Inria International programme
Associate Team
Final Report
(max 8 pages)

Title: Algorithms for large and Dynamic Networks (2013-2018)

Associate Team acronym: AlDyNet

Principal investigator (Inria): Nicolas NISSE (CRISAM, EPI COATI)

Principal investigator (Main team): Karol SUCHAN, Universidad Adolfo Ibáñez (UAI), Santiago, Chile

Other participants: *if the project involves other partners on either side name them here (Inria project-team, university, research center...)*

Center for Mathematical Modeling (CMM) - University of Chile: Juan Carlos Maureira

Departamento de Ingeniería Matemática (DIM) - University of Chile: Mauricio Soto, Marcos Kiwi

Univ. Federal do Ceara, Fortaleza, Brazil: Julio Aráujo

Key Words: Add key words with regard to: *Please refer to the online Scientific Cartography Portal (Référentiel des mots-clés du Portail de la Cartographie Scientifique):* `https://cartographie.inria.fr/SIKeywords/accueilKW`

A- Research themes on digital science: *(at most 5 keywords)*

A7.1.3. Algorithmique des graphes ; A8.1. Mathématiques discrètes, combinatoire ; A8.2. Optimisation ; A7.1.1. Algorithmique distribuée ; A1.2.3. Routage

B- Other research themes and application areas: *(at most 5 keywords)*

B7.2. Déplacements intelligents ; B6.3.3. Gestion des réseaux

1 Overview of the Activities

1.1 Short Visits (duration < 1 month)

- Visit from Chile (UAI) to France

  Eduardo Moreno: Associate Prof., 15-23rd September, 2016 (1 week)

  Karol Suchan: Associate Prof., 10-25th February, 2017 (2 weeks), 10-22nd September, 2018 (2 weeks)

- Visits from France (CRISAM) to Chile

  David Coudert: DR2 Inria, October 24th to November 10th, 2016. (2 1/2 weeks), November 17th to December 1st, 2017. (2 weeks), December 1st- 15th, 2018. (2 weeks).

  Fionn Mc Inerney: PhD. student, November 17th to December 1st, 2017. (2 weeks)

  Nicolas Nisse: CRCN Inria, October 24th to November 10th, 2016. (2 1/2 weeks), November 17th to December 1st, 2017. (2 weeks), December 1st- 15th, 2018. (2 weeks).

1.2 Long Visits (duration > 1 month)

1.3 Seminars

E. Moreno: gave a seminar on September 20th, 2016 at Inria Sophia Antipolis, on Reliable network design under dependent failures.

D. Coudert: gave a seminar on November 30th, 2017 at Univ. Adolfo Ibáñez, on the Flinders Hamiltonian Cycle Problem Challenge.

F. Mc Inerney: gave a seminar on November 23rd, 2017 at Univ. Adolfo Ibáñez, on Spy Games in Graphs.

N. Nisse: gave a seminar on November 4th, 2016 at Univ. Adolfo Ibáñez, on Recovery of disrupted airline operations; and a seminar on November 21st, 2017 at Univ. Adolfo Ibáñez, on Maintaining Balanced Trees For Structured Distributed Streaming Systems.

1.4 Joint Workshops

1.5 Submission of Joint Projects

1.5.1 On the French Side

1.5.2 On the European Commission Side

1.5.3 On the Partner's Country Side

Submission of a proposal Stic-AmSud together with Inria, UAI and Univ. Federal do Ceara (Fortaleza, Brazil): "Problems of Diffusion of Information in Urban Networks using Graphs" (PUDDING) in 2016 (without success) and "Graph ALgorithms for Optimization Problems (GALOP) 2018 (results expected in Nov. 2018).

1.6 Co-organization of Scientific Events

1.7 Students Co-supervision

1.8 Research Internships for Master and PhD students

1. S. Muñoz, *Structural analysis of the solution space for vehicle routing problems: Impact of the variants on the performance of search algorithms*, **Ph.D.** under the supervision of K. Suchan, UAI, since 2018.

2. H. Lespay, *On the problem of territory design for vehicle routing with consistency in service*, **Ph.D.** under the supervision of K. Suchan, UAI, since 2017.

