Activity Report 2015

Team INOCS

Integrated Optimization with Complex Structure

Inria teams are typically groups of researchers working on the definition of a common project, and objectives, with the goal to arrive at the creation of a project-team. Such project-teams may include other partners (universities or research institutions).

RESEARCH CENTER
Lille - Nord Europe

THEME
Optimization, machine learning and statistical methods

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Team INOCS

Creation of the Team: 2015 May 01

Keywords:

Computer Science and Digital Science:

6. - Modeling, simulation and control
6.2. - Scientific Computing, Numerical Analysis & Optimization
6.2.6. - Optimization

Other Research Topics and Application Domains:

4. - Energy
4.2. - Renewable energy production
4.3. - Energy delivery
6. - IT and telecom
6.3.2. - Network protocols
7. - Transport and logistics
7.1. - Traffic management
7.1.2. - Road traffic
8.1. - Smart building/home
8.1.1. - Energy for smart buildings

1. Members

Research Scientist

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2. Overall Objectives

2.1. Introduction

INOCS is a new cross-border "France-Belgium" project team in the Applied Mathematics Computation and Simulation Inria domain. The main goal of this team is the study of optimization problems involving complex structures. In short this project team is called INOCS for INtegrated Optimization with Complex Structures. The scientific objectives of INOCS are related to modeling and methodological concerns. The INOCS team will focus on:

1. integrated models for problems with complex structure (CS) taking into account the whole structure of the problem;
2. on the development of solution methods taking explicitly into account *the nature and the structure of the decisions as well as the properties of the problem*.

Even if CS problems are in general NP-hard due to their complex nature, exact solution methods or matheuristics (heuristics based on exact optimization methods) will be developed by INOCS. The scientific contribution of INOCS will result in a toolbox of models and methods to solve challenging real life problems.

2.2. Schedule of tasks

The research program development of INOCS is to move alternatively :

- *from problems towards new approaches in optimization*: Models and solution algorithms will be developed to fit the structure and properties of the problem. From them, new generic approaches will be used to optimize problems with similar properties.
- *from innovative approaches towards problems*: The relevance of the proposed approaches will be assessed by designing new models and/or solution methods for various classes of problems. These models and methods will be based on the extension and integration of specific, well studied, models and methods.

Even if these two axes are developed sequentially in a first phase, their interactions will lead us to explore them jointly in the mid-term.

3. Research Program

3.1. Introduction

An optimization problem consists in finding a best solution from a set of feasible solutions. Such a problem can be typically modeled as a mathematical program in which decision variables must

1. satisfy a set of constraints that translate the feasibility of the solution and
2. optimize some (or several) objective function(s). Optimization problems are usually classified according to types of decision to be taken into strategic, tactical and operational problems.

We consider that an optimization problem presents a complex structure when it involves decisions of different types/nature (i.e. strategic, tactical or operational), and/or presenting some hierarchical leader-follower structure. The set of constraints may usually be partitioned into global constraints linking variables associated with the different types/nature of decision and constraints involving each type of variables separately. Optimization problems with a complex structure lead to extremely challenging problems since a global optimum with respect to the whole sets of decision variables and of constraints must be determined.

Significant progresses have been made in optimization to solve academic problems. Nowadays large-scale instances of some NP-Hard problems are routinely solved to optimality. *Our vision within INOCS is to make the same advances while addressing CS optimization problems*. To achieve this goal we aim to develop global solution approaches at the opposite of the current trend. INOCS team members have already proposed some successful methods following this research lines to model and solve CS problems (e.g. ANR project RESPET, Brotcorne *et al.* 2011, 2012, Gendron *et al.* 2009, Strack *et al.* 2009). However, these are preliminary attempts and a number of challenges regarding modeling and methodological issues have still to be met.

3.2. Modeling problems with complex structures

A classical optimization problem can be formulated as follows:

$$\begin{array}{ll} \min & f(x) \\ s.t. & x \in X, \end{array} \tag{1}$$

In this problem, X is the set of feasible solutions. Typically, in mathematical programming, X is defined by a set of constraints. x may be also limited to non-negative integer values.

