sample of the Twitter graph : 240GB on disk, 398M vertices, 23G edges, average degree of 58 and max degree of 24635412.

We started the project in 2014 with the evaluation of existing middlewares (GraphX / Spark and Giraph / Hadoop). After having tested some useful algorithms (written according to the BSP model) we decided to develop our own platform.

This platform is based on the existing BIGGRPH library and we are now in the phasis where we focus on the quality and the improvement of the code. In particular we have designed strong test suites and some non trivial bugs have been fixed. We also have solved problems of scalability, in particular concerning the communication layer with billions of messages exchanged between BSP steps. We also have implemented specific data structures for BSP and support for distributed debugging. This comes along with the implementation of algorithms such as BFS or strongly connected components that are run on the NEF cluster.

In 2017 we have developed a multi-threaded shared-memory parallel version of the Bulk Synchronous Parallel framework. This new version uses advanced synchronization mechanisms and strategies to minimize the congestion of multiple threads working on the same graph. Using the NEF cluster (Inria Sophia Antipolis), this parallel version exhibits speed-ups up to 6.5 using 8 nodes (16 cores each) when computing a BFS on the 23 G edges Twitter graph sample.

- Participants: Luc Hogie, Michel Syska and Nicolas Chleq
- Partner: CNRS
- Contact: Luc Hogie
- URL: http://www.i3s.unice.fr/~hogie/software/?name=biggrph

6.3. 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. Trolliet and S. Pérennes to count K2,2s, 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.

- Contact: Luc Hogie
- URL: http://www.i3s.unice.fr/~hogie/software/?name=jmaxgraph

6.4. Sagemath

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 FUNCTIONAL DESCRIPTION: See http://www.sagemath.org/changelogs/sage-8.4.txt
NEWS OF THE YEAR: 1) Implementation of a linear time algorithm for partitioning a graph into 3-connected components. Done in the context of Google Summer of Code 2018. 2) Main contributor for making the graph module (more than 100,000 lines of code) of SageMath compatible with Python3 (ongoing, already more than 100 patchs)

- Participant: David Coudert
- Contact: David Coudert
- URL: http://www.sagemath.org/

7. New Results

7.1. Network Design and Management

Participants: Jean-Claude Bermond, Christelle Caillouet, David Coudert, Frédéric Giroire, Frédéric Havet, Nicolas Huin, Joanna Moulierac, Nicolas Nisse, Stéphane Pérennes, Andrea Tomassilli.

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 the new network paradigms, Software-Defined Networks (SDN) and Network Function Virtualization (NFV). On the contrary to legacy networks, in SDN, a centralized controller is in charge of the control plane and takes the routing decisions for the switches and routers based on the network conditions. This new technology brings new constraints and therefore new algorithmic problems such as the problem of limited space in the switches to store the forwarding rules. We then tackle the problem of placement of virtualized resources. We validated our algorithms on a real SDN platform [1]. Secondly, we consider different scenarios regarding wireless networks and connected Unmanned Aerial Vehicules (UAVs). Third, we tackle routing in the Internet. Last, we study live streaming in distributed systems.

7.1.1. Software Defined Networks (SDN)

Software-defined Networks (SDN) is a new networking paradigm enabling innovation through network programmability. SDN is gaining momentum with the support of major manufacturers. Over past few years, many applications have been built using SDN such as server load balancing, virtual-machine migration, traffic engineering and access control.

7.1.1.1. Bringing Energy Aware Routing Closer to Reality With SDN Hybrid Networks

Energy-aware routing aims at reducing the energy consumption of Internet service provider (ISP) networks. The idea is to adapt routing to the traffic load to turn off some hardware. However, it implies to make dynamic changes to routing configurations which is almost impossible with legacy protocols. The software defined network (SDN) paradigm bears the promise of allowing a dynamic optimization with its centralized controller. In [34], we propose smooth energy aware routing (SENAtoR), an algorithm to enable energy-aware routing in a scenario of progressive migration from legacy to SDN hardware. Since in real life, turning off network devices is a delicate task as it can lead to packet losses, SENAtoR also provides several features to safely enable energy saving services: tunneling for fast rerouting, smooth node disabling, and detection of both traffic spikes and link failures. We validate our solution by extensive simulations and by experimentation. We show that SENAtoR can be progressively deployed in a network using the SDN paradigm. It allows us to reduce the energy consumption of ISP networks by 5%–35% depending on the penetration of SDN hardware while diminishing the packet loss rate compared to legacy protocols.

7.1.1.2. Energy-Aware Routing in Software-Defined Network using Compression

Over past few years, many applications have been built using SDN such as server load balancing, virtual-machine migration, traffic engineering and access control. In [31], we focus on using SDN for energy-aware routing (EAR). Since traffic load has a small influence on the power consumption of routers, EAR allows putting unused links into sleep mode to save energy. SDN can collect traffic matrix and then computes routing solutions satisfying QoS while being minimal in energy consumption. However, prior works on EAR have assumed that the SDN forwarding table switch can hold an infinite number of rules. In practice, this assumption

[1] Testbed with SDN hardware, in particular a switch HP 5412 with 96 ports, hosted at I3S laboratory. A complete fat-tree architecture with 16 servers can be built on the testbed.

does not hold since such flow tables are implemented in Ternary Content Addressable Memory (TCAM) which is expensive and power-hungry. We consider the use of wildcard rules to compress the forwarding tables. In [31], we propose optimization methods to minimize energy consumption for a backbone network while respecting capacity constraints on links and rule space constraints on routers. In details, we present two exact formulations using Integer Linear Program (ILP) and introduce efficient heuristic algorithms. Based on simulations on realistic network topologies, we show that using this smart rule space allocation, it is possible to save almost as much power consumption as the classical EAR approach.

7.1.1.3. Complexity of Compressing Two Dimensional Routing Tables with Order

Motivated by routing in telecommunication network using Software Defined Network (SDN) technologies, we consider the following problem of finding short routing lists using aggregation rules. We are given a set of communications $\mathcal{X}$, which are distinct pairs $(s,t) \subseteq S \times T$, (typically S is the set of sources and T the set of destinations), and a port function $\pi : \mathcal{X} \to P$ where P is the set of ports. A *routing list* $\mathcal{R}$ is an ordered list of triples which are of the form (s,t,p), $(*,t,p)$, $(s,*,p)$ or $(*,*,p)$ with $s \in S$, $t \in T$ and $p \in P$. It *routes* the communication (s,t) to the port $r(s,t) = p$ which appears on the first triple in the list $\mathcal{R}$ that is of the form (s,t,p), $(*,t,p)$, $(s,*,p)$ or $(*,*,p)$. If $r(s,t) = \pi(s,t)$, then we say that (s,t) is *properly routed* by $\mathcal{R}$ and if all communications of $\mathcal{X}$ are properly routed, we say that $\mathcal{R}$ *emulates* $(\mathcal{X},\pi)$. The aim is to find a shortest routing list emulating $(\mathcal{X},\pi)$. In [30], we carry out a study of the complexity of the two dual decision problems associated to it. Given a set of communication $\mathcal{X}$, a port function π and an integer k, the first one called ROUTING LIST (resp. the second one, called LIST REDUCTION) consists in deciding whether there is a routing list emulating $(\mathcal{X},\pi)$ of size at most k (resp. $|\mathcal{X}| - k$). We prove that both problems are NP-complete. We then give a 3-approximation for LIST REDUCTION, which can be generalized to higher dimensions. We also give a 4-approximation for ROUTING LIST in the fundamental case when there are only two ports (i.e. $|P| = 2$), $\mathcal{X} = S \times T$ and $|S| = |T|$.

7.1.2. Provisioning Service Function Chains

7.1.2.1. Optimal Network Service Chain Provisioning

Service chains consist of a set of network services, such as firewalls or application delivery controllers, which are interconnected through a network to support various applications. While it is not a new concept, there has been an extremely important new trend with the rise of Software-Defined Network (SDN) and Network Function Virtualization (NFV). The combination of SDN and NFV can make the service chain and application provisioning process much shorter and simpler. In [33], [48], we study the provisioning of service chains jointly with the number/location of Virtual Network Functions (VNFs). While chains are often built to support multiple applications, the question arises as how to plan the provisioning of service chains in order to avoid data passing through unnecessary network devices or servers and consuming extra bandwidth and CPU cycles. It requires choosing carefully the number and the location of the VNFs. We propose an exact mathematical model using decomposition methods whose solution is scalable in order to conduct such an investigation. We conduct extensive numerical experiments, and show we can solve exactly the routing of service chain requests in a few minutes for networks with up to 50 nodes, and traffic requests between all pairs of nodes. Detailed analysis is then made on the best compromise between minimizing the bandwidth requirement and minimizing the number of VNFs and optimizing their locations using different data sets.

7.1.2.2. Energy-Efficient Service Function Chain Provisioning

Network Function Virtualization (NFV) is a promising network architecture concept to reduce operational costs. In legacy networks, network functions, such as firewall or TCP optimization, are performed by specific hardware. In networks enabling NFV coupled with the Software Defined Network (SDN) paradigm, Virtual Network Functions (VNFs) can be implemented dynamically on generic hardware. This is of primary interest to implement energy efficient solutions, in order to adapt the resource usage dynamically to the demand. In [35], we study how to use NFV coupled with SDN to improve the energy efficiency of networks. We consider a setting in which a flow has to go through a Service Function Chain, that is several network functions in a specific order. We propose an ILP formulation, an ILP-based heuristic, as well as a decomposition model that relies on joint routing and placement configuration to solve the problem. We show that virtualization provides between 22% to 62% of energy savings for networks of different sizes.

7.1.2.3. Placement of Service Function Chains with Ordering Constraints

A Service Function Chain (SFC) is an ordered sequence of network functions, such as load balancing, content filtering, and firewall. With the Network Function Virtualization (NFV) paradigm, network functions can be deployed as pieces of software on generic hardware, leading to a flexibility of network service composition. Along with its benefits, NFV brings several challenges to network operators, such as the placement of virtual network functions. In [49], [50], [62], we study the problem of how to optimally place the network functions within the network in order to satisfy all the SFC requirements of the flows. Our optimization task is to minimize the total deployment cost. We show that the problem can be seen as an instance of the Set Cover Problem, even in the case of ordered sequences of network functions. It allows us to propose two logarithmic factor approximation algorithms which have the best possible asymptotic factor. Further, we devise an optimal algorithm for tree topologies. Finally, we evaluate the performances of our proposed algorithms through extensive simulations. We demonstrate that near-optimal solutions can be found with our approach.