3. F. Ríos, *Distribution logistics in a food company*, **Master** thesis, under the supervision of K. Suchan, UAI, defended on March 28th, 2018.

4. M. Zima, Routing in Multimodal Networks With Bicycles. **Master** thesis, Univ. Nice Sophia Antipolis, supervised by D. Coudert and N. Nisse, March-August, 2018.

5. M. Oleksiyenko, Bicycle-oriented itinerary computation for smart cities. **Master** thesis, Univ. Nice Sophia Antipolis, supervised by D. Coudert and N. Nisse, 2017.

6. **G. Ducoffe**. Propriétés métriques des grands graphes. **Ph.D.** thesis, Univ. Nice Sophia Antipolis, supervised by D. Coudert, defended on December 9th, 2016.

7. V. Zaika, Optimizing the transport network of a large metropolitan area to improve citizen accessibility. **Master** thesis, Univ. Nice Sophia Antipolis, supervised by N. Nisse, March-August, 2016.

2 Scientific Achievements (2016-2018)

This is the continuation of the EA AlDyNet (2013-2015) that has focused on the study of the structure of networks (modeled by graphs) to design both efficient algorithms and reliable network topologies suitable to applications such as routing. During the period 2016-2018, we have continued our algorithmic study of graph properties (see below) and have used our expertise to improve models of transportation for urban networks (focussing on Santiago and Nice agglomerations).

Below we detail further the main scientific achievements of AlDyNet.

On graph decompositions. Graph decompositions are a way to decompose graphs into small pieces (subsets of nodes) that are arranged in order to preserve the connectivity properties. They are widely used by dynamic programming algorithms (divide and conquer) in order to solve efficiently graph problems that are difficult in general. One prerequisite for running this kind of algorithms is the computation of good graph decompositions, which itself is an NP-hard problem. We have focused on the computation of tree-decompositions with various measures of quality.

The problem of minimizing the number of pieces appears to be NP-hard in general graphs and the case of trees is still open [1]. On the other hand, we study tree-decompositions where some metric properties are imposed to the pieces of the decompositions. Precisely, we are not interested by keeping the pieces small (treewidth), but to make them have small diameter (treelength) or small radius (treebreadth). We prove that, in large graph classes, the treelength may be used to approximate the treewidth of graphs [23]. We also prove that deciding whether

the treebreadth of a graph is at most one is NP-hard in general graphs, but can be solved in polynomial-time in bipartite graphs and planar graphs [24]. All these results are relevant on the way to obtain efficient approximation algorithms to compute tree-decompositions.

We also consider the computation of path-decompositions with the design of an efficient branch and bound algorithm for computing them [22] and on some of their properties in directed graphs [21]. We also work on path-decompositions through their game theoretic interpretation, namely the Graph Searching [8]. Roughly, in Graph Searching, we aim at computing the minimum number of mobile agents necessary to capture an invisible arbitrarily fast intruder. A strategy of such a team of agents is equivalent to a path-decomposition of the graph. We consider a variant of Graph Searching where two agents cannot occupy a vertex simultaneously [10]. This leads to the first model of Graph Searching whose complexity differs from the complexity of the classical model [11]. We finally consider Graph Searching in a distributed setting [12], extending some joint work done during the first phase of AlDyNet.

On graph parameters. We have been interested in the design and implementation (with SageMath, for our particular use and to share with the scientific community) of practical algorithms for computing graph structural properties.

Gromov hyperbolicity is a graph parameter reflecting the metric structure of a graph, and that has important practical implications for routing in graphs [13]. We propose an efficient algorithm for computing the hyperbolicity of graphs [12] and study this parameter via particular embeddings of graphs [14]. We also address the parameterized approach to this problem [7]. Our results are part of the current hot topic of parametrized complexity of problems in P.

A convexity in graphs can be roughly described as the rules of propagation of an infection process on the vertices [15]. Many different notions of convexity have been proposed depending on the infection process. Recently, cycle convexity in graphs has been defined for its applications in Knot Theory. In [2], we investigate the computational complexity of corresponding graph parameters. We prove they are NP-complete in general and give polynomial-time and FPT algorithms in many graph classes.