INOCS team plan to address optimization problem where two types of decision are addressed jointly and are interrelated. More precisely, let us assume that variables x and y are associated with these decisions. A generic model for CS problems is the following:

$$\begin{array}{ll} \min & g(x,y) \\ s.t. & x \in X, \\ (x,y) & \in XY, \\ y & \in Y(x). \end{array} \tag{2}$$

In this model, X is the set of feasible values for x. XY is the set of feasible values for x and y jointly. This set is typically modeled through linking constraints. Last, $Y(x)$ is the set of feasible values for y for a given x. In INOCS, we do not assume that $Y(x)$ has any properties.

The INOCS team plans to model optimization CS problems according to three types of optimization paradigms: large scale complex structures optimization, bilevel optimization and robust/stochastic optimization. These paradigms instantiate specific variants of the generic model.

Large scale complex structures optimization problems can be formulated through the simplest variant of the generic model given above. In this case, it is assumed that $Y(x)$ does not depend on x. In such models, X and Y are associated with constraints on x and on y, XY are the linking constraints. x and y can take continuous or integer values. Note that all the problem data are deterministically known.

Bilevel programs allow the modeling of situations in which a decision-maker, hereafter the leader, optimizes his objective by taking explicitly into account the response of another decision maker or set of decision makers (the follower) to his/her decisions. Bilevel programs are closely related to Stackelberg (leader-follower) games as well as to the principal-agent paradigm in economics. In other words, bilevel programs can be considered as demand-offer equilibrium models where the demand is the result of another mathematical problem. Bilevel problems can be formulated through the generic CS model when $Y(x)$ corresponds to the optimal solutions of a mathematical program defined for a given x, i.e. $Y(x) = \operatorname{argmin}\{h(x,y)|y \in Y_2, (x,y) \in XY_2\}$ where Y_2 is defined by a set of constraints on y, and XY_2 is associated with the linking constraints.

In robust/stochastic optimization, it is assumed that the data related to a problem are subject to uncertainty. In stochastic optimization, probability distributions governing the data are known, and the objective function involves mathematical expectation(s). In robust optimization, uncertain data take value within specified sets, and the function to optimize is formulated in terms of a min-max objective typically (the solution must be optimal for the worst-case scenario). . A standard modeling of uncertainty on data is obtained by defining a

set of possible scenarios that can be described explicitly or implicitly. In stochastic optimization, in addition, a probability of occurrence is associated with each scenario and the expected objective value is optimized.

3.3. Solving problems with complex structures

Standard solution methods developed for CS problems solve independent sub-problems associated with each type of variables without explicitly integrating their interactions or integrating them iteratively in a heuristic way. However these subproblems are intrinsically linked and should be addressed jointly. In *mathematical optimization* a classical approach is to approximate the convex hull of the integer solutions of the model by its linear relaxation. The main solution methods are i) polyhedral solution methods which strengthen this linear relaxation by adding valid inequalities, ii) decomposition solution methods (Dantzig Wolfe, Lagrangian Relaxation, Benders decomposition) which aim to obtain a better approximation and solve it by generating extreme points/rays. Main challenges are i) the analysis of the strength of the cuts and their separations for polyhedral solution methods, ii) the decomposition schemes and iii) the extreme points/rays generations for the decomposition solution methods.

The main difficulty in solving *bilevel problems* is due to their non convexity and non differentiability. Even linear bilevel programs, where all functions involved are affine, are computationally challenging despite their apparent simplicity . Up to now, much research has been devoted to bilevel problems with linear or convex follower problems. In this case, the problem can be reformulated as a single-level program involving complementarity constraints, exemplifying the dual nature, continuous and combinatorial, of bilevel programs.

4. Application Domains

4.1. Introduction

It is hard to find an aspect of our modern-day economy whose design, management and control do not critically depend on the solution of one or more CS decision problems. Even if they are pervasive, many of them are still not "satisfactorily" solved and constitute a strong challenge to research teams nowadays. The innovative research goals of INOCS have, without doubt, a strategic importance in the application field. CS problems appear in a broad range of application fields such as the next one cited hereafter.

1. *the energy sector* where decisions of distinct nature such as production and distribution are jointly determined;
2. *supply chain management* where location and routing decisions have to be defined jointly even if they refer to different time horizons;
3. *revenue management* where the determination of prices for services or products requires to take explicitly into account the strategic consumers' behaviour.