7.1.2.4. Resource Requirements for Reliable Service Function Chaining

We study in [51], [49] the problem of deploying reliable Service Function Chains over a virtualized network function architecture. While there is a need for reliable service function chaining, there is a high cost to pay for it in terms of bandwidth and VNF processing requirements. We investigate two different protection mechanisms and discuss their resource requirements, as well as the latency of their paths. For each mechanism, we develop a scalable exact mathematical model using column generation.

7.1.2.5. Path protection in optical flexible networks with distance-adaptive modulation formats

Thanks to a flexible frequency grid, Elastic Optical Networks (EONs) will support a more efficient usage of the spectrum resources. On the other hand, this efficiency may lead to even more disruptive effects of a failure on the number of involved connections with respect to traditional networks. In [52], we study the problem of providing path protection to the lightpaths against a single fiber failure event in the optical layer. Our optimization task is to minimize the spectrum requirements for the protection in the network. We develop a scalable exact mathematical model using column generation for both shared and dedicated path protection schemes. The model takes into account practical constraints such as the modulation format, regenerators, and shared risk link groups. We demonstrate the effectiveness of our model through extensive simulation on two real-world topologies of different sizes. Finally, we compare the two protection schemes under different scenario assumptions, studying the impact of factors such as number of regenerators and demands on their performances.

7.1.2.6. Reconfiguring Service Functions chains with a make-before-break approach

The centralized routing model of SDN jointly with the possibility of instantiating VNFs on-demand open the way for a more efficient operation and management of networks. In [58], we consider the problem of reconfiguring network connections with the goal of bringing the network from a sub-optimal to an optimal operational state. We propose optimization models based on the *make-before-break* mechanism, in which a new path is set up before the old one is torn down. Our method takes into consideration the chaining requirements of the flows and scales well with the number of nodes in the network. We show that, with our approach, the network operational cost defined in terms of both bandwidth and installed network function costs can be reduced and a higher acceptance rate can be achieved.

7.1.3. Capacity defragmentation

Optical multilayer optimization continuously reorganizes layer 0-1-2 network elements to handle both existing and dynamic traffic requirements in the most efficient manner. This delays the need to add new resources for new requests, saving CAPEX and leads to optical network defragmentation.

In [46], [47], we focus on Layer 2, i.e., on capacity defragmentation at the Optical Transport Network (OTN) layer when routes (e.g., LSPs in MPLS networks) are making unnecessarily long detours to evade congestion. Reconfiguration into optimized routes can be achieved by redefining the routes, one at a time, so that they use the vacant resources generated by the disappearance of services using part of a path that transits the congested section. For the Quality of Service, it is desirable to operate under Make-Before-Break (MBB), with the minimum number of rerouting. The challenge is to identify the rerouting order, one connection at a time, while minimizing the bandwidth requirement. We propose in [46], [47] an exact and scalable optimization model for computing a minimum bandwidth rerouting scheme subject to MBB in the OTN layer of an optical network. Numerical results show that we can successfully apply it on networks with up to 30 nodes, a very significant improvement with the state of the art. We also provide some defragmentation analysis in terms of the bandwidth requirement vs. the number of reroutings.

In [37], we focus on wavelength defragmentation in WDM networks. We propose a MBB wavelength defragmentation process which minimizes the bandwidth requirement of the resulting provisioning. Comparisons with minimum bandwidth provisioning that is not subject to MBB show that, on average, the best seamless lightpath rerouting is never more than 5% away (less than 1% on average) from an optimal lightpath provisioning.

7.1.4. Spectrum assignment in elastic optical tree-networks

To face the explosion of the Internet traffic, a new generation of optical networks is being developed; the Elastic Optical Networks (EONs). EONs use the optical spectrum efficiently and flexibly, but that gives rise to more difficulty in the resource allocation problems. In [16], we study the problem of Spectrum Assignment (SA) in Elastic Optical Tree-Networks. Given a set of traffic requests with their routing paths (unique in the case of trees) and their spectrum demand, a spectrum assignment consists in allocating to each request an interval of consecutive slots (spectrum units) such that a slot on a given link can be used by at most one request. The objective of the SA problem is to find an assignment minimizing the total number of spectrum slots to be used. We prove that SA is NP-hard in undirected stars of 3 links and in directed stars of 4 links, and show that it can be approximated within a factor of 4 in general stars. Afterwards, we use the equivalence of SA with a graph coloring problem (interval coloring) to find constant-factor approximation algorithms for SA on binary trees with special demand profiles.

7.1.5. Optimizing drone coverage

In the context of a collaboration with Tahiry Razafindralambo from the University of la Réunion we have studied several problems related to deployment of drones in order to collect data generated from sensors. Those problems may be seen as belonging to the category of "cover" problems and we have designed and proposed efficient formulations using linear programming models with columns generation.

Drones (Unmanned Aerial Vehicles, UAV) can be used to provide anytime and anywhere network access to targets located on the ground, using air-to-ground and air-to-air communications through directional antennas. In [43] we study how to deploy these drones to cover a set of fixed targets. It is a complex problem since each target should be covered, while minimizing (i) the deployment cost and (ii) the drones altitudes to ensure good communication quality. We also consider connectivity between the drone and a base station in order to collect and send information to the targets, which is not considered in many similar studies. We provide an efficient optimal program to solve the problem and show the trade-off analysis due to conflicting objectives. We propose a fair trade-off optimal solution and also evaluate the cost of adding connectivity to the drone deployment.

In [41], [42] we introduce a Linear Programming (LP) model for the problem of data gathering with mobile drones. The goal is to deploy a connected set of Unmanned Aerial Vehicles (UAVs) continuously monitoring mobile sensors and reporting information to a fixed base station for efficient data collection. We propose an effective optimization model reducing the number of variables of the problem and solved using column generation. Results show that our model is tractable for large topologies with several hundreds of possible 3D locations for the UAVs deployment and provides integer solutions with the generated columns very close to the optimum. Moreover, the deployment changes among time remains low in terms of number of UAVs and cost, to maintain connectivity and minimize the data collection delay to the base station.

We also have studied a problem arising when one will to recharge wireless sensor networks using drones and wireless power transfer; in [44] we consider the optimal energy replenishment problem (OERP). The goal is to operate a given number of flying drones in order to efficiently recharge wireless sensor nodes. We present a linear program that maximizes the amount of harvested energy to the sensors. We show that the model is solved to optimality in a few seconds for sensor networks with up to 50 nodes. The small number of available drones is shown to be optimally deployed at low altitude in order to efficiently recharge the batteries of at least half of the sensor nodes.

7.1.6. Other results in wireless networks

7.1.6.1. Backbone colouring and algorithms for TDMA scheduling

We investigate graph colouring models for the purpose of optimizing TDMA link scheduling in Wireless Networks. Inspired by the $BPRN$-colouring model recently introduced by Rocha and Sasaki, we introduce a new colouring model, namely the $BMRN$-colouring model, which can be used to model link scheduling problems where particular types of collisions must be avoided during the node transmissions.

In [64], we initiate the study of the $BMRN$-colouring model by providing several bounds on the minimum number of colours needed to $BMRN$-colour digraphs, as well as several complexity results establishing the hardness of finding optimal colourings. We also give a special focus on these considerations for planar digraph topologies, for which we provide refined results. Some of these results extend to the $BPRN$-colouring model as well.

7.1.6.2. Gossiping with interference in radio chain networks

In [53], we study the problem of gossiping with interference constraint in radio chain networks. Gossiping (or total exchange information) is a protocol where each node in the network has a message and wants 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. The network is assumed to be synchronous, the time is slotted into steps, and each device is equipped with a half duplex interface; so, a node cannot both receive and transmit during a step. We use a binary asymmetric model of interference based on the distance in the communication digraph. We determine exactly the minimum number of rounds R needed to achieve a gossiping when transmission network is a dipath P_n on $n \geq 3$ nodes and the interference distance is $d_I = 1$.

7.2. Graph Algorithms

Participants: Julien Bensmail, Jean-Claude Bermond, Nathann Cohen, David Coudert, Frédéric Giroire, Frédéric Havet, Fionn Mc Inerney, Nicolas Nisse, Stéphane Pérennes.

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

7.2.1.1. Parameterized complexity of polynomial optimization problems (FPT in P)

Parameterized complexity theory has enabled a refined classification of the difficulty of NP-hard optimization problems on graphs with respect to key structural properties, and so to a better understanding of their true difficulties. More recently, hardness results for problems in P were established under reasonable complexity theoretic assumptions such as: Strong Exponential Time Hypothesis (SETH), 3SUM and All-Pairs Shortest-Paths (APSP). According to these assumptions, many graph theoretic problems do not admit truly subquadratic algorithms, nor even truly subcubic algorithms (Williams and Williams, FOCS 2010 [83] and Abboud *et al.* SODA 2015 [67]). A central technique used to tackle the difficulty of the above mentioned problems is fixed-parameter algorithms for polynomial-time problems with *polynomial dependency* in the fixed parameter (P-FPT). This technique was rigorously formalized by Giannopoulou et al. (IPEC 2015) [74], [75]. Following that, it was continued by Abboud *et al.* (SODA 2016) [68], by Husfeldt (IPEC 2016) [76] and Fomin *et al.* (SODA 2017) [73], using the treewidth as a parameter. Applying this technique to *clique-width*, another important graph parameter, remained to be done.

In [45] we study several graph theoretic problems for which hardness results exist such as *cycle problems* (triangle detection, triangle counting, girth), *distance problems* (diameter, eccentricities, Gromov hyperbolicity, betweenness centrality) and *maximum matching*. We provide hardness results and fully polynomial FPT algorithms, using clique-width and some of its upper-bounds as parameters (split-width, modular-width and P_4-sparseness). We believe that our most important result is an $\mathcal{O}(k^4 \cdot n + m)$-time algorithm for computing a maximum matching where k is either the modular-width or the P_4-sparseness. The latter generalizes many algorithms that have been introduced so far for specific subclasses such as cographs, P_4-lite graphs, P_4-extendible graphs and P_4-tidy graphs. Our algorithms are based on preprocessing methods using modular decomposition, split decomposition and primeval decomposition. Thus they can also be generalized to some graph classes with unbounded clique-width.

