IN PARTNERSHIP WITH:
CNRS

Université Denis Diderot (Paris 7)

Activity Report 2019

Project-Team GANG

Networks, Graphs and Algorithms

IN COLLABORATION WITH: Institut de Recherche en Informatique Fondamentale

RESEARCH CENTER
Paris

THEME
Networks and Telecommunications

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Creation of the Project-Team: 2007 July 01

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1. Team, Visitors, External Collaborators

Research Scientists

Laurent Viennot [Team leader, Inria, Senior Researcher, HDR]
Pierre Fraigniaud [CNRS, Senior Researcher, HDR]
Amos Korman [CNRS, Researcher, HDR]
Adrian Kosowski [Inria, Researcher, until Sep 2019, HDR]

Faculty Members

Michel Habib [Paris University, Professor emeritus, HDR]
Yacine Boufkhad [Univ Denis Diderot, Associate Professor]
Pierre Charbit [Univ Denis Diderot, Associate Professor]
Fabien de Montgolfier [Univ Denis Diderot, Associate Professor]
Hugues Fauconnier [Univ Denis Diderot, Associate Professor, HDR]
Carole Gallet Delporte [Univ Denis Diderot, Professor, HDR]

PhD Students

Mengchuan Zou [Inria, PhD Student, until Nov 2019]
Simon Collet [ERC BDA, PhD Student, until Nov 2019]
Brieuc Guinard [ERC BDA, PhD Student]
Zeinab Nehaïï [Université Paris Diderot, PhD Student]

Intern and Apprentice

Antonin Decimo [Inria, from Mar 2019 until Aug 2019]

Administrative Assistants

Christine Anocq [Inria, Administrative Assistant]

Nelly Maloisel [Inria, Administrative Assistant]

2. Overall Objectives

2.1. Overall Objectives

GANG focuses on algorithm design for large scale networks using structural properties of these networks. Application domains include the development of optimized protocols for large dynamic networks such as mobile networks or overlay networks over Internet. This includes for instance peer-to-peer applications, or the navigability of social networks. GANG tools come from recent advances in the field of graph algorithms, both in centralized and distributed settings. In particular, this includes graph decomposition and geometric properties (such as low doubling dimension, low dimension embedding, etc.). Today, the management of large networks, Internet being the reference, is best effort. However, the demand for mobility (ad hoc networks, wireless connectivity, etc.) and for dynamicity (node churn, fault tolerance, etc.) is increasing. In this distributed setting, it becomes necessary to design a new generation of algorithms and protocols to face the challenge of large scale mobility and dynamicity. In the mean time, recent and sophisticated theoretical results have emerged, offering interesting new tracks for managing large networks. These results concern centralized and decentralized algorithms for solving key problems in communication networks, including routing, but also information retrieval, localization, or load balancing. They are mainly based on structural properties observed in most of real networks: approximate topology with low dimension metric spaces, low treewidth, low doubling dimension, graph minor freeness, etc. In addition, graph decomposition techniques have recently progressed. The scientific community has now tools for optimizing network management. First striking results include designing overlay networks for peer-to-peer systems and understanding the navigability of large social networks.

3. Research Program

3.1. Graph and Combinatorial Algorithms

We focus on two approaches for designing algorithms for large graphs: decomposing the graph and relying on simple graph traversals.

3.1.1. Graph Search

We more deeply study multi-sweep graph searches. In this domain a graph search only yields a total ordering of the vertices which can be used by the subsequent graph searches. This technique can be used on huge graphs and does not need extra memory. We have already obtained preliminary results in this direction and many well-known graph algorithms can be put in this framework. The idea behind this approach is that each sweep discovers some structure of the graph. At the end of the process either we have found the underlying structure (for example an interval representation for an interval graph) or an approximation of it (for example in hard discrete optimization problems). We envision applications to exact computations of centers in huge graphs, to underlying combinatorial optimization problems, but also to networks arising in biology.

3.1.2. Graph Decomposition

In order to summarize a graph into a more compact and more human-readable form, we introduced the hub-laminar decomposition. It is suitable for graphs that are dominated by long isometric cycles or shortest paths, called laminar, which meet only at their extremities, called hubs. Computing this decomposition is NP-hard but a canonical approximation may be computed under some hypotheses on the distances between hubs. It provides a distance labelling for the decomposable graphs. We also investigated the case were the decomposition is reduced to a single cycle, yielding the problem of fining the longest isometric cycle, which is NP-complete and for which a first approximation algorithm was proposed in ENTCS.

3.1.3. Graph Exploration

In the course of graph exploration, a mobile agent is expected to regularly visit all the nodes of an unknown network, trying to discover all its nodes as quickly as possible. Our research focuses on the design and analysis of agent-based algorithms for exploration-type problems, which operate efficiently in a dynamic network environment, and satisfy imposed constraints on local computational resources, performance, and resilience. Our recent contributions in this area concern the design of fast deterministic algorithms for teams of agents operating in parallel in a graph, with limited or no persistent state information available at nodes. We plan further studies to better understand the impact of memory constraints and of the availability of true randomness on efficiency of the graph exploration process.

3.2. Distributed Computing

The distributed computing community can be viewed as a union of two sub-communities. This is also true in our team. Although they have interactions, they are disjoint enough not to leverage each other's results. At a high level, one is mostly interested in timing issues (clock drifts, link delays, crashes, etc.) while the other one is mostly interested in spatial issues (network structure, memory requirements, etc.). Indeed, one sub-community is mostly focusing on the combined impact of asynchronism and faults on distributed computation, while the other addresses the impact of network structural properties on distributed computation. Both communities address various forms of computational complexity, through the analysis of different concepts. This includes, e.g., failure detectors and wait-free hierarchy for the former community and compact labeling schemes, and computing with advice for the latter community. We have an ambitious project to achieve the reconciliation between the two communities by focusing on the same class of problems, the yes/no-problems, and establishing the scientific foundations for building up a consistent theory of computability and complexity for distributed computing. The main question addressed is therefore: is the absence of globally coherent computational complexity theories covering more than fragments of distributed computing, inherent to the field? One issue is obviously the types of problems located at the core of distributed computing. Tasks like consensus, leader election, and broadcasting are of very different nature. They are not *yes-no* problems, neither are they minimization problems. Coloring and Minimal Spanning Tree are optimization problems but we are often more interested in constructing an optimal solution than in verifying the correctness of a given solution. Still, it makes full sense to analyze the *yes-no* problems corresponding to checking the validity of the output of tasks. Another issue is the power of individual computation. The FLP impossibility result as well as Linial's lower bound hold independently of the individual computational power of the involved computing entities. For instance, the individual power of solving NP-hard problems in constant time would not help overcoming these limits, which are inherent to the fact that computation is distributed. A third issue is the abundance of models for distributed computing frameworks, from shared memory to message passing, spanning all kinds of specific network structures (complete graphs, unit-disk graphs, etc.) and/or timing constraints (from complete synchronism to full asynchronism). There are however models, typically the wait-free model and the LOCAL model, which, though they do not claim to reflect accurately real distributed computing systems, enable focusing on some core issues. Our ongoing research program is to carry many important notions of Distributed Computing into a *standard* computational complexity.