Working on graphs often requires to have a "good" ordering of the vertices, i.e., with interesting properties. Typical examples are the search-traversal (BFS, DFS, Lex-BFS, etc.) that are used as corner-stones of many algorithms. We investigate the distance preserving orderings which encompass many well known vertex-orderings (perfect elimination orderings, dismantable orderings). We prove that deciding if a graph admits such an ordering is NP-complete [3].

Finally, we have worked on problems related to domination in graphs [9,10,11,20]

Optimization in wireless networks. The reliability of a fixed wireless backhaul network is the probability that the network can meet all the communication requirements, considering the uncertainty (e.g., due to weather) in the maximum capacity of each link. In [5], we provide an algorithm to compute the exact reliability of a backhaul network, given a discrete probability distribution on the possible capacities available at each link. We also have studied the impact of some specific routing constraints (e.g., mono-routing, load balancing, stretch) on the design and reliability of the networks.

In [4,6], we study the disconnection of a moving vehicle from a linear access network composed by cheap WiFi Access Points in the context of telecommuting in massive transportation systems. In particular, we carry out a sensitivity analysis and supply a guide for operators when choosing the parameters of the networks.

Optimization in geographical networks. We aim at considering transportation networks of medium-size cities in order to see the performances of various routing or graph algorithms on

them. In our collaboration with the Chilean government, we have collected data on education, transportation, urban infrastructure, etc. An interesting first task has been that of correcting errors in the maps created by human users of ArcGIS. This exercise was not trivial, given thr scale of networks to be corrected and the nature of problems ranging from erroneous coordinates and duplicate or missing nodes and edges to wrong street orientation. The Master 2 internship of V. Zaika [10] has been devoted to this task. During the Master internships of Marko Oleksiyenko and Mykhailo Zima, we have extracted data of the city of Nice (mainly from OpenStreetMap) and applied to it the hub-labeling algorithm of Kosowski and Viennot (Inria Paris). A way to obtain better performances is to partition such a network into smaller cells. We have used a Linear Programme for this purpose. However, we think that our work on graph Domination (at some distance) may help to obtain different (possibly better) partitions. During our last visit in Santiago (Nov. 2017), we worked on improving the consistency in the Multi-Period Vehicle Routing Problem (see the master thesis of F. Ríos). We will continue this work during our next visit (Dec. 2018) together with the new Ph.D. students H. Lespay and S. Muñoz.

3 Production & Impact

3.1 Publications of the project (2016-2018)

3.1.1 Joint Publications

1. **B. Li, F. Zahra Moataz, N. Nisse** and **K. Suchan**, Minimum Size Tree-Decompositions. Discrete Applied Maths, 245 :109-127, 2018.

2. **J. Araujo**, **G. Ducoffe, N. Nisse** and **K. Suchan**. On interval number in cycle convexity. Discrete Mathematics & Theoretical Computer Science, 20(1), 2018.

3. **D. Coudert, G. Ducoffe, N. Nisse** and **M. Soto**. Distance-preserving orderings in graphs. Discrete Applied Maths, 243 :140- 153, 2018.

4. **F. Giroire** and **J-C. Maureira**. Analysis of the failure tolerance of linear access networks. IEEE Trans. Intelligent Transportation Systems, 19(4) :1166-1175, 2018.

5. **D. Coudert**, J. Luedtke, **E. Moreno**, Konstantinos Priftis. Computing and maximizing the exact reliability of wireless backhaul networks. In proceedings of International Network Optimization Conference (INOC), https://hal.inria.fr/hal-01394593, 2017.