7.2.1.2. *Revisiting Decomposition by Clique Separators*

We study in [26] the complexity of decomposing a graph by means of clique separators. This common algorithmic tool, first introduced by Tarjan [79], allows to cut a graph into smaller pieces, and so, it can be applied to preprocess the graph in the computation of optimization problems. However, the best-known algorithms for computing a decomposition have respective $\mathcal{O}(nm)$-time and $\mathcal{O}(n^{(3+\alpha)/2}) = o(n^{2.69})$-time complexity, with $\alpha < 2.3729$ being the exponent for matrix multiplication. Such running times are prohibitive for large graphs. In [26], we prove that for every graph G, a decomposition can be computed in $\mathcal{O}(T(G) + \min\{n^\alpha, \omega^2 n\})$-time with $T(G)$ and ω being respectively the time needed to compute a minimal triangulation of G and the clique-number of G. In particular, it implies that every graph can be decomposed by clique separators in $\mathcal{O}(n^\alpha \log n)$-time. Based on prior work from Kratsch and Spinrad [77], we prove in addition that decomposing a graph by clique-separators is as least as hard as triangle detection. Therefore, the existence of any $o(n^\alpha)$-time algorithm for this problem would be a significant breakthrough in the field of algorithmic. Finally, our main result implies that planar graphs, bounded-treewidth graphs and bounded-degree graphs can be decomposed by clique separators in linear or quasi-linear time.

7.2.1.3. *Distance-preserving elimination orderings in graphs*

For every connected graph G, a subgraph H of G is *isometric* if the distance between any two vertices in H is the same in H as in G. A *distance-preserving elimination ordering* of G is a total ordering of its vertex-set $V(G)$, denoted $(v_1, v_2, ..., v_n)$, such that any subgraph $G_i = G \setminus (v_1, v_2, ..., v_i)$ with $1 \leq i < n$ is isometric. This kind of ordering has been introduced by Chepoi in his study on weakly modular graphs [71]. In [27], we prove that it is NP-complete to decide whether such ordering exists for a given graph | even if it has diameter at most 2. Then, we prove on the positive side that the problem of computing a distance-preserving ordering when there exists one is fixed-parameter-tractable in the treewidth. Lastly, we describe a heuristic in order to compute a distance-preserving ordering when there exists one that we compare to an exact exponential time algorithm and to an ILP formulation for the problem.

7.2.1.4. *Complexity of computing strong pathbreadth*

The strong pathbreadth of a given graph G is the minimum ρ such that G admits a Robertson and Seymour's path decomposition where every bag is the complete ρ-neighbourhood of some vertex in G. In [29] [2], we prove that deciding whether a given graph has strong pathbreadth at most one is NP-complete. This answers negatively to a conjecture of Leitert and Dragan [78].

7.2.1.5. *Improving matchings in trees, via bounded-length augmentations*

In [13] Due to a classical result of Berge, it is known that a matching of any graph can be turned into a maximum matching by repeatedly augmenting alternating paths whose ends are not covered. In a recent work, Nisse, Salch and Weber considered the influence, on this process, of augmenting paths with length at most k only. Given a graph G, an initial matching $M \subseteq E(G)$ and an odd integer k, the problem is to find a longest sequence of augmenting paths of length at most k that can be augmented sequentially from M. They proved that, when only paths of length at most $k = 3$ can be augmented, computing such a longest sequence can be done in polynomial time for any graph, while the same problem for any $k \geq 5$ is *NP*-hard. Although the latter result remains true for bipartite graphs, the status of the complexity of the same problem for trees is not known.

[2] Work done while G. Ducoffe was a member of COATI and published this year.

This work is dedicated to the complexity of this problem for trees. On the positive side, we first show that it can be solved in polynomial time for more classes of trees, namely bounded-degree trees (via a dynamic programming approach), caterpillars and trees where the nodes with degree at least 3 are sufficiently far apart. On the negative side, we show that, when only paths of length *exactly* k can be augmented, the problem becomes *NP*-hard already for $k = 3$, in the class of planar bipartite graphs with maximum degree 3 and arbitrary large girth. We also show that the latter problem is *NP*-hard in trees when k is part of the input.

7.2.2. Dynamics of formation of communities in social networks

We consider in [40] a community formation problem in social networks, where the users are either friends or enemies. The users are partitioned into conflict-free groups (i.e., independent sets in the conflict graph $G^- = (V, E)$ that represents the enmities between users). The dynamics goes on as long as there exists any set of at most k users, k being any fixed parameter, that can change their current groups in the partition simultaneously, in such a way that they all strictly increase their utilities (number of friends i.e., the cardinality of their respective groups minus one). Previously, the best-known upper-bounds on the maximum time of convergence were $O(|V|\alpha(G^-))$ for $k \leq 2$ and $O(|V|^3)$ for $k = 3$, with $\alpha(G^-)$ being the independence number of G^-. Our first contribution in this paper consists in reinterpreting the initial problem as the study of a dominance ordering over the vectors of integer partitions. With this approach, we obtain for $k \leq 2$ the tight upper-bound $O(|V| \min \alpha(G^-), \sqrt{|V|})$ and, when G^- is the empty graph, the exact value of order $\frac{(2|V|)^{3/2}}{3}$. The time of convergence, for any fixed $k \geq 4$, was conjectured to be polynomial. In [40], we disprove this. Specifically, we prove that for any $k \geq 4$, the maximum time of convergence is an $\Omega(|V|^{\Theta(\log |V|)})$.

7.2.3. Application to bioinformatics

For a (possibly infinite) fixed family of graphs $\mathcal{F}$, we say that a graph G *overlays* $\mathcal{F}$ on a hypergraph H if $V(H)$ is equal to $V(G)$ and the subgraph of G induced by every hyperedge of H contains some member of $\mathcal{F}$ as a spanning subgraph. While it is easy to see that the complete graph on $|V(H)|$ overlays $\mathcal{F}$ on a hypergraph H whenever the problem admits a solution, the MINIMUM $\mathcal{F}$-OVERLAY problem asks for such a graph with at most k edges, for some given $k \in \mathbb{N}$. This problem allows to generalize some natural problems which may arise in practice. For instance, if the family $\mathcal{F}$ contains all connected graphs, then MINIMUM $\mathcal{F}$-OVERLAY corresponds to the MINIMUM CONNECTIVITY INFERENCE problem (also known as SUBSET INTERCONNECTION DESIGN problem) introduced for the low-resolution reconstruction of macro-molecular assembly in structural biology, or for the design of networks.

In [23], we prove a strong dichotomy result regarding the polynomial vs. NP-complete status with respect to the considered family $\mathcal{F}$. Roughly speaking, we show that the easy cases one can think of (e.g. when edgeless graphs of the right sizes are in $\mathcal{F}$, or if $\mathcal{F}$ contains only cliques) are the only families giving rise to a polynomial problem: all others are $\mathcal{NP}$-complete. We then investigate the parameterized complexity of the problem and give similar sufficient conditions on $\mathcal{F}$ that give rise to W[1]-hard, W[2]-hard or FPT problems when the parameter is the size of the solution. This yields an FPT/W[1]-hard dichotomy for a relaxed problem, where every hyperedge of H must contain some member of $\mathcal{F}$ as a (non necessarily spanning) subgraph.

7.3. Games on Graphs

Participants: Julien Bensmail, Nicolas Nisse, Fionn Mc Inerney, Stéphane Pérennes.

We study several two-player games on graphs. Some of these games allow to model real-life applications. In the case of the Spy-game presented below, we propose a successful new approach by studying fractional relaxation of such games.

7.3.1. Spy-game on graphs and eternal domination

In [24] we define and study the following two-player game on a graph G. Let $k \in \mathbf{N}^*$. A set of k guards is occupying some vertices of G while one spy is standing at some node. At each turn, first the spy may move along at most s edges, where $s \in \mathbf{N}^*$ is his speed. Then, each guard may move along one edge. The spy and the guards may occupy the same vertices. The spy has to escape the surveillance of the guards, i.e., must reach a vertex at distance more than $d \in \mathbf{N}$ (a predefined distance) from every guard. Can the spy win against k guards? Similarly, what is the minimum distance d such that k guards may ensure that at least one of them remains at distance at most d from the spy? This game generalizes two well-studied games: Cops and robber games (when $s = 1$) and Eternal Dominating Set (when s is unbounded).

In [24], we consider the computational complexity of the problem, showing that it is NP-hard (for every speed s and distance d) and that some variant of it is PSPACE-hard in DAGs. Then, we establish tight tradeoffs between the number of guards, the speed s of the spy and the required distance d when G is a path or a cycle.

In order to determine the smallest number of guards necessary for this task, we analyze in [25] the game through a Linear Programming formulation and the fractional strategies it yields for the guards. 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 torus. We believe that the approach using fractional relaxation and Linear Programming is promising to obtain new results in the field of combinatorial games.

In [60] we pursue the study of the eternal domination game (which is equivalent to the spy game when s is unbounded and $d = 0$) on strong grids $P_n \Box P_m$. Cartesian grids $P_n \Box P_m$ have been vastly studied with tight bounds existing for small grids such as $k \times n$ grids for $k \in \{2, 3, 4, 5\}$. It was recently proven that $\gamma^{\infty}_{all}(P_n \Box P_m) = \gamma(P_n \Box P_m) + O(n + m)$ where $\gamma(P_n \Box P_m)$ is the domination number of $P_n \Box P_m$ which lower bounds the eternal domination number. We prove that, for all $n, m \in \mathbb{N}^*$ such that $m \geq n$, $\lceil \frac{nm}{9} \rceil + \Omega(n + m) = \gamma^{\infty}_{all}(P_n \boxtimes P_m) = \lceil \frac{nm}{9} \rceil + O(m\sqrt{n})$ (note that $\lceil \frac{nm}{9} \rceil$ is the domination number of $P_n \boxtimes P_m$).

7.3.2. Metric dimension & localization

The questions that we study there are variant of the usual *Metric Dimension* problem in which one wishes to identify the vertices of a graph from the knowledge of the distances to a few points. This is motivated by localization problems, e.g., in cellular networks. few anchors.

In [19] we introduce a generalization of metric dimension based on a pursuit graph game that resembles the famous Cops and Robbers game. In this game, an invisible target is hidden at some vertex of a graph (at each turn, it may move to a neighbor). At every step, $k \geq 1$ vertices of G can be probed which results in the knowledge of the distances between each of these vertices and the secret location of the target. We provide upper bounds on the related graph invariant $\zeta(G)$, defined as the least number of probes per turn needed to localize the robber on a graph G, for several classes of graphs (trees, bipartite graphs, etc). Our main result is that, surprisingly, there exists planar graphs of treewidth 2 and unbounded $\zeta(G)$. On a positive side, we prove that $\zeta(G)$ is bounded by the pathwidth of G. We then show that the algorithmic problem of determining $\zeta(G)$ is NP-hard in graphs with diameter at most 2. Finally, we show that at most one cop can approximate (arbitrary close) the location of the robber in the Euclidean plane. We further study this problem in [18] where, in particular, we prove that $\zeta(G) \leq 3$ in outer-planar graphs.