3.3. Network Algorithms and Analysis

Based on our scientific expertise in both graph algorithms and distributed algorithms, we plan to analyze the behavior of various networks such as future Internet, social networks, overlay networks resulting from distributed applications or online social networks.

3.3.1. Information Dissemination

One of the key aspects of networks resides in the dissemination of information among the nodes. We aim at analyzing various procedures of information propagation from dedicated algorithms to simple distributed schemes such as flooding. We also consider various models, e.g. where noise can alter information as it propagates or where memory of nodes is limited.

3.3.2. Routing Paradigms

We try to explore new routing paradigms such as greedy routing in social networks for example. We are also interested in content centric networking where routing is based on content name rather than content address. One of our targets is multiple path routing: how to design forwarding tables providing multiple disjoint paths to the destination?

3.3.3. Beyond Peer-to-Peer

Based on our past experience of peer-to-peer application design, we would like to broaden the spectrum of distributed applications where new efficient algorithms can be designed and their analysis can be performed. We especially target online social networks as we see them as collaborative tools for exchanging information. A basic question resides in making the right connections for gathering filtered and accurate information with sufficient coverage.

3.3.4. SAT and Forwarding Information Verification

As forwarding tables of networks grow and are sometimes manually modified, the problem of verifying them becomes critical and has recently gained interest. Some problems that arise in network verification such as loop detection for example, may be naturally encoded as Boolean Satisfiability problems. Beside theoretical interest in complexity proofs, this encoding allows one to solve these problems by taking advantage of efficient Satisfiability testing solvers. Indeed, SAT solvers have proved to be very efficient in solving problems coming from various areas (Circuit Verification, Dependency and Conflicts in Software distributions...) and encoded in Conjunctive Normal Form. To test an approach using SAT solvers in network verification, one needs to collect data sets from a real network and to develop good models for generating realistic networks. The technique of encoding and the solvers themselves need to be adapted to this kind of problems. All this represents a rich experimental field of future research.

3.3.5. Network Analysis

Finally, we are interested in analyzing the structural properties of practical networks. This can include diameter computation or ranking of nodes. As we mostly consider large networks, we are often interested in efficient heuristics. Ideally, we target heuristics that give exact answers and are reasonably fast in practice although short computation time is not guaranteed for all networks. We have already designed such heuristics for diameter computation; understanding the structural properties that enable short computation time in practice is still an open question.

3.3.6. Network Parameter

Betweenness centrality is a graph parameter that has been successfully applied to network analysis. In the context of computer networks, it was considered for various objectives, ranging from routing to service placement. However, as observed by Maccari et al. [INFOCOM 2018], research on betweenness centrality for improving protocols was hampered by the lack of a usable, fully distributed algorithm for computing this parameter. In [21], we resolved this issue by designing an efficient algorithm for computing betweenness centrality, which can be implemented by minimal modifications to any distance-vector routing protocol based on Bellman-Ford. The convergence time of our implementation is shown to be proportional to the diameter of the network.

4. Application Domains

4.1. Large scale networks

Application domains include evaluating Internet performances, the design of new peer-to-peer applications, enabling large scale networks, and developping tools for transportation networks.

5. Highlights of the Year

5.1. Highlights of the Year

5.1.1. Awards

Amos Korman won the 2020 prize of innovations in distributed computing.

Pierre Fraigniaud and his co-authors obtained the best paper award at SSS 2019:

BEST PAPER AWARD:

[19]
A. CASTAÑEDA, P. FRAIGNIAUD, A. PAZ, S. RAJSBAUM, M. ROY, C. TRAVERS. *Synchronous t-Resilient Consensus in Arbitrary Graphs*, in "SSS 2019 - 21st International Symposium on Stabilization, Safety, and Security of Distributed Systems", Pisa, Italy, October 2019 [*DOI :* 10.1007/978-3-030-34992-9_5], https://hal.inria.fr/hal-02433524

6. New Software and Platforms

6.1. big-graph-tools

KEYWORD: Graph algorithmics

FUNCTIONAL DESCRIPTION: Gang is developping a software for big graph manipulation. A preliminary library offering diameter and skeleton computation. This library was used to compute the diameters of the worldwide road network (200M edges) and the largest strongly connected component of the Twitter follower-followee graph (23G edges).

- Contact: Laurent Viennot
- URL: https://who.rocq.inria.fr/Laurent.Viennot/dev/big-graph-tools/

6.2. 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/

7. New Results

7.1. Graph and Combinatorial Algorithms

7.1.1. Fast Diameter Computation within Split Graphs

When can we compute the diameter of a graph in quasi linear time? In [22], we address this question for the class of *split graphs*, that we observe to be the hardest instances for deciding whether the diameter is at most two. We stress that although the diameter of a non-complete split graph can only be either 2 or 3, under the Strong Exponential-Time Hypothesis (SETH) we cannot compute the diameter of a split graph in less than quadratic time. Therefore it is worth to study the complexity of diameter computation on *subclasses* of split graphs, in order to better understand the complexity border. Specifically, we consider the split graphs with bounded *clique-interval number* and their complements, with the former being a natural variation of the concept of interval number for split graphs that we introduce in this paper. We first discuss the relations between the clique-interval number and other graph invariants such as the classic interval number of graphs, the treewidth, the *VC-dimension* and the *stabbing number* of a related hypergraph. Then, in part based on these above relations, we almost completely settle the complexity of diameter computation on these subclasses of split graphs:

- For the k-clique-interval split graphs, we can compute their diameter in truly subquadratic time if $k = \mathcal{O}(1)$, and even in quasi linear time if $k = o(\log n)$ and in addition a corresponding ordering is given. However, under SETH this cannot be done in truly subquadratic time for any $k = \omega(\log n)$.
- For the *complements* of k-clique-interval split graphs, we can compute their diameter in truly subquadratic time if $k = \mathcal{O}(1)$, and even in time $\mathcal{O}(km)$ if a corresponding ordering is given. Again this latter result is optimal under SETH up to polylogarithmic factors.

Our findings raise the question whether a k-clique interval ordering can always be computed in quasi linear time. We prove that it is the case for $k = 1$ and for some subclasses such as bounded-treewidth split graphs, threshold graphs and comparability split graphs. Finally, we prove that some important subclasses of split graphs – including the ones mentioned above – have a bounded clique-interval number.

