



Regional Program Scientific Cooperation

STIC – AmSud

Final Report

Deadline : March 31st, 2021

Project Number:	9-STIC-05
Project Acronym:	GALOP
Project Title:	Graphs ALgorithms for Optimization Problems
Investigation Area:	Graph theory
Starting year:	2019

Project Website:	https://team.inria.fr/coati/projects/sticamsud-galop/
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1. Participants

1.1. International Coordinator:

Name	Nicolas NISSE
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1.2. Scientific Coordinators:

	Institution	Name of the Scientific Coordinator	E mail
French Partner A	Inria	Nicolas Nisse	nicolas.nisse@inria.fr
South American Partner A	Univ. Federale do Ceara (UFC), Fortaleza, Brazil	Claudia Linhares Sales	linhares@lia.ufc.br
South American Partner B	Universidad Diego Portales, Santiago, Chile	Karol Suchan	karol.suchan@mail.udp.cl

1.3. List of the investigators involved in the project:

Name	Institution	Status (Senior, post-doctoral investigator, PhD student)
Julien Bensmail	UCA, Inria, CNRS, I3S, France	Assistant Professor
Thomas Dissaux	UCA, Inria, CNRS, I3S, France	Ph.D. student (2020-)
Foivos Fioravantes	UCA, Inria, CNRS, I3S, France	Ph.D. student (2019-)
Frédéric Giroire	UCA, Inria, CNRS, I3S, France	CR CNRS (till 2020), DR CNRS
Frédéric Havet	UCA, Inria, CNRS, I3S, France	DR CNRS
Fionn Mc Inerney	UCA, Inria, CNRS, I3S, France	Ph.D. student (2016-19), Postdoc (2019-)
Nicolas Nisse	UCA, Inria, CNRS, I3S, France	CR Inria
Julio Araujo	Univ. Federale do Ceara	Associate Prof.
Fabrcio Siqueira Benevides	Univ. Federale do Ceara	Associate Prof.
Victor Campos	Univ. Federale do Ceara	Associate Prof.
Ana Karolinnna Maia	Univ. Federale do Ceara	Associate Prof.
Claudia Linhares Sales	Univ. Federale do Ceara	Professor
Raul Lopez	Univ. Federale do Ceara	Ph.D. student (2017-)

Ana Shirley Ferreira da Silva	Univ. Federale do Ceara	Associate Prof.
Jonas Costa Ferreira da Silva	Univ. Federale do Ceara	Ph.D. student (2018-)
Karol Suchan	Universidad Diego Portales	Associate Prof.
Hernán Lespay	Universidad Diego Portales	Ph.D. student (2017-2021)
Sebastián Muñoz	Universidad Diego Portales	Ph.D. student (2018-)

1.4. Number of senior investigators involved in the project: 10

1.5. Number of post-doctoral students involved in the project: 0

1.6. Number of PhD students involved in the project: 7

2. Financial evaluation

2.1. Funds from funding agencies (in euros):

Funding Agencies	2019		2020	
	Funds received	Funds spent	Funds received	Funds spent
UMSA (Bolivia)				
CAPES (Brasil)	4416	4416	0	0
MINCIENCIAS (Colombia)				
CONCYTEC (Peru)				
ANID (ex-CONICYT) (Chile)	4750	4750	4750	0
CONACYT (Paraguay)				
ANII (Uruguay)				
INRIA (France)	5000	5000	5000 (promised)	0 (due to Covid...)
Institut Telecom (France)				
MEAE (France)				
CNRS (France)				
MPPEUCT (Venezuela)				
Ministerio de Ciencia, Tecnología e Innovación (Argentina)				
SENESCYT (Ecuador)				
TOTAL :	14166	14166	9750	0

2.2. Total of funds spent (in euros): In addition to the above mentioned fund, we have received from CAPES: 26855 euros for one year of postdoc of Fabricio Benevides (Ass. Prof UFC) at COATI, and 18645 euros for a visit of one year of Jonas Costa (Ph.D. student UFC) at COATI. In total, we have received and spent 59658 euros (see below for the details).

2.3. Number of missions¹: All missions planned in 2020 have been canceled (due to Covid). This explains that few students have been able to travel since we had planned their missions for 2020.

It has been 6 missions of 2 weeks and 2 missions of one year (see below).