In [39], [56], [38], we address the sequential metric dimension when the invisible target is immobile. The objective of the game is to minimize the number of steps needed to locate the target whatever be its location. 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 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.

In [57] we try to understand the phenomena when one choose an orientation of an (undirected) graphs. Namely, 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 $\frac{nm}{2}$.

7.3.3. Orienting edges to fight fire in graphs

In [12], we investigate a new oriented variant of the Firefighter Problem. In the traditional Firefighter Problem, a fire breaks out at a given vertex of a graph, and at each time interval spreads to neighbouring vertices that have not been protected, while a constant number of vertices are protected at each time interval. In our version of the problem, the firefighters are able to orient the edges of the graph before the fire breaks out, but the fire could start at any vertex. We consider this problem when played on a graph in one of several graph classes, and give upper and lower bounds on the number of vertices that can be saved. In particular, when one firefighter is available at each time interval, and the given graph is a complete graph, or a complete bipartite graph, we present firefighting strategies that are provably optimal. We also provide lower bounds on the number of vertices that can be saved as a function of the chromatic number, of the maximum degree, and of the treewidth of a graph. For a sub-cubic graph, we show that the firefighters can save all but two vertices, and this is best possible.

7.3.4. Network decontamination

The Network Decontamination problem consists in coordinating a team of mobile agents in order to clean a contaminated network. The problem is actually equivalent to tracking and capturing an invisible and arbitrarily fast fugitive. This problem has natural applications in network security in computer science or in robotics for search or pursuit-evasion missions. In this Chapter, we focus on networks modeled by graphs. Many different objectives have been studied in this context, the main one being the minimization of the number of mobile agents necessary to clean a contaminated network. Another important aspect is that this optimization problem has a deep graph-theoretical interpretation. Network decontamination and, more precisely, graph searching models, provide nice algorithmic interpretations of fundamental concepts in the Graph Minors theory by Robertson and Seymour. For all these reasons, graph searching variants have been widely studied since their introduction by Breish (1967) and mathematical formalizations by Parsons (1978) and Petrov (1982). Our chapter [61] consists of an overview of algorithmic results on graph decontamination and graph searching.

7.3.5. Hyperopic Cops and Robbers

We introduce in [17] a new variant of the game of Cops and Robbers played on graphs, where the robber is invisible unless outside the neighbor set of a cop. The hyperopic cop number is the corresponding analogue of the cop number, and we investigate bounds and other properties of this parameter. We characterize the cop-win graphs for this variant, along with graphs with the largest possible hyperopic cop number. We analyze the cases of graphs with diameter 2 or at least 3, focusing on when the hyperopic cop number is at most one greater than the cop number. We show that for planar graphs, as with the usual cop number, the hyperopic cop number is at most 3. The hyperopic cop number is considered for countable graphs, and it is shown that for connected chains of graphs, the hyperopic cop density can be any real number in $[0, 1/2]$.

7.4. Graph theory

Participants: Julien Bensmail, Frédéric Havet, William Lochet, Nicolas Nisse, Fionn Mc Inerney, Stéphane Pérennes, Bruce Reed.

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

7.4.1. Interval number in cycle convexity

Recently, Araujo et al. [Manuscript in preparation, 2017] introduced the notion of Cycle Convexity of graphs. In their seminal work, they studied the graph convexity parameter called hull number for this new graph convexity they proposed, and they presented some of its applications in Knot theory. Roughly, the *tunnel number* of a knot embedded in a plane is upper bounded by the hull number of a corresponding planar 4-regular graph in cycle convexity. In [4], we go further in the study of this new graph convexity and we study the interval number of a graph in cycle convexity. This parameter is, alongside the hull number, one of the most studied parameters in the literature about graph convexities. Precisely, given a graph G, its *interval number* in cycle convexity, denoted by $CCIHN(G)$, is the minimum cardinality of a set $S \subseteq V(G)$ such that every vertex $w \in V(G) \setminus S$ has two distinct neighbors $u, v \in S$ such that u and v lie in same connected component of $G[S]$, i.e. the subgraph of G induced by the vertices in S.

In [4] we provide bounds on $CCIHN(G)$ and its relations to other graph convexity parameters, and explore its behaviour on grids. Then, we present some hardness results by showing that deciding whether $CCIHN(G) \leq k$ is NP-complete, even if G is a split graph or a bounded-degree planar graph, and that the problem is W[2]-hard in bipartite graphs when k is the parameter. As a consequence, we obtain that $CCIHN(G)$ cannot be approximated up to a constant factor in the classes of split graphs and bipartite graphs (unless $P = NP$).

On the positive side, we present polynomial-time algorithms to compute $CCIHN(G)$ for outerplanar graphs, cobipartite graphs and interval graphs. We also present fixed-parameter tractable (FPT) algorithms to compute it for $(q, q-4)$-graphs when q is the parameter and for general graphs G when parameterized either by the treewidth or the neighborhood diversity of G.

Some of our hardness results and positive results are not known to hold for related graph convexities and domination problems. We hope that the design of our new reductions and polynomial-time algorithms can be helpful in order to advance in the study of related graph problems.

7.4.2. Steinberg-like theorems for backbone colouring

A function $f : V(G) \rightarrow \{1, ..., k\}$ is a (proper) k-colouring of G if $|f(u) - f(v)| \geq 1$, for every edge $uv \in E(G)$. The *chromatic number* $\chi(G)$ is the smallest integer k for which there exists a proper k-colouring of G. Given a graph G and a subgraph H of G, a circular q-backbone k-colouring f of (G, H) is a k-colouring of G such that $q \leq |c(u) - c(v)| \leq k - q$, for each edge $uv \in E(H)$. The *circular q-backbone chromatic number* of a graph pair (G, H), denoted $\mathrm{CBC}_q(G, H)$, is the minimum k such that (G, H) admits a circular q-backbone k-colouring. Steinberg conjectured that if G is planar and G contains no cycles on 4 or 5 vertices, then $\chi(G) \leq 3$. If this conjecture is correct, then one could deduce that $\mathrm{CBC}_2(G, H) \leq 6$, for any $H \subseteq G$. In [5], we first show that if G is a planar graph containing no cycle on 4 or 5 vertices and $H \subseteq G$ is a forest, then $\mathrm{CBC}_2(G, H) \leq 7$. Then, we prove that if $H \subseteq G$ is a forest whose connected components are paths, then $\mathrm{CBC}_2(G, H) \leq 6$.

7.4.3. Homomorphisms of planar signed graphs and absolute cliques

Homomorphisms are an important topic in graph theory, as example the chromatic number of a graph G is the minimum k such that G maps onto the complete graph K_k. A signed graph (G, Σ) is a (simple) graph with sign function $\Sigma E(G) \rightarrow \{-1, 1\}$. A closed-walk is unbalanced if it has an odd number of negative edges, it is balanced otherwise. Homomorphisms of signed graphs are mapping that preserve adjacency and balance of cycles. Naserasr, Rollova and Sopena (Journal of Graph Theory 2015) posed the important question of finding out the minimum size k such that any planar signed graph (G, Σ) admits a homomorphism to a signed graph with k vertices. The question can be seen as the counterpart of the 4 color theorem which implies that any palnar graph maps onto K_4. It is known that if this minimum value is equal to 10, then every planar signed graph maps to a particular unique signed graph $(P^{+}9, \Gamma^{+})$ with 10 vertices. A graph G is an underlying absolute signed clique if there exists a signed graph (G, Σ) which does not admit any homomorphism to any signed graph (H, Π) with $|V(H)| < |V(G)|$. In [66] we characterize all underlying absolute signed planar cliques up to spanning subgraph inclusion. Furthermore, we show that every signed planar graph having underlying graphs obtained by (repeated, finite) k-clique sums ($k \leq 3$) of underlying absolute signed planar cliques admits a homomorphism to $(P^{+}9, \Gamma^{+})$. Based on this evidence, we conjecture that every planar signed graph admits a homomorphism to $(P+9, \Gamma^{+})$.

7.4.4. Edge-partitioning a graph into paths: the Barát-Thomassen conjecture

In 2006, Barát and Thomassen conjectured that there is a function f such that, for every fixed tree T with t edges, every $f(t)$-edge-connected graph with its number of edges divisible by t has a partition of its edges into copies of T. We recently proved this conjecture with Merker [69].

The path case of the Barát-Thomassen conjecture (i.e $\forall k, m = |E| \, mod \, k = 0$ there exists $f(k)$ such that if the connectivity of G is larger than $f(k)$ then G can be partitionned into P_k) has also been studied, notably by Thomassen [80], [81], [82], and had been solved by Botler, Mota, Oshiro and Wakabayashi [70]. In [15] we propose an alternative proof of the path case with a weaker hypothesis: Namely, we prove that there is a function f such that every 24-edge-connected graph with minimum degree $f(k)$ has an edge-partition into paths of length k. We also show that 24 can be dropped to 4 when the graph is Eulerian.

7.4.5. Some Aspects of Arbitrarily Partitionable Graphs

An n-graph G is arbitrarily partitionable (AP) if, for every partition of n as $n = n_1 + ... + n_p$, there is a partition $(V_1, ..., V_p)$ of $V(G)$ such that for $i = 1, ..., p$ $G[V_i]$ is connected and $|V_i| = n_i$. The property of being AP is related to other well-known graph notions, such as perfect matchings and Hamiltonian cycles (obviously Hamiltonian graph is AP), with which it shares several properties. In [65] This work we studying two aspects of AP graphs.

On the one hand, we consider the algorithmic aspects. 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 *NP*-hard for several classes of graphs, confirming a conjecture of Barth and Fournier.

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

7.4.6. Incident Sum problems and the 1-2-3 Conjecture

How can one distinguish the adjacent vertices of a graph through an edge-weighting? In the last decades, this question has been attracting increasing attention, which resulted in the active field of distinguishing labelings. One of its most popular problems is the one where neighbours must be distinguishable via their incident sums of weights. An edge-weighting verifying this is said to be *proper*. The popularity of this notion arises mainly due to the influence of the famous 1-2-3 Conjecture (posed by Karoński, Łuczak and Thomason), which claims that proper weightings with weights in $\{1, 2, 3\}$ exist for graphs with no isolated edge.

The questions that we study aim at solving or at progressing toward the solution of the 1-2-3 conjecture and similar problems.