7.1.2. Diameter computation on H-minor free graphs and graphs of bounded (distance) VC-dimension

Under the Strong Exponential-Time Hypothesis, the diameter of general unweighted graphs cannot be computed in truly subquadratic time. Nevertheless there are several graph classes for which this can be done such as bounded-treewidth graphs, interval graphs and planar graphs, to name a few. We propose to study unweighted graphs of constant *distance VC-dimension* as a broad generalization of many such classes – where the distance VC-dimension of a graph G is defined as the VC-dimension of its ball hypergraph: whose hyperedges are the balls of all possible radii and centers in G. In particular for any fixed H, the class of H-minor free graphs has distance VC-dimension at most $|V(H)| - 1$. In [23], we show the following.

- Our first main result is a Monte Carlo algorithm that on graphs of distance VC-dimension at most d, for any fixed k, either computes the diameter or concludes that it is larger than k in time $\widetilde{\mathcal{O}}(k \cdot mn^{1-\varepsilon_d})$, where $\varepsilon_d \in (0;1)$ only depends on d. We thus obtain a *truly subquadratic-time parameterized* algorithm for computing the diameter on such graphs.
- Then as a byproduct of our approach, we get the first truly subquadratic-time randomized algorithm for *constant* diameter computation on all the *nowhere dense* graph classes. The latter classes include all proper minor-closed graph classes, bounded-degree graphs and graphs of bounded expansion.
- Finally, we show how to remove the dependency on k for *any* graph class that excludes a fixed graph H as a minor. More generally, our techniques apply to any graph with constant distance VC-dimension and *polynomial expansion* (or equivalently having strongly sublinear balanced separators). As a result for all such graphs one obtains a truly subquadratic-time randomized algorithm for computing their diameter.

We note that all our results also hold for *radius* computation. Our approach is based on the work of Chazelle and Welzl who proved the existence of spanning paths with strongly sublinear *stabbing number* for every hypergraph of constant VC-dimension. We show how to compute such paths efficiently by combining known algorithms for the stabbing number problem with a clever use of ε-nets, region decomposition and other partition techniques.

7.1.3. Approximation of eccentricites and distance using δ-hyperbolicity

In [9], we show that the eccentricities of all vertices of a δ-hyperbolic graph $G = (V, E)$ can be computed in linear time with an additive one-sided error of at most $c \cdot \delta$, i.e., after a linear time preprocessing, for every vertex v of G one can compute in $O(1)$ time an estimate $\overline{ecc_G(v)}$ of its eccentricity $ecc_G(v) := max\{d_G(u, v) : u \in V\}$ such that $ecc_G(v) \leq \overline{ecc_G(v)} \leq ecc_G(v) + c \cdot \delta$ for a small constant c. We prove that every δ-hyperbolic graph G has a shortest path tree T, constructible in linear time, such that for every vertex v of G, $ecc_G(v) \leq ecc_T(v) \leq ecc_G(v) + c \cdot \delta$, where $ecc_T(v) := max\{d_T(u, v) : u \in V\}$. These results are based on an interesting monotonicity property of the eccentricity function of hyperbolic graphs: the closer a vertex is to the center of G, the smaller its eccentricity is. We also show that the distance matrix of G with an additive one-sided error of at most $c' \cdot \delta$ can be computed in $O(|V|^2 log^2|V|)$ time, where $c' < c$ is a small constant. Recent empirical studies show that many real world graphs (including Internet application networks, web networks, collaboration networks, social networks, biological networks, and others) have small hyperbolicity. So, we analyze the performance of our algorithms for approximating eccentricities and distance matrix on a number of real-world networks. Our experimental results show that the obtained estimates are even better than the theoretical bounds.

7.1.4. Graph and Hypergraph Decompositions

In [26], we study modular decomposition of hypergraphs and propose some polynomial algorithms to this aim. We also study several notions of approximation of modular decomposition of graphs, by relaxing the definition of modules introducing a tolerance (ϵ edges can miss) this will be presented at CALDAM 2020, Hyderabad. Both topics can be seen as the search for new models of regularity in discrete structures, as in particular bipartite graphs. In both references our polynomial algorithms have to be improved before being applied on real-world data.

7.2. Distributed Computing

7.2.1. Distributed Interactive Proofs

In a distributed locally-checkable proof, we are interested in checking the legality of a given network configuration with respect to some Boolean predicate. To do so, the network enlists the help of a *prover* — a computationally-unbounded oracle that aims at convincing the network that its state is legal, by providing the nodes with certificates that form a distributed proof of legality. The nodes then verify the proof by examining their certificate, their local neighborhood and the certificates of their neighbors.

In [24], we examine the power of a *randomized* form of locally-checkable proof, called *distributed Merlin-Arthur protocols*, or dMA for short. In a dMA protocol, the prover assigns each node a short certificate, and the nodes then exchange *random messages* with their neighbors. We show that while there exist problems for which dMA protocols are more efficient than protocols that do not use randomness, for several natural problems, including Leader Election, Diameter, Symmetry, and Counting Distinct Elements, dMA protocols are no more efficient than standard nondeterministic protocols. This is in contrast with Arthur-Merlin (dAM) protocols and Randomized Proof Labeling Schemes (RPLS), which are known to provide improvements in certificate size, at least for some of the aforementioned properties.

The study of interactive proofs in the context of distributed network computing is a novel topic, recently introduced by Kol, Oshman, and Saxena [PODC 2018]. In the spirit of sequential interactive proofs theory, we study in [20] the power of distributed interactive proofs. This is achieved via a series of results establishing trade-offs between various parameters impacting the power of interactive proofs, including the number of interactions, the certificate size, the communication complexity, and the form of randomness used. Our results also connect distributed interactive proofs with the established field of distributed verification. In general, our results contribute to providing structure to the landscape of distributed interactive proofs.

7.2.2. Topological Approach of Network Computing

More than two decades ago, combinatorial topology was shown to be useful for analyzing distributed fault-tolerant algorithms in shared memory systems and in message passing systems. In [18], we show that combinatorial topology can also be useful for analyzing distributed algorithms in networks of arbitrary structure. To illustrate this, we analyze consensus, set-agreement, and approximate agreement in networks, and derive lower bounds for these problems under classical computational settings, such as the LOCAL model and dynamic networks.

In [19], we study the number of rounds needed to solve consensus in a synchronous network G where at most t nodes may fail by crashing. This problem has been thoroughly studied when G is a complete graph, but very little is known when G is arbitrary. We define a notion of radius that considers all ways in which t nodes may crash, and present an algorithm that solves consensus in radius rounds. Then we derive a lower bound showing that our algorithm is optimal for vertex-transitive graphs, among oblivious algorithms.