2.4. Detailed missions expenses:

A) Senior investigators' missions:

Investigator (name, institution, status)	Mission details	Travelling Costs	Travel Allowance	TOTAL (euros)
Nicolas Nisse	Objective : doing research Place : UFC Date : May 4-18 2019 Duration : 2 weeks	800	1600	2500 euros
Julien Bensmail	Objective : doing research Place : UFC Date : May 4-18 2019 Duration : 2 weeks	800	1600	2500 euros
Karol Suchan	Objective : doing research Place : UFC Date : August 10-19 2019 Duration : 1,5 weeks	595,9 €	947,7 €	1543,6 €
Julio Araujo	Objective : doing research Place : Inria Sophia Antipolis Date : December 4-20th 2019 Duration : 2 weeks	514,74	1790,35	2305,09 euros
Claudia Linhares	Objective : doing research Place : Inria Sophia Antipolis Date : December 4-20th 2019 Duration : 2 weeks	771,37	1342,69	2114,06 euros
Fabricio Benevides	Objective : one year postdoc Place : Inria Sophia Antipolis Date : September 2019- July 2020 Duration : 11 months	1655	25200	26855 euros
Karol Suchan	Objective : doing research Place : Inria Sophia Antipolis Date : December 8-21th 2019 Duration : 2 weeks	2018,4 €	1188 €	3206,4 €
TOTAL (euros) :				41013

B) Students' missions (Post-doctoral position, PHD student...):

Students (name, institution, status)	Mission details	Travelling Costs	Travel Allowance	TOTAL (euros)
Jonas Silva	Objective : PhD thesis "sandwich » Place : Inria Sophia Antipolis Date : December 2019- November 2020 Duration : 1 year	1745	16900	18645 euros
TOTAL (euros) :				18645

¹ One mission is one round trip.

3. Scientific Evaluation

3.1. Short description of the main scientific results of the project:

The goal of the project is to progress in the study of the Computational Complexity of several important problems arising in networks, focussing in particular on the computation of metric or structural properties and parameters of large networks. As planned, we have addressed in parallel three main lines of research: (1) computing structural parameters of graphs (with a particular interest in graph decompositions) and with applications in transportation networks, (2) studying graph metric properties (e.g., via combinatorial games) and in particular in directed graphs, and (3) considering coloring problems and structures in (di)graphs.

1. We have obtained new structural results in graphs (e.g. [10]) and in particular in the computation of tree-decompositions of graphs. Precisely, in [6], we proved that deciding whether the treelength of a serie-parallel graph (subclass of planar graphs) is at most 2 can be solved in polynomial time (while this problem is NP-hard in general graphs).

We worked on the parameterized complexity of some graph optimization problems. In [3], several results concerning the computation of the geodetic hull number of a graph from the parameterized complexity point of view were considered. In [14,15], obtain parameterized results to the max-min version of two well-known problems: Vertex Cover and Hitting Sets; as well as to the recent notion of Blocking Sets. Among such results, there is a new framework to prove kernelization lower bounds that may have interesting consequences to several problems in the literature.

Our expertise on graphs' properties allowed us to progress in problems concerning transportation networks [1,11,12].

2. Combinatorial games have been widely studied in the Ph.D. thesis of F. Mc Inerney. In particular, we studied a game version of the metric dimension of graphs. A set R of vertices of a graph G is resolving if every vertex of G can be uniquely determined by its distances to the vertices in R . The metric dimension of a graph is the smallest size of a resolving set in it. The computation of small resolving sets has been widely studied in undirected graphs. We have obtained new results in the (more difficult) case of directed graphs [4,8]. We also have studied games related to the spreading of infection in graphs [9] (closely related to the Game of Life problem defined by J. Conway). Another kind of combinatorial games involving graph coloring, in which two players color the vertices of a given graph step by step, has also been studied [2].

3. An important part of our work has been dedicated to the study of structural properties of directed graphs. In [7], we have obtained new results on necessary and/or sufficient connectivity properties for a digraph to admit arc-disjoint branching flows. In [17], we characterize directed planar graphs that are butterfly minor of a cylindrical grid (such a result is important since it is known that a planar digraph H has the Erdos-Posa property if and only if it is such a graph). We also considered graph coloring problems related to possible orientations of a given input graph [13, 16]. We also studied graph convexity parameters of oriented graphs [5].

Overall, even if the current context has made the collaboration harder (for instance, the year that J. Costa and F. Benevides have spent in the COATI team has been disturbed by the several lockdowns in France), the GALOP project has been very fruitful in many research directions that we wanted to address. GALOP has consolidated the strong connection between COATI, Univ. Diego Portales and UFC and it makes no doubt that this collaboration will go on.

3.2. List of publications related to the project (**the publications should mention the STIC-AmSud program. Please include the publications as an active link in the form or send them as .PDF:**

Publications with (*) involve co-authors of different partners of the project.