In [8] we study locally irregular decompositions of sub-cubic graphs. A graph G is locally irregular if every two adjacent vertices of G have different degrees (this corresponds to a uniform weight). A locally irregular decomposition of G is a partition $E_1, \cdots, E_k$ of the edge set $E(G)$ such that each $G[E_i]$ is locally irregular. Not all graphs admit locally irregular decompositions, but for those who are decomposable, it was conjectured by Baudon, Bensmail, Przybyło and Woźniak that the decomposition uses at most 3 locally irregular graphs. Towards that conjecture, it was recently proved by Bensmail, Merker and Thomassen that every decomposable graph decomposes into at most 328 locally irregular graphs. Our work focuses on the case of sub-cubic graphs, which form an important family of graphs in this context, as all non-decomposable graphs are sub-cubic. As a main result, we prove that decomposable sub-cubic graphs decompose into at most 5 locally irregular graphs, and at most 4 when the maximum average degree is less than $\frac{12}{5}$. We then consider weaker decomposition, where subgraphs can also include regular connected components, and prove the relaxations of the conjecture above for sub-cubic graphs.

In [9] we pursue recent works generalizing "Neighbour Sum problems" (e.g. the well-known 1-2-3 Conjecture, or the notion of locally irregular decomposition) to digraphs. We introduce and study several variants of the 1-2 Conjecture for digraphs and for every such variant, we state conjectures concerning the number of weights necessary to obtain a desired total-weighting in any digraph. We verify some of these conjectures, while we obtain close results towards the solution of the ones that are still open.

In [10] we study a variant of the classical 1-2-3 Conjecture. This conjecture asks whether every graph but K_2 can be 3-edge-weighted so that every two adjacent vertices u and v can be distinguished via the sum of their incident weights, that is the incident sums of u and v differ by at least 1. In this work we investigate the consequences on the 1-2-3 Conjecture of requiring a stronger distinction condition, that is requiring the incident sums to differ by at least 2. Our conjecture is that every graph but K_2 admits a 5-edge-weighting permitting to distinguish the adjacent vertices in this stronger way. We prove this conjecture for several classes of graphs, including bipartite graphs and cubic graphs. We then consider algorithmic aspects, and show that it is *NP*-complete to determine the smallest k such that a given bipartite graph admits such a k-edge-weighting. In contrast, we show that the same problem can be solved in polynomial time when the graph is a tree.

In [11] we prove a 1-2-3-4 result for the 1-2-3 Conjecture in 5-regular graphs. Currently the best-known result toward te 1-2-3 conjecture is due to Kalkowski, Karoński and Pfender, who proved that it holds when relaxed to 5-edge-weightings.Their proof builds upon a weighting algorithm designed by Kalkowski for a total version of the problem (.i.e in our context total means that both the vertices and the edges are assigned weights). Our work, present new mechanisms for using Kalkowski's algorithm in the context of the 1-2-3 Conjecture. As a main result we prove that every 5-regular graph admits a 4-edge-weighting that permits to distinguish adjacent vertices.

In [63] we investigate another aspect of edge weighting that allow to distinguish adjacent vertices (we shall call them *proper*). Namely we study the minimum number of distinct neighbourhood sums we can produce using such proper weightings. Clearly, this minimum number is bounded below by the chromatic number $\chi(G)$ of G. When using weights in Z, we show that we can always produce proper edge-weightings generating $\chi(G)$ distinct sums but in the peculiar case where G is a balanced bipartite graph, in which case exactly $\chi(G)+1$ distinct sums have to be generated. When using k consecutive weights $1, ..., k$, we provide both lower and upper bounds, as a function of the maximum degree Δ, on the maximum least number of sums that can be generated for a graph with maximum degree Δ. For trees, which, in general, admit neighbour-sum-distinguishing 2-edge-weightings, we prove that this maximum, when using weights 1 and 2, is of order $2\log_2\Delta$. Finally, we also establish the *NP*-hardness of several decision problems related to these questions.

The 1-2-3 Conjecture has recently been investigated from a decompositional angle, via so-called locally irregular decompositions, which are edge-partitions into locally irregular subgraphs. Through several recent studies, it was shown that this concept is quite related to the 1-2-3 Conjecture. However, the full connection between all those concepts was not clear. In [55], we propose an approach that generalizes all concepts above, involving coloured weights and sums. As a consequence, we get another interpretation of several existing results related to the 1-2-3 Conjecture. We also propose new related conjectures, to which we give some support.

7.4.7. Identifying codes

For G a graph or a digraph, let $\mathrm{id}(G)$ be the minimum size of an identifying code of G if one exists, and $\mathrm{id}(G)=+\infty$ otherwise. For a graph G, let $\mathrm{idor}(G)$ be the minimum of $\mathrm{id}(D)$ overall orientations D of G. In [20], we give some lower and upper bounds on $\mathrm{idor}(G)$. In particular, we show that $\mathrm{idor}(G)\leq 3/2\mathrm{id}(G)$ for every graph G. We also show that computing $\mathrm{idor}(G)$ is NP-hard, while deciding whether $\mathrm{idor}(G)\leq |V(G)|-k$ is polynomial-time solvable for every fixed integer k.

7.5. Digraph theory

Participants: Julien Bensmail, Frédéric Havet, Nicolas Nisse, William Lochet.

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 the 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.

7.5.1. Constrained ear decompositions in graphs and digraphs

Ear decompositions of graphs are a standard concept related to several major problems in graph theory like the Traveling Salesman Problem. For example, the Hamiltonian Cycle Problem, which is notoriously NP-complete, is equivalent to deciding whether a given graph admits an ear decomposition in which all ears except one are trivial (i.e. of length 1). On the other hand, a famous result of Lovász states that deciding whether a graph admits an ear decomposition with all ears of odd length can be done in polynomial time. In [59], we study the complexity of deciding whether a graph admits an ear decomposition with prescribed ear lengths. We prove that deciding whether a graph admits an ear decomposition with all ears of length at most is polynomial-time solvable for all fixed positive integer. On the other hand, deciding whether a graph admits an ear decomposition without ears of length in F is NP-complete for any finite set F of positive integers. We also prove that, for any $k \geq 2$, deciding whether a graph admits an ear decomposition with all ears of length $0 \mod k$ is NP-complete. We also consider the directed analogue to ear decomposition, which we call handle decomposition, and prove analogous results : deciding whether a digraph admits a handle decomposition with all handles of length at most is polynomial-time solvable for all positive integer ; deciding whether a digraph admits a handle decomposition without handles of length in F is NP-complete for any finite set F of positive integers (and minimizing the number of handles of length in F is not approximable up to $n(1-\varepsilon)$); for any $k \geq 2$, deciding whether a digraph admits a handle decomposition with all handles of length $0 \mod k$ is NP-complete. Also, in contrast with the result of Lovász, we prove that deciding whether a digraph admits a handle decomposition with all handles of odd length is NP-complete. Finally, we conjecture that, for every set A of integers, deciding whether a digraph has a handle decomposition with all handles of length in A is NP-complete, unless there exists $h \in \mathbf{N}$ such that $A = \{1, \cdots, h\}$.

7.5.2. Substructures in digraphs

We study substructures in digraphs. We study all kind of substructures: subdigraphs (induced or not), subdivision, immersion, minors, etc. We are both interested in the algorithmic point of view, that is determining the complexity of finding a (fixed or given) substructure in a given graph, and the structural point of view, that is finding sufficient conditions to guarantee the existence of a substructure.

In [32], we study the algorithmic complexity of the problem of deciding if a digraph contains a subdivision of a fixed digraph F. Up to 5 exceptions, we completely classify for which 4-vertex digraphs F, the F-subdivision problem is polynomial-time solvable and for which it is NP-complete. While all NP-hardness proofs are made by reduction from some version of the 2-linkage problem in digraphs, some of the polynomial-time solvable cases involve relatively complicated algorithms.

In [25], [22] we study conditions under which a digraph contain a subdivision of an oriented cycle. An oriented cycle is an orientation of a undirected cycle. We first show that for any oriented cycle C, there are digraphs containing no subdivision of C (as a subdigraph) and arbitrarily large chromatic number. In contrast, we show that for any C a cycle with two blocks, every strongly connected digraph with sufficiently large chromatic number contains a subdivision of C. We prove a similar result for the antidirected cycle on four vertices (in which two vertices have out-degree 2 and two vertices have in-degree 2). We study the existence of more general structures than cycles. A $(k_1 + k_2)$-bispindle is the union of k_1 (x, y)-dipaths and k_2 (y, x)-dipaths, all these dipaths being pairwise internally disjoint. The above-mentioned results on cycle with two blocks [25] can be restated as follows: for every $(1, 1)$-bispindle B, there exists an integer k such that every strongly connected digraph with chromatic number greater than k contains a subdivision of B. In [21], we investigate generalizations of this result by first showing constructions of strongly connected digraphs with large chromatic number without any $(3, 0)$-bispindle or $(2, 2)$-bispindle. We then consider $(2, 1)$-bispindles. Let $B(k_1, k_2; k_3)$ denote the $(2, 1)$-bispindle formed by three internally disjoint dipaths between two vertices

x, y, two (x, y)-dipaths, one of length k_1 and the other of length k_2, and one (y, x)-dipath of length k_3. We conjecture that for any positive integers k_1, k_2, k_3, there is an integer $g(k_1, k_2, k_3)$ such that every strongly connected digraph with chromatic number greater than $g(k_1, k_2, k_3)$ contains a subdivision of $B(k_1, k_2; k_3)$. As evidence, we prove this conjecture for $k_2 = 1$ (and k_1, k_3 arbitrary).

In [36], we prove the existence of a function $h(k)$ such that every simple digraph with minimum outdegree greater than $h(k)$ contains an immersion of the transitive tournament on k vertices. This solves a conjecture of Devos, McDonald, Mohar and Scheide [72].

In [3], we study χ-bounded families of oriented graphs. A famous conjecture of Gyárfás and Sumner states for any tree T and integer k, if the chromatic number of a graph is large enough, either the graph contains a clique of size k or it contains T as an induced subgraph. We present some results and open problems about extensions of this conjecture to oriented graphs. In particular, we conjecture that for every oriented star S and integer k, if the chromatic number of a digraph is large enough, either the digraph contains a clique of size k or it contains S as an induced subgraph. As an evidence, we prove that for any oriented star S, every oriented graph with sufficiently large chromatic number contains either a transitive tournament of order 3 or S as an induced subdigraph. We then study for which sets $\mathcal{P}$ of orientations of P_4 (the path on four vertices) similar statements hold. We establish some positive and negative results.

7.5.3. Partitions of digraphs

We also study partitions of digraphs. Again we are interested in the algorithmic point of view, that is determining the complexity of finding a partition satisfying some properties in a digraph, and the structural point of view, that is finding sufficient conditions to guarantee the existence of such a partition.