7.2.3. Making Local Algorithms Wait-Free

When considering distributed computing, reliable message-passing synchronous systems on the one side, and asynchronous failure-prone shared-memory systems on the other side, remain two quite independently studied ends of the reliability/asynchrony spectrum. The concept of locality of a computation is central to the first one, while the concept of wait-freedom is central to the second one. In [8], we propose a new DECOUPLED model in an attempt to reconcile these two worlds. It consists of a synchronous and reliable communication graph of nodes, and on top a set of asynchronous crash-prone processes, each attached to a communication node. To illustrate the DECOUPLED model, the paper presents an asynchronous 3-coloring algorithm for the processes of a ring. From the processes point of view, the algorithm is wait-free. From a locality point of view, each process uses information only from processes at distance $O(log^*n)$ from it. This local wait-free algorithm is based on an extension of the classical Cole and Vishkin's vertex coloring algorithm in which the processes are not required to start simultaneously.

In [31], we show that, for any task T associated to a locally checkable labeling (lcl), if T is solvable in t rounds by a deterministic algorithm in the local model, then T remains solvable by a deterministic algorithm in $O(t)$ rounds in an asynchronous variant of the local model whenever $t = O(polylogn)$.

7.2.4. Towards Synthesis of Distributed Algorithms with SMT Solvers

In [32], we consider the problem of synthesizing distributed algorithms working on a specific execution context. We show it is possible to use the linear time temporal logic in order to both specify the correctness of algorithms and their execution contexts. We then provide a method allowing to reduce the synthesis problem of finite state algorithms to some model-checking problems. We finally apply our technique to automatically generate algorithms for consensus and epsilon-agreement in the case of two processes using the SMT solver Z3.

7.2.5. On Weakest Failure Detector

Failure detectors are devices (objects) that provide the processes with information on failures. They were introduced to enrich asynchronous systems so that it becomes possible to solve problems (or implement concurrent objects) that are otherwise impossible to solve in pure asynchronous systems where processes are prone to crash failures. The most famous failure detector (which is called “eventual leader” and denoted Ω) is the weakest failure detector which allows consensus to be solved in n-process asynchronous systems where up to $t = n - 1$ processes may crash in the read/write communication model, and up to $t < n/2$ processes may crash in the message-passing communication model.

When looking at the mutual exclusion problem (or equivalently the construction of a lock object), while the weakest failure detectors are known for both asynchronous message-passing systems and read/write systems in which up to $t < n$ processes may crash, for the starvation-freedom progress condition, it is not yet known for weaker deadlock-freedom progress condition in read/write systems. In [34], we extend the previous results, namely, it presents the weakest failure detector that allows mutual exclusion to be solved in asynchronous n-process read/write systems where any number of processes may crash, whatever the progress condition (deadlock-freedom or starvation-freedom).

In read/read/write communication model, and in the message-passing communication model, all correct processes are supposed to participate in a consensus instance and in particular the eventual leader.

In [33], we considers the case where some subset of processes that do not crash (not predefined in advance) are allowed not to participate in a consensus instance. In this context Ω cannot be used to solve consensus as it could elect as eventual leader a non-participating process. This paper presents the weakest failure detector that allows correct processes not to participate in a consensus instance.This failure detector, denoted Ω^*, is a variant of Ω. The paper presents also an Ω^*-based consensus algorithm for the asynchronous read/write model, in which any number of processes may crash, and not all the correct processes are required to participate.

7.2.6. Multi-Round Cooperative Search Games with Multiple Players

We study search in the context of competing agents. The setting we consider combines game-theoretic concepts with notions related to parallel computing. Assume that a treasure is placed in one of M boxes according to a known distribution and that k searchers are searching for it in parallel during T rounds. In [27], we study the question of how to incentivize selfish players so that group performance would be maximized. Here, this is measured by the *success probability*, namely, the probability that at least one player finds the treasure. We focus on *congestion policies* $C(\ell)$ that specify the reward that a player receives if it is one of ℓ players that (simultaneously) find the treasure for the first time. Our main technical contribution is proving that the *exclusive policy*, in which $C(1) = 1$ and $C(\ell) = 0$ for $\ell > 1$, yields a *price of anarchy* of $\left(1 - (1 - 1/k)^k\right)^{-1}$, and that this is the best possible price among all symmetric reward mechanisms. For this policy we also have an explicit description of a symmetric equilibrium, which is in some sense unique, and moreover enjoys the best success probability among all symmetric profiles. For general congestion policies, we show how to polynomially find, for any $\theta > 0$, a symmetric multiplicative $(1 + \theta)(1 + C(k))$-equilibrium.

Together with an appropriate reward policy, a central entity can suggest players to play a particular profile at equilibrium. As our main conceptual contribution, we advocate the use of symmetric equilibria for such purposes. Besides being fair, we argue that symmetric equilibria can also become highly robust to crashes of players. Indeed, in many cases, despite the fact that some small fraction of players crash (or refuse to participate), symmetric equilibria remain efficient in terms of their group performances and, at the same time, serve as approximate equilibria. We show that this principle holds for a class of games, which we call *monotonously scalable* games. This applies in particular to our search game, assuming the natural *sharing policy*, in which $C(\ell) = 1/\ell$. For the exclusive policy, this general result does not hold, but we show that the symmetric equilibrium is nevertheless robust under mild assumptions.

7.3. Models and Algorithms for Networks

7.3.1. Exploiting Hopsets: Improved Distance Oracles for Graphs of Constant Highway Dimension and Beyond

For fixed $h \geq 2$, we consider in [25] the task of adding to a graph G a set of weighted shortcut edges on the same vertex set, such that the length of a shortest h-hop path between any pair of vertices in the augmented graph is exactly the same as the original distance between these vertices in G. A set of shortcut edges with this property is called an *exact h-hopset* and may be applied in processing distance queries on graph G. In particular, a 2-hopset directly corresponds to a distributed distance oracle known as a *hub labeling*. In this work, we explore centralized distance oracles based on 3-hopsets and display their advantages in several practical scenarios. In particular, for graphs of constant highway dimension, and more generally for graphs of constant skeleton dimension, we show that 3-hopsets require *exponentially* fewer shortcuts per node than any previously described distance oracle, and also offer a speedup in query time when compared to simple oracles based on a direct application of 2-hopsets. Finally, we consider the problem of computing minimum-size h-hopset (for any $h \geq 2$) for a given graph G, showing a polylogarithmic-factor approximation for the case of unique shortest path graphs. When $h = 3$, for a given bound on the space used by the distance oracle, we provide a construction of hopset achieving polylog approximation both for space and query time compared to the optimal 3-hopset oracle given the space bound.