6. **F. Giroire** and **Juan-Carlos Maureira**. Analysis of the Failure Tolerance of Linear Access Networks. IEEE Global Communications Conference (GLOBECOM), 2016

3.1.2 Related publications by members of the project

7. **D. Coudert, G. Ducoffe**, A. Popa: Fully polynomial FPT algorithms for some classes of bounded clique-width graphs. Twenty-Ninth Annual ACM-SIAM Symposium on Discrete Algorithms (SODA) 2018: 2765-2784

8. **N. Nisse**, Network Decontamination [Research Report] Inria & Université Nice Sophia Antipolis, CNRS, I3S, Sophia Antipolis, France. 2018, pp.1-30

9. **F. Mc Inerney, N. Nisse, S. Pérennes**, Eternal Domination in Grids, [Research Report] Inria & Univ. Nice Sophia Antipolis, CNRS, I3S, Sophia Antipolis, France. 2018

10. J. Bensmail, D. Mazauric, **F. Mc Inerney, N. Nisse, S. Pérennes**, Sequential Metric Dimension, 16th Workshop on Approximation and Online Algorithms (WAOA). 2018

11. N. Cohen, N. A. Martins, **F. Mc Inerney, N. Nisse, S. Pérennes** and R. M. Sampaio: Spy-game on graphs: Complexity and simple topologies. Theor. Comput. Sci. 725: 1-15 (2018)

12. N. Cohen, **D. Coudert**, **G. Ducoffe**, A. Lancin. Applying clique-decomposition for computing Gromov hyperbolicity. Theoretical Computer Science, 2017, 690, 114-139.

13. S. Sahhaf, W. Tavernier, D. Papadimitriou, D. Careglio, A. Kumar, C. Glacet, **D. Coudert**, **N. Nisse**, L. Fàbrega, P. Vilà, M. Camelo, P. Audenaert, D. Colle, P. Demeester. Routing at Large Scale: Advances and Challenges for Complex Networks. IEEE Network, Institute of Electrical and Electronics Engineers, 2017, pp.12 – 22.

14. **D. Coudert**, **G. Ducoffe**. A simple approach for lower-bounding the distortion in any Hyperbolic embedding. Europ. Conf. on Combinatorics, Graph Theory and Applications (EUROCOMB'17), Electronic Notes in Discrete Mathematics, 61, pp.293 - 299, 2017.

15. K. Knauer, **N. Nisse**. Computing metric hulls in graphs. Research Report] Inria - Sophia Antipolis. 2017

16. L. Blin, J. Burman and **N. Nisse**. Exclusive Graph Searching. Algorithmica, Volume 77(3), pages 942-969, 2017.

17. E. Markou, **N. Nisse** and **S. Pérennes**. Exclusive Graph Searching vs. Pathwidth. Information and Computation, Volume 252, pages 243-260, 2017

18. G. D'Angelo, A. Navarra and **N. Nisse**. Gathering and Exclusive Searching on Rings under Minimal Assumptions. Distributed Computing, Volume 30(1), pages 17-48, 2017.

19. **F. Giroire**, R. Modrzejewski, **N. Nisse** and **S. Pérennes**, Maintaining Balanced Trees For Structured Distributed Streaming Systems. Discrete Applied Maths 232: 176-188 (2017).

20. N. Cohen, F. **Mc Inerney**, **N. Nisse**, and **S. Pérennes**. Study of a combinatorial game in graphs through Linear Programming. To appear in Proceedings of 28th International Symposium on Algorithms and Computation (ISAAC), 2017.

21. **N. Nisse, R. Pardo Soares**: On the monotonicity of process number. Discrete Applied Mathematics 210: 103-111 (2016)

22. **D. Coudert**, Dorian Mazauric, **N. Nisse**: Experimental Evaluation of a Branch-and-Bound Algorithm for Computing Pathwidth and Directed Pathwidth. ACM Journal of Experimental Algorithmics 21(1): 1.3:1-1.3:23 (2016)

23. **D. Coudert, G. Ducoffe and N. Nisse**: To Approximate Treewidth, Use Treelength! SIAM J. Discrete Math. 30(3): 1424-1436 (2016)

24. **G. Ducoffe**, Sylvain Legay, **N. Nisse**: On the Complexity of Computing Treebreadth. In 27th International Workshop on Combinatorial Algorithms (IWOCA 2016): LNCS 9843, Springer, 3-15, 2016.