For a given 2-partition (V_1, V_2) of the vertices of a (di)graph G, we study in [7] properties of the spanning bipartite subdigraph $B_G(V_1, V_2)$ of G induced by those arcs/edges that have one end in each V_i, $i \in \{1, 2\}$. We determine, for all pairs of non-negative integers k_1, k_2, the complexity of deciding whether G has a 2-partition (V_1, V_2) such that each vertex in V_i (for $i \in \{1, 2\}$) has at least k_i (out-)neighbours in V_{3-i}. We prove that it is NP-complete to decide whether a digraph D has a 2-partition (V_1, V_2) such that each vertex in V_1 has an out-neighbour in V_2 and each vertex in V_2 has an in-neighbour in V_1. The problem becomes polynomially solvable if we require D to be strongly connected. We give a characterization of the structure of $\mathcal{NP}$-complete instances in terms of their strong component digraph. When we want higher in-degree or out-degree to/from the other set the problem becomes NP-complete even for strong digraphs. A further result is that it is NP-complete to decide whether a given digraph D has a 2-partition (V_1, V_2) such that $B_D(V_1, V_2)$ is strongly connected. This holds even if we require the input to be a highly connected Eulerian digraph.

The dichromatic number $\overrightarrow{\chi}(D)$ of a digraph D is the least number k such that the vertex set of D can be partitioned into k parts each of which induces an acyclic subdigraph. Introduced by Neumann-Lara in 1982, this digraph invariant shares many properties with the usual chromatic number of graphs and can be seen as the natural analog of the graph chromatic number. In [14], we study the list dichromatic number of digraphs, giving evidence that this notion generalizes the list chromatic number of graphs. We first prove that the list dichromatic number and the dichromatic number behave the same in many contexts, such as in small digraphs (by proving a directed version of Ohba's Conjecture), tournaments, and random digraphs. We then consider bipartite digraphs, and show that their list dichromatic number can be as large as $\Omega(\log_2 n)$. We finally give a Brooks-type upper bound on the list dichromatic number of digon-free digraphs.

8. Partnerships and Cooperations

8.1. Regional Initiatives

8.1.1. COSIT, 2018-2019

Participants: Mohammed Amine Ait Ouahmed, Ali Al Zoobi, David Coudert, Nicolas Nisse.

Program: Innovation project, Centre de reference “Smart City” of IDEX UCA^{JEDI}.

Project acronym: COSIT

Project title: Convergent Service for Intermodal Transportation

Duration: February 2018 - January 2019

Coordinator: David Coudert

Other partners: UMR ESPACE (France) and SME Instant-System

Abstract: On-demand transportation is a highly flexible mode of transportation that aims at optimizing transit operator service by reducing operational cost while increasing the number of passengers per vehicles, and to increase customer satisfaction. We are considering a service where a fleet of vehicles (minibuses with a limited number of seats) is used to answer user requests. Vehicle trajectories need to be recalculated dynamically as new queries arrive. It is a complementary offer to existing public transport services (bus, tram, metro, etc.) and intermediate in terms of cost and quality of service between public transport and individual transport (taxi, VTC).

In the COSIT project, we studied different aspects of the problem including static and dynamic algorithms for the assignment of users to vehicles, the study of user flows in the city, and the prediction of users queries. We will developed a graphical interface to visualize the evolution of vehicle itineraries as the demands of users arrive.

8.1.2. SNIF, 2018-2021

Participants: David Coudert, Frédéric Giroire, Nicolas Nisse, Stéphane Pérennes.

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.

Abstract: 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.

8.2. National Initiatives

8.2.1. ANR-17-CE22-0016 MultiMod, 2018-2021

Participants: Mohammed Amine Ait Ouahmed, 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 2021

Coordinator: David Coudert

Other partners: Inria Paris, EP GANG; team CeP, I3S laboratory; SME Instant-System; SME Benomad

Abstract: 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/

8.2.2. PEPS POCODIS

Program PEPS

Project Acronym: POCODIS

Project Title: POndérations et COlorations DIStinguantes de graphes

Duration: Février-Décembre 2018

Coordinator: Julien Bensmail

Others Partners: None

Abstract: This project is about two conjectures on *proper* weightings of a graph, namely the 1-2-3 conjecture and a conjecture about localy irregular decompositions. A weighting is proper whenever the coloring obtained by taking as color for a vertex v the sum of the weight in the neighbourhood of v is a proper coloring, more concisely adjacent vertices have different sums. The main objective of the project is to address several open questions around (i.e. motivated by) these conjectures since we believe that this could lead to significant progress toward the solution of the two main conjectures. To that aim we will make use of several recent and innovative tools and technique in the field, such as the probabilistic method and the polynomial method. In order to use and understand these techniques to their best we shall strengthen several international collaborations with experts from the field.

8.2.3. PICS DISCO

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: organisme, labo (pays) CNRS LIRMM (Montpellier), Syddansk universitet (Odense, Danemark)

Abstract: 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 is a very important modelling tool for practical applications and so a better undestanding 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 undestanding 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.

8.2.4. GDR Actions

8.2.4.1. GDR RSD, ongoing (since 2006)

Members of COATI are involved in the working group RESCOM (*Réseaux de communications*) of GDR RSD, CNRS (http://rescom.asr.cnrs.fr/). In particular, David Coudert is co-chair of this working group since 2017 and has organized its annual summer school, RESCOM'18. Christelle Caillouet was co-chair of the programme committee of the annual conference AlgoTel'18.

We are also involved in the working group "Energy" of GDR RSD. In particular, Frédéric Giroire is co-hair of this working group.

8.2.4.2. 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.

8.2.4.3. GDR MADICS, ongoing (since 2017)

Members of COATI are involed 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/).

The annual summer school RESCOM'18 of GDR RSD has been co-organized with GDR MADICS.

8.3. International Initiatives

8.3.1. IFCAM Program, Applications of Graph homomorphisms

Program: IFCAM 2018-2020 (http://math.iisc.ac.in/~ifcam/)

Project acronym: –

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.

Abstract: 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.

8.3.2. Inria International Labs

Inria Chile

Associate Team involved in the International Lab:

8.3.2.1. ALDYNET

Title: distributed ALgorithms for DYnamic NETworks

International Partner (Institution - Laboratory - Researcher):

Universidad Adolfo Ibañez (Chile) - Facultad de Ingeniería y Ciencias - Karol SUCHAN

Start year: 2016

See also: https://team.inria.fr/coati/projects/aldynet/

This associated team would be the natural continuation of the fruitful EA AlDyNet (2013-2015, https://team.inria.fr/coati/projects/aldynet/)

The main goal of this Associate Team is to design and implement practical algorithms for computing graph structural properties. We will then use these algorithms on a concrete case of study which concerns the transportation network of the Santiago agglomeration. We are both interested in theoretical results concerning the feasibility of computing graph properties, and by their practical implementation (using Sagemath) for our application and their diffusion in the scientific community. There are three main objectives:

1) Design efficient algorithms to compute important graph properties (hyperbolicity, treelength, centrality, treewidth...) in real networks. We are not only interested by the worst-case time-complexity of these algorithms but by their performance in practice.

2) Implement and document our algorithms using the open-source framework SageMath. One advantage of using SageMath is that it has interfaces with other graph libraries (igraph, Boost...) and with Linear Programming solver (GLPK, Cplex...). Moreover, the success of SageMath (which has accumulated thousands of users over the last 10 years) will participate to the diffusion of our algorithms.

3) Apply our algorithms on the Santiago transportation network that have been collected by our Chilean partner during the last year of AlDyNet (2013-2015). Based on the results, propose tools for decision support in designing bus routes, timetables, etc. More precisely, we have collected information about the use of public transport (data of smart cards for automatic fare collection -BIP-, bus routes and bus schedules, etc.), urban infrastructure information, schools' addresses, and approximate locations where students live. We have started to clean and consolidate these data. We will then develop decision support tools, for example, for improving quality education accessibility.

8.3.3. Inria International Partners

8.3.3.1. 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;

RWTH Aachen Univ., Lehrstuhl II für Mathematik (Aachen, Germany), Prof. Arie M.C.A. Koster;

Concordia Univ. (Montréal, Québec, Canada), Prof. Brigitte Jaumard.

8.4. International Research Visitors

8.4.1. Visits of International Scientists

- Jørgen Bang-Jensen

  University of Southern Denmark, Odense, Denmark. June 2018.

- Romuald Elie

  Paris-Est University. February 3 - March 2 2018.

- Gwenael Joret
  Université Libre de Bruxelles, Belgique. March 2018.
- Takako Kodate
  Tokyo's Woman's Christian University. December 15 2017 till March 31 2018.
- Kasper Szabo Lyngsie
  Technical University of Denmark, Lyngby, Denmark. June 27 - July 8.
- Joseph Peters
  Simon Fraser University, Vancouver, BC, Canada. October 1 2017 till March 31 2018.
- Tahiry Razafindralambo
  Université de la Réunion. July 8-28 2018.
- Leonardo Sampaio Rocha
  University Federal de Ceara, Fortaleza, Brazil. July 1 2018 till June 30 2019.
- Karol Suchan
  Universidad Adolfo Ibañez, Santiago, Chile. September 9-23 2018.
- Robert E. Tarjan
  Princetown University, Princetown, NJ, USA. July 2018.
- Min-Li (Joseph) Yu
  University of the Fraser Valley, Abbotsford, BC, Canada. March 1 till April 15 2018.

8.4.2. Visits to International Teams

8.4.2.1. Research Stays Abroad

- Julien Bensmail :
  Northwestern Polytechnical University, Xi'an, China. 22 Avril-13 Mai.
  LaBRI, Bordeaux, France. 23 Mai-12 Juin.
  Technical University of Denmark, Lyngby, Denmark. 22 Août-2 Septembre.
  AGH University, Krakow, Poland. 24 Novembre-2 Décembre.
- David Coudert :
  Universidad Adolfo Ibañez, Santiago, Chile, December 1-14, 2018.
- Frédéric Havet :
  University of Southern Denmark, Odense, Denmark. April 2018.
  Ecole Normale Supérieure de Lyon, France, January and September 2018.
- Nicolas Nisse :
  Xidian University, Xi'an, China, September 1-15, 2018
  Univ. Adolfo Ibañez, Santiago, Chile, December 1-15, 2018

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. Scientific Events Organisation

9.1.1.1. General Chair, Scientific Chair

- David Coudert :

RESCOM'18 : school of the *pôle ResCom of GDR ASR of CNRS* on "Apprentissage et fouille de données dans les réseaux", Porquerolles, France, June 18-22, 2018. This edition was organized in collaboration with GDR MADICS.

- Frédéric Havet :

  School on Graph Theory (SGT 2018), Séve, France, June 11-15 2018.