7.3.2. Hardness of exact distance queries in sparse graphs through hub labeling

A *distance labeling scheme* is an assignment of bit-labels to the vertices of an undirected, unweighted graph such that the distance between any pair of vertices can be decoded solely from their labels. An important class of distance labeling schemes is that of *hub labelings*, where a node $v \in G$ stores its distance to the so-called hubs $S_v \subseteq V$, chosen so that for any $u, v \in V$ there is $w \in S_u \cap S_v$ belonging to some shortest uv path. Notice that for most existing graph classes, the best distance labelling constructions existing use at some point a hub labeling scheme at least as a key building block.

In [28], our interest lies in hub labelings of sparse graphs, i.e., those with $|E(G)| = O(n)$, for which we show a lowerbound of $\frac{n}{2^{O(\sqrt{\log n})}}$ for the average size of the hubsets. Additionally, we show a hub-labeling construction for sparse graphs of average size $O(\frac{n}{RS(n)^c})$ for some $0 < c < 1$, where $RS(n)$ is the so-called Ruzsa-Szemerédi function, linked to structure of induced matchings in dense graphs. This implies that further improving the lower bound on hub labeling size to $\frac{n}{2^{(\log n)^{o(1)}}}$ would require a breakthrough in the study of lower bounds on $RS(n)$, which have resisted substantial improvement in the last 70 years.

For general distance labeling of sparse graphs, we show a lowerbound of $\frac{1}{2^{\Theta(\sqrt{\log n})}} SumIndex(n)$, where $SumIndex(n)$ is the communication complexity of the Sum-Index problem over Z_n. Our results suggest that the best achievable hub-label size and distance-label size in sparse graphs may be $\Theta(\frac{n}{2^{(\log n)^c}})$ for some $0 < c < 1$.

7.3.3. Fast Public Transit Routing with Unrestricted Walking through Hub Labeling

In [30], we propose a novel technique for answering routing queries in public transportation networks that allows unrestricted walking. We consider several types of queries: earliest arrival time, Pareto-optimal journeys regarding arrival time, number of transfers and walking time, and profile, i.e. finding all Pareto-optimal journeys regarding travel time and arrival time in a given time interval. Our techniques uses hub labeling to represent unlimited foot transfers and can be adapted to both classical algorithms RAPTOR and CSA. We obtain significant speedup compared to the state-of-the-art approach based on contraction hierarchies. A research report version is deposited on HAL with number hal-02161283.

7.3.4. Independent Lazy Better-Response Dynamics on Network Games

In [29], we study an *independent* best-response dynamics on network games in which the nodes (players) decide to revise their strategies independently with some probability. We are interested in the *convergence time* to the equilibrium as a function of this probability, the degree of the network, and the potential of the underlying games.

7.3.5. A Comparative Study of Neural Network Compression

There has recently been an increasing desire to evaluate neural networks locally on computationally-limited devices in order to exploit their recent effectiveness for several applications; such effectiveness has nevertheless come together with a considerable increase in the size of modern neural networks, which constitute a major downside in several of the aforementioned computationally-limited settings. There has thus been a demand of compression techniques for neural networks. Several proposal in this direction have been made, which famously include hashing-based methods and pruning-based ones. However, the evaluation of the efficacy of these techniques has so far been heterogeneous, with no clear evidence in favor of any of them over the others. In [36], we address this latter issue by providing a comparative study. While most previous studies test the capability of a technique in reducing the number of parameters of state-of-the-art networks , we follow [CWT + 15] in evaluating their performance on basic architectures on the MNIST dataset and variants of it, which allows for a clearer analysis of some aspects of their behavior. To the best of our knowledge, we are the first to directly compare famous approaches such as HashedNet, Optimal Brain Damage (OBD), and magnitude-based pruning with L1 and L2 regularization among them and against equivalent-size feed-forward neural networks with simple (fully-connected) and structural (convolutional) neural networks. Rather surprisingly, our experiments show that (iterative) pruning-based methods are substantially better than the HashedNet architecture, whose compression doesn't appear advantageous to a carefully chosen convolutional network. We also show that, when the compression level is high, the famous OBD pruning heuristics deteriorates to the point of being less efficient than simple magnitude-based techniques.

8. Partnerships and Cooperations

8.1. National Initiatives

8.1.1. ANR DESCARTES

Participants: Carole Gallet Delporte, Hugues Fauconnier, Pierre Fraigniaud, Adrian Kosowski, Laurent Viennot.

Cyril Gavoille (U. Bordeaux) leads this project that grants 1 Post-Doc. H. Fauconnier is the local coordinator (This project began in October 2016).

Despite the practical interests of reusable frameworks for implementing specific distributed services, many of these frameworks still lack solid theoretical bases, and only provide partial solutions for a narrow range of services. We argue that this is mainly due to the lack of a generic framework that is able to unify the large body of fundamental knowledge on distributed computation that has been acquired over the last 40 years. The DESCARTES project aims at bridging this gap, by developing a systematic model of distributed computation that organizes the functionalities of a distributed computing system into reusable modular constructs assembled via well-defined mechanisms that maintain sound theoretical guarantees on the resulting system. DESCARTES arises from the strong belief that distributed computing is now mature enough to resolve the tension between the social needs for distributed computing systems, and the lack of a fundamentally sound and systematic way to realize these systems.

8.1.2. ANR MultiMod

Participants: Adrian Kosowski, Laurent Viennot.

David Coudert (Sophia Antipolis) leads this project. L. Viennot coordinates locally. The project began in 2018.

The MultiMod project aims at enhancing the mobility of citizens in urban areas by providing them, through a unique interface enabling to express their preferences, the most convenient transportation means to reach their destinations. Indeed, the increasing involvement of actors and authorities in the deployment of more responsible and cost-effective logistics and the progress made in the field of digital technology have made possible to create synergies in the creation of innovative services for improving the mobility in cities. However, users are faced with a number of solutions that coexist at different scales, providing complementary information for the mobility of users, but that make very complex to find the most convenient itinerary at a given time for a specific user. In this context, MultiMod aims at improving the mobility of citizens in urban areas by proposing contextualized services, linking users, to facilitate multimodal transport by combining, with flexibility, all available modes (planned/dynamic carpooling, public transport (PT), car-sharing, bicycle, etc.).

We consider the use of carpooling in metropolitan areas, and so for short journeys. Such usage enables itineraries that are not possible with PT, allows for opening up areas with low PT coverage by bringing users near PT (last miles), and for faster travel-time when existing PT itineraries are too complex or with too low frequency (e.g., one bus per hour). In this context, the application must help the driver and the passenger as much as possible. In particular, the application must propose the meeting-point, indicate the driver the detour duration, and indicate the passenger how to reach this meeting-point using PT. Here, the time taken by drivers and passengers to agree becomes a critical issue and so the application must provide all needed information to quickly take a decision (i.e., in one click).