3.2 Software

3.3 Patents

3.4 Demos & Videos

3.5 Current Position of Students and Postdocs Involved in the Associate Team

- Ronan Pardo Soares (Ph.D. Inria, defended on Nov. 2013) is now an Assistant Professor at Univ. Federal do Ceara, Fortaleza, Brazil.
- Bi Li (Ph.D. Inria, defended on Nov. 2014) is now an Assistant Professor at Xidian Univ., Xi'an, China.
- Fatima Zahra Moataz (Ph.D. Inria, defended on Oct. 2015) is now a Trust and Safety Strategist at Google, Dublin, Ireland.
- Guillaume Ducoffe (Ph.D. Inria, defended on Nov. 2016) is now a Scientific Researcher at National Institute of Research and Development in Informatics (I.C.I.), Roumania.
- Fionn Mc Inerney (Ph.D. student Inria, since Oct. 2016) now in third year of Ph.D. studies.
- Sebastián Muñoz (Ph.D. student UAI, since 2018) is now in first year of Ph.D. studies.
- Hernán Lespay (Ph.D. student UAI, since 2017) is now in second year of Ph.D. studies.
- Francisco Ríos (M.Sc. UAI, defended on March 28th, 2018) is now a Business Analytics Specialist at Cencosud, Chile.

3.6 Other Forms of Impact

4 Future of the Partnership

We hope to pursue the collaboration. In particular, we will continue to work jointly on transportation problems: public transportation in France and last mile delivery in Chile. The objective is twofold: to advance theoretical research on structural analysis of related networks, and to design efficient algorithms for the practical problems involved. To advance in this directions, we will be supported by the collaborations, with BeNomad and Instant-System in France and Ariztía, Salcobrand and Sodimac in Chile, that have been established during AlDyNet. For this purpose, K. Suchan will apply for founding from Fondecyt (Conicyt, Chile). We will also submit a proposal during the next call of ECOS-Sud.

Also, AlDyNet has allowed to initiate new collaborations with Juan Carlos Maureira (CMM, Univ. de Chile). This collaboration will continue thanks to the Fondecyt project of J-C. Maureira related with handling massive data in astronomy. We will bring him our expertise on distributed fault-tolerant algorithms and large scale distributed storage.

Do you request the Inria International Partner (IIP) label (Yes/No)?

Yes, we do request the Inria International Partner label. We believe that it would help us to achieve more visibility and to recruit more talent to work on problems related to the emerging network science and its applications in transportation problems.

5 Self-Assessment

From the theoretical point of view, we have got numerous significant combinatorial and algorithmic results on the analysis and computation of graph parameters (as shown by the publications in international conferences and journals). The theoretical objectives of the project have been successfully achieved.

On the other hand, the more practical aspects of the projects have been slower to develop. This is mainly due to two factors. Firstly, the data that we got (from the Chilean government for Santiago, from OpenStreetMap and other free websites for Nice) contained a lot of mistakes and required much work to understand well the problems and then develop the algorithms needed. Moreover, the motivation from public services that we worked with (e.g., analysing and improving accessibility to schools) was not strong enough to justify computer science investigation of a more theoretical vein. Secondly, we have lacked of workforce, in particular of good students and postdocs with both programming and mathematical skills to work on the applications.

With all the lessons learned, we believe that refocusing the efforts on problems coming from applications in transportation will help to overcome the difficulties. We have planted the seeds, establishing collaborations with industrial partners that should help us attract young talent, by presenting challenges very relevant to the rapid changes experienced by the industries and the societies in general. Mobility, quality of service in retail and the environmental impact of transportation are among the priority topics in the public debate. And they arouse interest among the young researchers, as evidenced by the participation of Francisco Ríos, Hernán Lespay and Sebastián Muñoz in the activities of the Associated Team. Unfortunately, it took much time to find adequate industrial partners and establish collaborations with them during the second stage of the project, and for now we only have some preliminary results. But we believe that with the experience we have gained in course of AlDyNet, and with the support of Inria International Partner label and Inria Chile, we will be able to progress successfully in the area of practical applications.

6 Feed-back on the associate team's programme

The format of this programme is a good one since it is not too heavy in administration tasks and provides reasonable funds allowing the collaboration between the partners.