  Journées Combinatoire et Algorithmes du Littoral Méditerranéen (JCALM).

- Nicolas Nisse

  GRASTA'18 : 9th workshop on GRAph Searching, Theory & Applications, Berlin, Germany, 24-27 September 2018.

9.1.2. Scientific Events Selection

9.1.2.1. Chair of Conference Program Committees

- Christelle Caillouet :

  Program Committee Chair of AlgoTel'18 (20e Rencontres Francophones sur les Aspects Algorithmiques des Télécommunications): conférence of the *pôle ResCom of GDR ASR of CNRS* Roscoff, France, May 29-June 1, 2018.

9.1.2.2. Member of the Conference Program Committees

- David Coudert :

  ONDM'18: 22nd Conference on Optical Network Design and Management, Dublin, Ireland, May 14-17, 2018.

  IEEE ICC'18 : IEEE International Conference on Communications, Kansas City, MO, USA, May 20-24, 2018.

  SEA'18: 17th International Symposium on Experimental Algorithms, L'Aquila, Italy, June 27-29, 2018.

  IPEC'18: 13th International Symposium on Parameterized and Exact Computation, Helsinki, Finland, August 20–24, 2018.

  IEEE Globecom'18: IEEE Global Communications Conference, Abu Dhabi, UAE, December 9-13, 2018.

- Frédéric Havet :

  10th International Colloquium on Graph Theory (ICGT 2018), Lyon, France, July 9-13, 2018.

  Journées Graphes et Algorithmes (JGA 2018), Grenoble, France, 14-16 November, 2018.

- Nicolas Nisse

  SEA'18: 17th int. Symposium on Experimental Algorithms, L'Aquila, Italy, 27-29 June 2018.

  CoRes'18: 3rd conférence francophone centrée les réseaux et protocoles de communicatio. Roscoff, France, 29 May- 1st June 2018

9.1.3. Journal

9.1.3.1. Member of the Editorial Boards

Jean-Claude Bermond

Computer Science Reviews, Discrete Mathematics, Discrete Applied Mathematics, Journal of Graph Theory, Journal of Interconnection Networks (Advisory Board), Mathématiques et Sciences Humaines, Networks, Parallel Processing Letters, the SIAM book series on Discrete Mathematics, Transactions on Network Optimization and Control, Algorithms and Applications.

David Coudert

Discrete Applied Mathematics (Elsevier); Networks (Wiley).

Frédéric Giroire

Journal of Interconnection Networks (World Scientific).

Frédéric Havet

Discrete Mathematics and Theoretical Computer Science.

Bruce Reed

Journal of Graph Theory, Electronic Journal of Combinatorics.

9.1.3.2. Reviewer - Reviewing Activities

Members of COATI have reviewed numerous manuscripts submitted to international journals, including:

ACM Journal of Experimental Algorithmics, Ad Hoc Networks, Ars Combinatorica, Computer Networks (COMNET) Discrete Applied Mathematics (DAM), Discrete Mathematics, Discrete Mathematics and Theoretical Computer Science (DMTCS), European Journal of Combinatorics, IEEE/OSA Journal of Lightwave Technology (JLT), IEEE/ACM Transactions on Networking (ToN), IEEE Transactions on Parallel and Distributed Systems (TPDS), Journal of Computer and System Sciences (JCSS), Theoretical Computer Science (TCS) Theory of Computing Systems (TOCS), Utilitas Mathematica.

9.1.4. Invited Talks

- Julien Bensmail

  Sequential Metric Dimension (in trees). Graph Theory 2018 (GT'18), Nyborg, Denmark. August 2018.

  Augmenting matchings in trees, via bounded-length augmentations. 3rd International Symposium on the Frontier of Graph Theory, Qinghai Normal University, Xining, China. April 2018.

  Sequential Metric Dimension (in trees). Seminarium Matematyka Dyskretna, AGH university, Kraków, Poland. November 2018.

  A Decompositional Approach to the 1-2-3 Conjecture. Seminar of the Department of Applied Mathematics, Northwestern Polytechnical University, Xi'an, China. May 2018.

  On partitioning graphs into connected subgraphs. Seminar of the School of Mathematical Sciences, Anhui University, Hefei, China. May 2018.

- Christelle Caillouet

  Optimization of mobile sensor coverage with UAVs. Workshop "L'Internet des Objets Industriels" (IIoT) of GDR RSD / ResCom and GDR MACS, Strasbourg, France, July 3, 2018.

- Frédéric Giroire

  Optimization of Network Infrastructures. Seminar of ETIS, University Cergy-Pontoise, France. November 2018.

- Frédéric Havet :

  Bispindles in strongly connected digraphs with large chromatic number. Graph Theory Meeting (GT 2018), Nyborg, Denmark, August 29 - September 1, 2018.

  Trees in tournaments. Journées Combinatoire Graphes et Algorithmes, Lyon, December 10-11, 2018.

- Nicolas Nisse

  When treewidth and treelength are equivalent: Seminar Xidian University, Xi'an, China, September 2018.

- Stéphane Pérennes, Luc Hogie, Michel Syska

  Parallel & Distributed Graph algorithms for large graphs, practical challenges: Atelier de programmation GRAMINEES in ANF APSEM2018 (Apprentissage et sémantique). November 2018.

9.1.5. Leadership within the Scientific Community

David Coudert

Member of the steering committee of *Pôle ResCom du GDR RSD du CNRS* since 2005, and co-chair since June 2017.

Frédéric Giroire

Member of the steering committee of *GT Energy of the GDR RSD du CNRS*.

Frédéric Havet :

Member of the steering committee of *GT Graphes of the GDR IM of CNRS*.

9.1.6. Scientific Expertise

- Jean-Claude Bermond

  Expert for DRTT-MESR Crédit impôt recherche (CIR et agréments).

- Frédéric Havet :

  Expert for ANR and NSERC (Canada)

- Nicolas Nisse

  Expert for ANR

  Expert for ODP (OPUS, Poland) 2018

  Expert for Millennium Science Initiative (Programme de financement chilien) (2018).

  Expert for ESF (European Science Foundation) 2018.

9.1.7. Research Administration

- Jean-Claude Bermond

  Responsible fo the cooperation between Inria and Greece (obtention of join grants and of financial support for internships via the Bodossakis Fundation).

- Christelle Caillouet

  Elected member of CPRH (Comité Permanent de Ressources Humaines) University of Nice Sophia Antipolis;

  Elected member of I3S laboratory committee since December 2016;

  Member of “Comité de Sélection” MCF 0403, Grenoble INP, 2018.

- David Coudert :

  Nominated member for Inria at the doctoral school STIC since September 2017;

  Member of the “Comité de Suivi Doctoral” of Inria (since 2009);

  Member of the scientific council of Academy RISE (Networks, Information, Digital Society) of UCA^{JEDI} till January 2018;

  Nominated member for Inria at the steering committee of Academy RISE (Networks, Information, Digital Society) of UCA^{JEDI} and EUR DS4H since Fébruary 2018;

  Member of “Comité de Sélection” 4109 - 0074 - PR 27 STS, Université d’Avignon et des Pays de Vaucluse, 2018.

  Member of “Comité de Sélection” 27 Pr 519, Université Nice - Sophia Antipolis, 2018;

- Frédéric Giroire :

  In charge of the internships of stream UbiNet of Master 2 IFI, UNS.

- Frédéric Havet :

  Head of COMRED team of I3S laboratory.
- Nicolas Nisse

  Elected member of Comité de Centre, Inria Sophia Antipolis since 2016

  Membre du CS Académie 1 UCA
- Michel Syska

  Elected member of CPRH (Comité Permanent de Ressources Humaines) University of Nice-Sophia Antipolis;

9.2. Teaching - Supervision - Juries

9.2.1. Teaching responsibilities

- Julien Bensmail

  In charge of the internships of first year students of QLIO département of IUT Nice Côte d'Azur.
- Joanna Moulierac

  "Directrice d'études" for the 1st-year students du 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).

9.2.2. Teaching

- Julien Bensmail

  Sécurité des systèmes d'information, 36h ETD, Level LP, IUT Nice Côte d'Azur, UNS;

  Recherche opérationnelle, 82h ETD, Level L2, IUT Nice Côte d'Azur, UNS;

  Systèmes de gestion de bases de données, 86h ETD, Level L2, IUT Nice Côte d'Azur, UNS.
- Christelle Caillouet

  Programmation Orientée Objet, 96h ETD, Level L1, IUT Nice Côte d'Azur, UNS;
- David Coudert

  Algorithms for Telecoms, 32h ETD, stream UbiNet of Master 2 IFI and Master RIF, UNS.
- Frédéric Giroire

  Algorithmics of Telecommunications, 18h ETD, stream UbiNet of Master 2 IFI, UNS;

  Data Mining for Networks, 18h ETD, stream UbiNet of Master 2 IFI, UNS;

  Introduction to probability and statistics, 15h ETD, International Master 1, UNS.
- Joanna Moulierac

  Introduction à l'algorithmique, 30h ETD, Level L1, IUT Nice Côte d'Azur, UNS;

  Introduction aux Réseaux, 60h ETD, Level L1, IUT Nice Côte d'Azur, UNS;

  Programmation répartie, 40h ETD, Level L1, IUT Nice Côte d'Azur, UNS.

  Réseaux avancés, 60h ETD, Level L2, IUT Nice Côte d'Azur, UNS;

  Compléments d'algorithmique, 30h ETD, Level L2, IUT Nice Côte d'Azur, UNS.
- Nicolas Nisse

  Graph Algorithms and Combinatorial Optimization, 18 ETD, Master 2, parcours Ubinet master IFI, UNS;

  Informatique théorique, 24 ETD, MPSI, classe préparatoire, CIV, Valbonne;

- Stéphane Pérennes

  Java pour le Calcul Ditribué et Concurrent, 60 h ETD Level : Master MIAGE Univ. Nice Côte d'Azur, UNS;
- Michel Syska

  Operating Systems: Advanced Programming, 28h ETD, Level L2, IUT Nice Côte d'Azur, UNS;

  Data Structures and Algorithms, 40h ETD, Level L2, IUT Nice Côte d'Azur, UNS;

  Algorithmics, 52h ETD, Level L2, IUT Nice Côte d'Azur, UNS;

  Distributed Programming, 58h ETD, Level L2, IUT Nice Côte d'Azur, UNS;

9.2.3. Supervision

9.2.3.1. PhD thesis

PhD: William Lochet, *Substructures in digraphs* [2], Université Côte d'Azur, July 19, 2018. Co-supervisors: Frédéric Havet and Stéphan Thomassé (ÉNS Lyon).