In addition, the era of Smart City gathers many emerging concepts, driven by innovative technological players, which enables the exploitation of real-time data (e.g., delay of a bus, traffic jam) made available by the various actors (e.g., communities in the framework of Open Data projects, users via their mobile terminals, traffic supervision authorities). In the MultiMod project, we will use these rich sources of data to propose itineraries that are feasible at query-time. Our findings will enable the design of a mobility companion able not only to guide the user along her journey, including when and how to change of transportation mean, but also to propose itinerary changes when the current one exceeds a threshold delay. The main originality of this project is thus to address the problem of computing itineraries in large-scale networks combining PT, carpooling and real-time data, and to satisfy the preferences of users. We envision that the outcome of this project will significantly improve the daily life of citizens.

The targeted metropolitan area for validating our solutions is Ile-de-France. Indeed, Instant-System is currently developing the new application “Vianavigo lab” which will replace the current “Vianavigo” application for the PT network of Ile-de-France. Our findings will therefore be tested at scale and eventually be integrated and deployed in production servers and mobile applications. The smaller networks of Bordeaux and Nice will be used to perform preliminary evaluations since Instant System already operates applications in these cities (Boogi Nice, Boogi Bordeaux). An important remark is that new features and algorithms can contractually be deployed in production every 4 months, thus enabling Instant System to measure and challenge the results of the MultiMod project in continue. This is a chance for the project to maximize its impact.

8.1.3. ANR FREDDA

Participants: Carole Gallet Delporte, Hugues Fauconnier, Pierre Fraigniaud.

Arnaud Sangnier (IRIF, Univ Paris Diderot) leads this project that grants 1 PhD. (This project began in October 2017).

Distributed algorithms are nowadays omnipresent in most systems and applications. It is of utmost importance to develop algorithmic solutions that are both robust and flexible, to be used in large scale applications. Currently, distributed algorithms are developed under precise assumptions on their execution context: synchronicity, bounds on the number of failures, etc. The robustness of distributed algorithms is a challenging problem that has not been much considered until now, and there is no systematic way to guarantee or verify the behavior of an algorithm beyond the context for which it has been designed. We propose to develop automated formal method techniques to verify the robustness of distributed algorithms and to support the development of robust applications. Our methods are of two kinds: statically through classical verification, and dynamically, by synthesizing distributed monitors, that check either correctness or the validity of the context hypotheses at runtime.

8.1.4. ANR Distancia

Participants: Pierre Charbit, Michel Habib, Laurent Viennot.

Victor Chepoi (Univ. Marseille) leads this project. P. Charbit coordinates locally. The project began in early-2018.

The theme of the project is Metric Graph Theory, and we are concerned both on theoretical foundations and applications. Such applications can be found in real world networks. For example, the hub labelling problem in road networks can be directly applied to car navigation applications. Understanding key structural properties of large-scale data networks is crucial for analyzing and optimizing their performance, as well as improving their reliability and security. In prior empirical and theoretical studies researchers have mainly focused on features such as small world phenomenon, power law degree distribution, navigability, and high clustering coefficients. Although those features are interesting and important, the impact of intrinsic geometric and topological features of large-scale data networks on performance, reliability and security is of much greater importance. Recently, there has been a surge of empirical works measuring and analyzing geometric characteristics of real-world networks, namely the Gromov hyperbolicity (called also the negative curvature) of the network. It has been shown that a number of data networks, including Internet application networks, web networks, collaboration networks, social networks, and others, have small hyperbolicity.

Metric graph theory was also indispensable in solving some open questions in concurrency and learning theory in computer science and geometric group theory in mathematics. Median graphs are exactly the 1–skeletons of CAT(0) cube complexes (which have been characterized by Gromov in a local-to-global combinatorial way). They play a vital role in geometric group theory (for example, in the recent solution of the famous Virtual Haken Conjecture). Median graphs are also the domains of event structures of Winskel, one of the basic abstract models of concurrency. This correspondence is very useful in dealing with questions on event structures.

Many classical algorithmic problems concern distances: shortest path, center and diameter, Voronoi diagrams, TSP, clustering, etc. Algorithmic and combinatorial problems related to distances also occur in data analysis. Low-distortion embeddings into l1-spaces (theorem of Bourgain and its algorithmical use by Linial et al.) were the founding tools in metric methods. Recently, several approximation algorithms for NP-hard problems were designed using metric methods. Other important algorithmic graph problems related to distances concern the construction of sparse subgraphs approximating inter-node distances and the converse, augmentation problems with distance constraints. Finally, in the distributed setting, an important problem is that of designing compact data structures allowing very fast computation of inter- node distances or routing along shortest or almost shortest paths. Besides computer science and mathematics, applications of structures involving distances can be found in archeology, computational biology, statistics, data analysis, etc. The problem of characterizing isometric subgraphs of hypercubes has its origin in communication theory and linguistics. . To take into account the recombination effect in genetic data, the mathematicians Bandelt and Dress developed in 1991 the theory of canonical decompositions of finite metric spaces. Together with geneticists, Bandelt successfully used it over the years to reconstruct phylogenies, in the evolutional analysis of mtDNA data in human genetics. One important step in their method is to build a reduced median network that spans the data but still contains all most parsimonious trees. As mentioned above, the median graphs occurring there constitute a central notion in metric graph theory.

With this project, we aim to participate at the elaboration of this new domain of Metric Graph Theory, which requires experts and knowledge in combinatorics (graphs, matroids), geometry, and algorithms. This expertise is distributed over the members of the consortium and a part of the success of our project it will be to share these knowledges among all the members of the consortium. This way we will create a strong group in France on graphs and metrics.

8.1.5. ANR HOSIGRA

Participants: Pierre Charbit, Michel Habib.