1. Hernan Lespay and Karol Suchan. A case study of Consistent Vehicle Routing Problem with Time Windows. *International Transactions in Operational Research* 28(3):1135--1163, 2021. (<http://doi.org/10.1111/itor.12885>)
2. Eurinaldo R. Costa, Victor Lage Pessoa, Rudini M. Sampaio, Ronan Soares. PSPACE-completeness of two graph coloring games. *Theoretical Computer Science*, 2020. (<http://dx.doi.org/10.1016/j.tcs.2020.03.022>)
3. M. Kanté, T. Marcilon and R.M. Sampaio. On the parameterized complexity of the geodesic hull number. *Theoretical Computer Science*, v. 791, p. 10-27, 2019. (<http://dx.doi.org/10.1016/j.tcs.2019.05.005>)
4. Julien Bensmail, Fionn Mc Inerney and Nicolas Nisse. Metric Dimension: from Graphs to Oriented Graphs. Accepted in *Discrete Applied Maths*, 2021. (<https://hal.inria.fr/hal-01938290>)
5. J. Araujo and P. Arraes. Hull and geodesic numbers for some classes of oriented graphs. Accepted in *Discrete Applied Mathematics*. (<https://arxiv.org/pdf/1911.10240.pdf>)
6. Thomas Dissaux, Guillaume Ducoffe, Nicolas Nisse, Simon Nivelles. Treelength of Series-parallel graphs. To appear in *Proceedings of 11th Latin-American Algorithms, Graphs and Optimization Symposium (LAGOS)*, 2021. (<https://hal.inria.fr/hal-03175837>)
7. (*) Cláudio Carvalho, Jonas Costa, Cláudia Sales, Raul Lopes, Ana Karolína Maia de Oliveira, Nicolas Nisse. On the characterization of networks with multiple arc-disjoint branching flows. In *Anais do Encontro de Teoria da Computação (ETC)*, Brazil, 2020. Submitted to *IWOCA 2021* (<https://hal.inria.fr/hal-03031759>)
8. (*) Julio Araujo, Julien Bensmail, Victor Campos, Frédéric Havet, Ana Karolína Maia de Oliveira, Nicolas Nisse, Ana Silva. On finding the best and worst orientations for the metric dimension. Research rep., 2020. Submitted. (<https://hal.archives-ouvertes.fr/hal-02921466>)
9. (*) Fabricio Benevides, Jean-Claude Bermond, Hicham Lesfari, Nicolas Nisse. Minimum lethal sets in grids and tori under 3-neighbour bootstrap percolation. Research Report, 2021. Submitted. (<https://hal.archives-ouvertes.fr/hal-03161419>).
10. S. Cichacz and Karol Suchan. Vertex-Fault Tolerant Complete Matching in Bipartite graphs: the Biregular Case. Submitted. (<https://arxiv.org/abs/1907.04844>)
11. T.H. Le, Brigitte Jaumard and Karol Suchan. Efficient Car Sorting in a Flat Yard. Submitted.
12. Hernan Lespay and Karol Suchan. Territory Design for Dynamic Multi-Period Vehicle Routing Problem with Time Windows. Submitted. (<https://arxiv.org/abs/2012.10506>)
13. J. Araujo, A. Cezar, C.V.G.C Lima, V.F. dos Santos, A.S. Silva. On the proper orientation number of chordal graphs. Submitted. (<https://arxiv.org/abs/2011.14719>)
14. J. Araujo, M. Bougeret, V. Campos and I. Sau. Kernelization of Maximum Minimal Vertex Cover. Submitted. (<https://arxiv.org/pdf/2102.02484.pdf>)
15. J. Araujo, M. Bougeret, V. Campos and I. Sau. Parameterized complexity of computing maximum minimal blocking and hitting sets. Submitted. (<https://arxiv.org/pdf/2102.03404.pdf>)
16. (*) Julio Araujo, Frédéric Havet, Claudia Linhares Sales, Nicolas Nisse, and Karol Suchan. Semi-proper orientations of chordal graphs. In preparation. (http://www-sop.inria.fr/members/Nicolas.Nisse/Semi_proper_orientation_of_chordal_graphs.pdf)
17. (*) Julien Bensmail, Victor Campos, Matheus Correia, Ana Karolína Maia, Nicolas Nisse, Ana Silva. Characterizing butterfly minors of cylindrical grids. In preparation. (<http://www-sop.inria.fr/members/Nicolas.Nisse/cylindrical.pdf>)

3.3. List of participations in seminars and congresses related to the project:

(the seminars of the COATI team can be found here :

<https://team.inria.fr/coati/seminars-and-conferences/seminars/>)

1. M. Sulkowska, Seminar at COATI on “Maximizing the expected number of components in an online search of a graph” (joint work with F. Benevides). February 16th, 2021.
2. J. Araujo, A. Cezar, C.V.G.C Lima, V.F. dos Santos, A.S. Silva. Proper orientation of chordal graphs. In: 5th Encontro de Teoria da Computação, XL Congresso da Sociedade Brasileira de Computação, Cuiabá, Brazil. November 2020. (<https://sol.sbc.org.br/index.php/etc/article/view/11080/10951>)
3. J. Costa, Seminar at COATI on “On the characterization of networks with multiple arc-disjoint branching flows.”, October 6th, 2020.