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: Brieuc Berruet, *Application des techniques de Machine Learning à la géolocalisation des objets connectés dans le contexte de la future 5G*, doctorale school SPIM, Université de Belfort Franche Comté, since November 2016. Supervisor: Alexandre Caminada and Oumaya Baala (Orange).

PhD in progress: Giuseppe di Lena, *Resilience of virtualized networks*, since April 2018. Co-supervisors: Thierry Turletti (DIANA), Chidung Lac (Orange Labs Lannion) and Frédéric Giroire.

PhD in progress: Adrien Gausseran, *Optimization Algorithms for Network Slicing for 5G*, since October 2018. Supervisors: Joanna Moulierac and Nicolas Nisse.

PhD in progress: Mehdi Katranji, *Utilisation des méthodes de Machine Learning pour apprendre les modèles de mobilité humaine selon leurs attibuts socio-démographiques et géographiques*, doctorale school SPIM, Université de Belfort Franche Comté, since September 2016. Supervisor: Alexandre Caminada and Fouad Hadjselem (Orange).

PhD in progress: Fionn McInerney, *Combinatorial Games in Graphs*, since October 2016. Supervisor: Nicolas Nisse.

PhD in progress: Andrea Tomassilli, *Diffusion of information on large dynamic graphs*, since October 2016. Supervisors: Stéphane Pérennes and Frédéric Giroire.

PhD in progress: Thibaud Trolliet, *Exploring Trust on Twitter*, since October 2017. Co-supervisors: Arnaud Legout (DIANA) and Frédéric Giroire.

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 Mazauric (ABS).

9.2.3.2. Internships

- Eleni Batziou

  Date: from November 2017 until May 2018

  Institution: Master 2, National Technical University of Athens (Greece)

  Supervisors: David Coudert and Nicolas Nisse

  Subject: Enhancing urban mobility with shared on-demand services
- Florent Cabret

  Date: from April 2018 until June 2018

  Institution: DUT 2, IUT, Université Nice Sophia Antipolis

Supervisors: Luc Hogie and Michel Syska

Subject: Evaluation of Jmaxgraph, a distributed computing framework on large graphs

- Théo Frasquet

  Date: from July 2018 until August 2018

  Institution: SI4, Polytech'Nice, France

  Supervisors: David Coudert

  Subject: Decomposing a digraph into k-strongly connected components

- Adrien Gausseran

  Date: from March 2018 until september 2018

  Institution: Master 2 RIF, Université Nice Sophia Antipolis

  Supervisors: Frédéric Giroire and Joanna Moulierac

  Subject: Optimization Algorithms for Network Slicing for 5G

- Thibault Hilaire

  Date: from June-July 2018

  Institution: L3, ENS Saclay

  Supervisor: Nicolas Nisse

  Subject: Polynomial algorithm for connected graph searching.

- Allen Passos Ibiapina

  Date: from October 15 until December 14 2018

  Institution: Master 2, UFC Fortaleza, Brazil

  Supervisor: Frédéric Havet

  Subject: Constrained ear decompositions in graphs and digraphs.

- Badr Jouhar

  Date: from March 2018 until August 2018

  Institution: stream UbiNet of Master 2 IFI

  Supervisors: Frédéric Giroire and Andrea Tomassilli

  Subject: Joint optimization of network and data centers

- Thi-Viet-Ha Nguyen

  Date: from January 2018 until June 2018

  Institution: Master 2, ENS Lyon.

  Supervisors: Frédéric Havet, Dorian Mazauric (ABS) and Rémi Watrigant (ENS Lyon)

  Subject: Overlaying a hypergraph by graph families with bonded maximum degree.

- Meghana M. Reddy

  Date: from May 2018 until August 2018

  Institution: Master at IIIT-Bangalore, India

  Supervisors: David Coudert

  Subject: implementation of a linear time algorithms for decomposing a graph into 3-connected components in Sagemath. In the context of the Google Summer of Code (GSoC).

- Alexandre Simon

  Date: from June-July 2018

  Institution: L3, INSA Lyon

Supervisor: Nicolas Nisse

Subject: Treelength des graphes planaires.

- Sai Harsh Tondomker

  Date: from May 2018 until August 2018

  Institution: Master at IIIT-Hyderabad, India

  Supervisors: David Coudert

  Subject: implementation of algorithms for decomposing a graph into 3-connected components and organizing these components as a SPQR-tree in Sagemath. In the context of the Google Summer of Code (GSoC).

- Xuchun Zhang

  Date: from July 2018 until September 2018

  Institution: Master 1 MAM, Université de Nice Sophia Antipolis

  Supervisors: Jean-Baptiste Caillau, Enzo Giusti (Oui!Greens startup), Dorian Mazauric and Joanna Moulierac

  Subject: Optimal Assignment Problem for Oui!Greens

- Yin Zhuochao

  Date: from March 2018 until August 2018

  Institution: stream UbiNet of Master 2 IFI, UNS

  Supervisors: David Coudert and Nicolas Nisse

  Subject: On the pickup-and-delivery problem with time window

- Mykhailo Zima

  Date: from March 2018 until August 2018

  Institution: stream UbiNet of Master 2 IFI, UNS

  Supervisors: David Coudert and Nicolas Nisse

  Subject: Routing in multimodal networks with bicycles

9.2.4. Juries

- Jean-Claude Bermond :

  Member of the HDR jury of Ignasi Sau Valls, LIRMM, Montpellier, June 25 2018;

  President of the PhD prize committee *prix de thèse Graphes "Charles Delorme"* http://gtgraphes.labri.fr/pmwiki/pmwiki.php/PrixTheseDelorme/PrixTheseDelorme

- Christelle Caillouet :

  Member of the PhD jury of Alassanne Samba, IMT Atlantique, October 29, 2018;

- David Coudert :

  President of the PhD jury of Jianding Guo, Université de Technologie de Belfort-Montbéliard, June 6, 2018;

  President of the PhD jury of Mohammed Amine Ait Ouahmed, Université d'Avignon et des Pays de Vaucluse, October 15, 2018;

  Referee and member of HDR committee of Fen Zhou, Université d'Avignon et des Pays de Vaucluse, September 28, 2018;

  External referee in the PhD thesis monitoring committee of Karyna Gogunska, Université Côte d'Azur, March 19, 2018;

- Frédéric Giroire :

Invited member of the PhD jury of Marwa Dammak, ENSEA, Cergy-Pontoise, November 20, 2018;

- Frédéric Havet :

  Referee and member of PhD committee of Antoine Dailly, Université Lyon 1, September 2018.

  Referee and member of PhD committee of Tien-Nam Le, ENS Lyon, November 2018.

  Member of PhD committee of Leo Planche, Université Paris Descartes, November 2018.

  Referee and member of HDR committee of Laurent Beaudou, Université Clermont-Auvergne, December 2018.

  Referee and member of PhD committee of Tilde Nielsen, Southern Denmark University, Odense, Denmark, December 2018.

9.3. Popularization

9.3.1. Internal or external Inria responsibilities

- Frédéric Havet :

  Vice-president and member of the scientific committee of the association Institut Esope 21 (http://www.esope21.eu).

- Nicolas Nisse:

  Membre de Mastic (Médiation et Animation scientifiques Inria Sophia Antipolis - Méditerranée).

9.3.2. Education

- Frédéric Havet, Joanna Moulierac and Nicolas Nisse : Participation to Galejade projet.

  Design of pedagogical resources introducing graphs and algorithms to primary school students.

  Training of primary school teachers, ESPE April 9-10 2018.

9.3.3. Interventions

- Fête de la Science (Frédéric Havet, Nicolas Nisse, Fionn Mc Inerney, Ali Al Zoobi)

  Journée portes ouvertes, Inria Sophia Antipolis, Sunday October 7, 2018.

  Palais des Congrès de Juan-Les-Pins, October 20-21, 2018.

  Collège de Vinon-sur-Verdon (83), October 9-12, 2018.

- Frédéric Havet, Joanna Moulierac, and Nicolas Nisse

  Participation to the supervision of the internships of 12 pupils of 3eme, December 17-21, 2018.

- Frédéric Havet

  L'élégance des Mathématiques. Conference at Lycée Janetti, St Maximin, February 16, 2018. Audience: 3 classes (1e S and ES).

  La magie des graphes et du binaire. Conference at collège Alphonse Daudet, Nice, April 17, 2018. Audience: 2 classes of 4e and 1 of 6e.

  L'élégance des mathématiques. General audience conference, Rians, Var, France, April 28, 2018.

- Nicolas Nisse

  Training and awareness of school teachers (Cycle 2, CP-CE2) to scientific mediation. Le Cannet, November 21 and Mandelieu, November 28, 2018.

Training and awareness of future teachers to scientific mediation, Ecole Supérieure du Professorat et de l'Education (ESPE, ex IUFM) of Académie de Nice. March 19-20 and April 9-10, 2018.

Liens entre médiation numérique et recherche, Maison méditerranéenne des Sciences de l'homme (MMSH), Aix en Provence, March 14, 2018.

Mediation for the Master en science de l'éducation, Nice, October 18, 2018.

- Fionn Mc Inerney :

  Presentation at Collège Victor Hugo, Nevers, France, March 23, 2018.

  Participation in the day "*L'informatique, c'est pas génétique, filles ou garçons, les clics sont identiques!*", Lycée Raoul Follereau, Nevers, France, March 22, 2018.

  Presentation at Ecole Primaire Romain Rolland, Varennes-Vauzelles, France, March 21, 2018.

  Supervised internship of a school girl in 2nd, Inria Sophia-Antipolis - Méditerranée, France, June 18-22, 2018.

- Michel Syska :

  Organisation and supervision of the code competition "*La nuit de l'info*", December 6-7, 2018.

10. Bibliography

Publications of the year

Doctoral Dissertations and Habilitation Theses

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[2] W. LOCHET. *Substructure in digraphs*, Universite cote d'Azur, July 2018, https://hal.archives-ouvertes.fr/tel-01957030

Articles in International Peer-Reviewed Journals

[3] P. ABOULKER, J. BANG-JENSEN, N. BOUSQUET, P. CHARBIT, F. HAVET, F. MAFFRAY, J. ZAMORA. *χ-bounded families of oriented graphs*, in "Journal of Graph Theory", September 2018, vol. 89, n^o^ 3, pp. 304 - 326 [*DOI :* 10.1002/JGT.22252], https://hal.inria.fr/hal-01882395

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[12] J. BENSMAIL, N. BRETTELL. *Orienting edges to fight fire in graphs*, in "The Australasian Journal of Combinatorics", March 2018, vol. 71, n^{o} 1, pp. 12-42, https://hal.archives-ouvertes.fr/hal-01166577

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