This project starting in early-2018, led by Reza Naserasr, explores the connection between minors and colorings, exploiting the notion of signed graphs. With the four colour theorem playing a central role in development of Graph Theory, the notions of minor and coloring have been branded as two of the most distinguished concepts in this field. The geometric notion of planarity has given birth to the theory of minors among others, and coloring have proven to have an algebraic nature through its extension to the theory of graph homomorphisms. Great many projects have been completed on both subjects, but what remains mostly a mystery is the correlation of the two subjects. The four color theorem itself, in slightly stronger form, claims that if a complete graph on five vertices cannot be formed by minor operation from a given graph, then the graph can be homomorphically mapped into the complete graph on four vertices (thus a 4-coloring). Commonly regarded as the most challenging conjecture on graph theory, the Hadwiger conjecture claims that five and four in this theorem can be replaced with n and $n-1$ respectively for any value of n. The correlation of these two concepts has been difficult to study, mainly for the following reason: While the coloring or homomorphism problems roots back into intersections of odd-cycles, the minor operation is irrelevant of the parity of cycles. To overcome this barrier, the notion of signed graphs has been used implicitly since 1970s when coloring results on graphs with no odd-K4 is proved, following which a stronger form of the Hadwiger conjecture, known as Odd Hadwiger conjecture, was proposed by P. Seymour and B. Gerards, independently. Being a natural subclass of Matroids and a superclass of graphs, the notion of minor of signed graphs is well studied and many results from graph minor are either already extended to signed graphs or it is considered by experts of the subject. Observing the importance, and guided by some earlier works, in particular that of B. Guenin, we then started the study of algebraic concepts (coloring and homomormphisms) for signed graphs. Several results have been obtained in the past decade, and this project aims at exploring more of this topic.

8.2. European Initiatives

8.2.1. FP7 & H2020 Projects

Amos Korman has an ERC Consolidator Grant entitled “Distributed Biological Algorithms (DBA)”, started in May 2015. This project proposes a new application for computational reasoning. More specifically, the purpose of this interdisciplinary project is to demonstrate the usefulness of an algorithmic perspective in studies of complex biological systems. We focus on the domain of collective behavior, and demonstrate the benefits of using techniques from the field of theoretical distributed computing in order to establish algorithmic insights regarding the behavior of biological ensembles. The project includes three related tasks, for which we have already obtained promising preliminary results. Each task contains a purely theoretical algorithmic component as well as one which integrates theoretical algorithmic studies with experiments. Most experiments are strategically designed by the PI based on computational insights, and are physically conducted by experimental biologists that have been carefully chosen by the PI. In turn, experimental outcomes will be theoretically analyzed via an algorithmic perspective. By this integration, we aim at deciphering how a biological individual (such as an ant) “thinks”, without having direct access to the neurological process within its brain, and how such limited individuals assemble into ensembles that appear to be far greater than the sum of their parts. The ultimate vision behind this project is to enable the formation of a new scientific field, called algorithmic biology, that bases biological studies on theoretical algorithmic insights.

8.2.2. LIA Struco

Pierre Charbit is director of the LIA STRUCO, which is an Associated International Laboratory of CNRS between IÚUK, Prague, and IRIF, Paris. The director on the Czech side is Pr. Jaroslav Nešetřil. The primary theme of the laboratory is graph theory, more specifically: sparsity of graphs (nowhere dense classes of graphs, bounded expansion classes of graphs), extremal graph theory, graph coloring, Ramsey theory, universality and morphism duality, graph and matroid algorithms and model checking.

STRUCO focuses on high-level study of fundamental combinatorial objects, with a particular emphasis on comprehending and disseminating the state-of-the-art theories and techniques developed. The obtained insights shall be applied to obtain new results on existing problems as well as to identify directions and questions for future work.

One of the main goals of STRUCO is to provide a sustainable and reliable structure to help Czech and French researchers cooperate on long-term projects, disseminate the results to students of both countries and create links between these students more systematically. The chosen themes of the project indeed cover timely and difficult questions, for which a stable and significant cooperation structure is needed. By gathering an important number of excellent researchers and students, the LEA will create the required environment for making advances, which shall be achieved not only by short-term exchanges of researchers, but also by a strong involvement of Ph. D students in the learning of state-of-the-art techniques and in the international collaborations.

STRUCO is a natural place to federate and organize these many isolated collaborations between our two countries. Thus, the project would ensure long-term cooperations and allow young researchers (especially PhD students) to maintain the fruitful exchanges between the two countries in the future years, in a structured and federated way.

8.3. International Initiatives

8.3.1. Inria Associate Teams Not Involved in an Inria International Labs

Carole Delporte-Gallet and Hugues Fauconnier are members of the Inria-MEXICO Equipe Associée LiDiCo (At the Limits of Distributed Computability, https://sites.google.com/site/lidicoequipeassociee/).

8.3.2. Inria International Partners

8.3.2.1. Informal International Partners

Ofer Feinerman (Physics department of complex systems, Weizmann Institute of Science, Rehovot, Israel), is a team member in Amos Korman's ERC project DBA. This collaboration has been formally established by signing a contract between the CNRS and the Weizmann Institute of Science, as part of the ERC project.

Rachid Guerraoui (School of Computer and Communication Sciences, EPFL, Switzerland) maintains an active research collaboration with Gang team members (Carole Delporte, Hugues Fauconnier).

Sergio Rajsbaum (UNAM, Mexico) is a regular collaborator of the team, also involved formally in a joint French-Mexican research project (see next subsection).

Boaz Patt-Shamir (Tel Aviv University, Israel) is a regular collaborator of the team, also involved formally in a joint French-Israeli research project (see next subsection).

8.4. International Research Visitors

8.4.1. Visits to International Teams

- Laurent Viennot has visited Archontia Giannopoulou at National and Kapodistrian University of Athens from July 1st to July 7th.
- Michel Habib has visited Prof. M. Chen (Xiamen University of Technology) and Prof. Lin Cheng-Kuan (Fuzhou University) in China, 9-15 december.

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. Scientific Events: Organisation

9.1.1.1. General Chair, Scientific Chair

Adrian Kosowski was one of the organizing chairs of the workshop "CELLS: Computing among Cells", co-located with DISC 2019, Budapest, October 2019.

9.1.2. Scientific Events: Selection

9.1.2.1. Member of the Conference Program Committees

Carole Delporte was PC member of DISC 2019

Carole Delporte was PC member of NETYS 2019

9.1.3. Journal

9.1.3.1. Member of the Editorial Boards

- Pierre Fraigniaud is a member of the Editorial Board of Distributed Computing (DC).
- Pierre Fraigniaud is a member of the Editorial Board of Theory of Computing Systems (TOCS).

9.1.4. Invited Talks

Carole Delporte, Collège de France, Protocoles de population, Paris mars 2019.

Michel Habib International Summer School on Networks and Evolution, ”Centralities in Networks”, Roscoff juin 2019.

Michel Habib Participation to a CIMPA Research School in Tabriz (IRAN) “Graphs, Algorithms and Randomness”, june 2019. Cours de 8h: ”Efficient graph algorithms and applications”.

Michel Habib "Diameter computations in graphs and shortest paths problems", Université Libre de Bruxelles, june 2019

Pierre Fraigniaud was invited speaker [18] at SIROCCO 2019.