4. K. Suchan, Seminar at COATI on “Fault Tolerant Complete Matchings in Bipartite Graphs and Related Problems”, Dec. 17th, 2019.
5. J. Araujo, Seminar at COATI on “Weighted proper orientations of trees and graphs of bounded treewidth”, Dec. 10th 2019.
6. J. Araujo, C. Araujo, A. Cezar, A.S. Silva. Backbone Coloring of Graphs with Galaxy Backbones. In: X Latin and American Algorithms, Graphs and Optimization Symposium (LAGOS), Belo Horizonte, Brazil, May 2019, Electronic Notes in Theoretical Computer Science, vol. 346, Aug. 2019, pp. 53-64. (<http://doi.org/10.1016/j.entcs.2019.08.006>)
7. J. Araujo, P. Arraes, Hull and geodetic numbers for some classes of oriented graphs. In: X Latin and American Algorithms, Graphs and Optimization Symposium (LAGOS), Electronic Notes in Theoretical Computer Science, vol. 346, Aug. 2019, pp. 77-88, Belo Horizonte, Brazil, May 2019. (<https://doi.org/10.1016/j.entcs.2019.08.008>)
8. K. Suchan, Seminar at UFC on “Vertex-Fault Tolerant Complete Matching in Bipartite graphs: the Biregular Case” (August 13th 2019) during the Workshop organized for the 20 years of the team ParGO.
9. J. Bensmail, Seminar at UFC on « 1-2-3 conjecture », May 6th 2019.
10. N. Nisse, Seminar at UFC on « Recovery of disrupted airline operations and constrained matchings », May 10th 2019.

3.4. List of thesis developed in the project (mentioning if it is a PhD or a master thesis):

- Hernán Lespay. Consistent Vehicle Routing. Ph.D. thesis, Universidad Adolfo Ibáñez, Chile, January 22nd, 2021.
- Fionn McInerney. Domination and Identification Games in Graphs. Ph.D. thesis, Univ. Côte d’Azur, July 8th, 2019. (<https://tel.archives-ouvertes.fr/tel-02184625v2/>)
- Camila Sena Araújo. Colorações backbone em grafos com galáxias backbone. Master’s in Mathematics - Universidade Federal do Ceará. 2021.
- Pedro Santos Mota e Arraes. Números de envoltória e geodético em classes de grafos orientados. Master’s in Mathematics - Universidade Federal do Ceará. 2020.
- Thomas Dissaux. Graph Decompositions and treelength. M2 internship (March-August 2020), Univ. Côte d’Azur. (<http://www-sop.inria.fr/members/Nicolas.Nisse/ReportsStudents/Dissaux.pdf>)
- Pedro Paulo de Medeiros. Coloração Acíclica. Master’s in Mathematics - Universidade Federal do Ceará, 2019.

3.5. List of patents (in study, accepted...) related to the project:

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3.6. Cooperation developed with the private sector during the project:

3.7. Did the STIC-AmSud Program help in developing other relevant initiatives (research projects, European programs, bilateral programs, cooperation agreements, *Co-tutelles*...)?

Julio Araujo and Karol Maia were in the University of Montpellier - Laboratoire d’Informatique, de Robotique et de Microélectronique de Montpellier (LIRMM) - from March 2020 to February 2021 as visiting professors funded by CAPES-PrInt. During this period, Jonas Costa, a PhD student funded by GALOP could visit LIRMM and work with his advisor Karol Maia and other researchers from LIRMM.

During his one-year visit at COATI, F. Benevides invited Małgorzata Sulkowska (<https://cs.pwr.edu.pl/sulkowska/>) for two weeks in 2019. Since Sept. 2020, Małgorzata is now postdoc at COATI. We are working together on theoretical models of large scale networks (<https://hal.archives-ouvertes.fr/hal-03154836>).

3.8. Future perspectives of collaboration between the partners of the project :

As one may check at the end of the publications list, we have ongoing discussions and we shall have further publications in a near future. We plan to keep working on the project themes as many open questions remain unsolved. Thanks to the visit of Julio Araujo to the University of Montpellier, we also plan to enlarge our collaborations to englobe members of the AIGCo team from LIRMM. We also plan to apply for an associated team between COATI and UFC (we already tried once, during the call in 2019).

4. Program Observations

4.1. Point out the strong points of the program :

Several publications were obtained as we listed. We obtained results in most of the topics we proposed in the original submission. We also had several thesis on the project's themes and we should emphasize that one brazilian PhD student (Jonas Costa) had part of their thesis results obtained during the visits funded by GALOP.

4.2. Point out the weaknesses of the program :

The public demonstrations and strikes in Chile in the second semester of 2019 were decisive for the Brazilian work and study missions to Chile to be cancelled. The covid-19 pandemic has forbidden us to do any further missions in 2020.