9.1.5. Research Administration

- Hugues Fauconnier is director of the UFR d’informatique of Université Paris Diderot.
- Carole Delporte-Gallet is deputy director of the UFR d’informatique of Université Paris Diderot.
- Laurent Viennot is leader of the “Algorithms and discrete structures” department of the Institute de Recherche en Informatique Fondamentale (IRIF).

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Master: Carole Delporte and Hugues Fauconnier, Algorithmique distribuée avec mémoire partagée, 6h, M2, Université Paris Diderot

Master: Hugues Fauconnier, Cours Algorithmes répartis, 33h, M2, Univ. Paris Diderot

Master: Carole Delporte, Cours et TP Protocoles des services internet, 44h, M2, Univ. Paris Diderot

Master: Carole Delporte, Cours Programmation répartie, 33h, M2, Univ. Paris Diderot

Master: Carole Delporte and Hugues Fauconnier, Théorie et pratique de la concurrence, 48h, M1, Université Paris Diderot

Licence: Carole Delporte and Hugues Fauconnier, Culture informatique, 16h, L2, Univ. Paris Diderot

Licence: Boufkhad Yacine, Algorithmique et Informatique, 132h, L1, IUT de l’Université Paris Diderot

Licence: Boufkhad Yacine, Programmation Orientée Objet, 60h, L2, IUT de l’Université Paris Diderot

Licence: Boufkhad Yacine, Traitement de données, 16h, L2, IUT de l’Université Paris Diderot

DU Santé connectée, 12h réseau, Université Paris Diderot, public divers.

Master: Pierre Fraigniaud, Algorithmique parallèle et distribuée, 24h, Ecole Centrale Supélec Paris, M2

Master: Adrian Kosowski, Competitive Programming - Modal Course, 60h, M1, École Polytechnique

Licence: Adrian Kosowski, Design and Analysis of Algorithms, 32h, L3, École Polytechnique

Master: Pierre Fraigniaud and Adrian Kosowski, Algorithmique distribuée pour les réseaux, 24h, M2, Master Parisien de Recherche en Informatique (MPRI)

Master: Fabien de Montgolfier, Grand Réseaux d'Interaction, 44h, M2, Univ Paris Diderot

Licence: Fabien de Montgolfier, Protocoles Réseau (TP/TD), 24h, M1, Univ Paris Diderot

Licence: Fabien de Montgolfier, Programmation avancée (cours/TD/projet, bio-informatique), 52h, L3, Univ. Paris Diderot

Master: Fabien de Montgolfier, Algorithmique avancée (bio-informatique), 26h, M1, Univ Paris Diderot

Licence: Fabien de Montgolfier, Algorithmique (TD), 26h, L3, Ecole d'Ingénieurs Denis Diderot

License : Laurent Viennot, Algorithms, 12h, L3-M1 BioInfo, Univ. Paris Diderot

Licence: Pierre Charbit, Elements d'Algorithmique, 24h, L2, Université Paris Diderot, France

Licence: Pierre Charbit, Automates finis, 36h, L2, Université Paris Diderot, France

Licence: Pierre Charbit, Internet et Outils, 52h, L1, Université Paris Diderot, France

Master: Pierre Charbit, Programmation Objet, 60h, M2Pro PISE, Université Paris Diderot, France

Master: Pierre Charbit, Algorithmique de Graphes, 12h, M2 MPRI, Université Paris Diderot, France

9.2.2. Supervision

PhD defended: Simon Collet (co-advised by Amos Korman and Pierre Fraigniaud) [1]. Title of thesis is: "Algorithmic Game Theory Applied to Biology". Started September 2015, defended on December 9th, 2019 at Paris University.

PhD defended: Mengchuan Zou (co-advised by Adrian Kosowski and Michel Habib) [2]. Title of thesis is: "Aspects of Efficiency in Selected Problems of Computation on Large Graphs". Started October 2016, defended on December 17th at Paris University.

PhD in progress: Brieuc Guinard (advised by Amos Korman). Title of thesis is: "Algorithmic Aspects of Random Biological Processes". Started October 2016.

PhD in progress: Zeinab Nehaï (advised by Hugues Fauconnier). Title of thesis is : Verification of block-chain. Started October 2018

9.2.3. Juries

Carole Delporte-Gallet was on the jury committee of the PhD thesis of Jules Chouquet "Une Géométrie du calcul Réseaux de preuve, Appel-Par-Pousse-Valeur et topologie du Consensus", december 2019, Université Paris Diderot.

Carole Delporte-Gallet was the referee and on jury committee of the HDR thesis of Janna Burman "Distributed Computing with Limited Resources", december 2019, Université Paris-Sud.

Carole Delporte-Gallet was on the jury committee of the PhD thesis of Marjorie Bournat "Graceful Degradation and Speculation for Robots in Highly Dynamic Environments, june 2019, Sorbonne Université.

Hugues Fauconnier was on jury committee of the HDR thesis of Janna Burman "Distributed Computing with Limited Resources", december 2019, Université Paris-Sud.

Michel Habib was on the jury committee of the PhD thesis of Keno Merckx "Optimization and Realizability Problems for Convex Geometries", june 2019, Université Libre de Bruxelles.

Michel Habib was on the jury committee of the PhD thesis of Mehdi Kosravian Ghadikolaei, “Extension of NP Optimization problems”, Université de Dauphine (PSL), july 2019.

Michel Habib was on the jury committee of the PhD thesis of Antoine Roux, “Etude d’un code correcteur linéaire pour le canal à effacements de paquets et optimisation par comptage de forêts et calcul modulaire” at Sorbonne University, december 2019.

Laurent Viennot was referee and on the jury committee of the HDR thesis of David Ilcinkas on “Structural Information in Distributed Computing” at the University of Bordeaux, March 2019.

Laurent Viennot was referee and on the jury committee of the PhD thesis of Sébastien Ratel on “Densité, VC-dimension et étiquetages de graphes” at the University of Aix-Marseille, November 2019.

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Publications of the year

Doctoral Dissertations and Habilitation Theses

[1] S. COLLET. *Algorithmic Game Theory Applied to Networks and Populations*, Université Paris 7 - Diderot, December 2019, https://hal.inria.fr/tel-02433566

[2] M. ZOU. *Aspects of Efficiency in Selected Problems of Computation on Large Graphs*, Université de Paris, December 2019, https://tel.archives-ouvertes.fr/tel-02436610

Articles in International Peer-Reviewed Journals

[3] J. ASPLUND, P. CHARBIT, C. FEGHALI. *Enclosings of decompositions of complete multigraphs in 2-edge-connected r -factorizations*, in "Discrete Mathematics", August 2019, vol. 342, n° 8, pp. 2195-2203 [*DOI :* 10.1016/J.DISC.2019.04.021], https://hal.inria.fr/hal-02429274

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