5. Bilateral Contracts and Grants with Industry

5.1. Bilateral Contracts with Industry

- Industrial contract with EDF, Bilevel models for tariff setting problems in the energy field (2010-2011; 2012-2015)
- Industrial contract with Coliweb, Load charge assignent for freight deliveries (2015-2016)

5.2. Bilateral Grants with Industry

- Gaspard Monge Program for Optimisation and operationnal research, Design and Pricing of Electricity Services in a Competitive Environment (2015-2018)

- Gaspard Monge Program for Optimisation and Operationnal Research, BENMIP A Generic Benders Decomposition based (Mixed) Integer Programming Solver, (2015-2016)

6. Partnerships and Cooperations

6.1. National Initiatives

6.1.1. ANR

ANR project Transports Terrestres Durable "RESPET - Gestion de réseaux de service porte-à-porte efficace pour le transport de marchandises", in collaboration with LAAS (Toulouse), DHL, JASSP, LIA (Univ. Avignon) (2011-2015).

6.1.2. National Initiatives (Belgium)

Combinatorial Optimization: Meta-heuristics and Exact Methods (2012-2017, coordinator: Bernard Fortz (GOM-ULB/INOCS-Inria). Study and modeling of combinatorial optimization problems; Advancements in algorithmic techniques; Implementation of solution methods for large-scale, practically relevant problems.

6.2. European Initiatives

6.2.1. FP7 & H2020 Projects

Program: BEWARE FELLOWSHIPS Academia

Project acronym: PARROT

Project title: Planning Adapter performing ReRouting and Optimization of Timing

Duration: 10/2014 - 09/2017

Coordinator: Martine Labbé (ULB)

Other partners: INFRABEL (Belgique).

Abstract: The Belgian railway company needs a new tool for the trains which have to be rescheduled when the company must do some maintenance operations on the network. The difficulties are the number of constraints, the size of the network, the quantity of trains and many other features related to the Belgian railway system. These difficulties imply that some choices have to be made to balance the quantity of work feasible in the 3 years project. After developing an interface between the INFRABEL database and the framework used in this project, a first model (MIP) will be implemented and then tested.

6.2.2. Collaborations in European Programs, except FP7 & H2020

Program: JPI Urban Europe

Project acronym: e4-share

Project title: Models for Ecological, Economical, Efficient, Electric Car-Sharing

Duration: 11/2014 - 10/2017

Coordinator: Markus Leitner (U. Vienna, Austria)

Other partners:

- AIT, Vienna, Austria
- GOM, Université Libre de Bruxelles (Inria/INOCS)
- Department of Electrical, Electronics and information Engineering, Alma Mater University of Bologna, Italy
- iC consulenten Ziviltechniker GesmbH, Vienna, Austria

Abstract: Car-sharing systems and the usage of electric cars become increasingly popular among urban citizens. Thus, providing vast opportunities to meet todays challenges in terms of environmental objectives, sustainability and living quality. Our society needs to manage a transformation process that ultimately shall lead to fewer emissions and less energy consumption while increasing the quality of public space available.

In e4-share, the team will lay the foundations for efficient and economically viable electric car-sharing systems by studying and solving the optimization problems arising in their design and operations. A main goal is to derive generic methods and strategies for optimized planning and operating in particular for flexible variants which best meet preferences of customers but impose nontrivial challenges to operators. This project will develop novel, exact and heuristic, numerical methods for finding suitable solutions to the optimization problems arising at the various planning levels as well as new, innovative approaches considering these levels simultaneously.

The project e4-share (Models for Ecological, Economical, Efficient, Electric Car-Sharing) runs from October 2014 to October 2017 and is funded by FFG, INNOVIRIS and MIUR via Joint Programme Initiative Urban Europe. The project comprises an interdisciplinary team of five partners from Austria, Belgium and Italy.

6.3. International Initiatives

6.3.1. Informal International Partners

- CIRRELT, GERAD, Montreal (P. Marcotte, G. Savard, M. Gendreau, G. Laporte, B. Gendron, ..)
- University of Maastricht (Stan Van Hoesel)
- Politecnico di Milano (Edouardo Amaldi)
- University of Lisbon (Luis Gouveia)
- University of Aveiro (Cristina Requejo)
- University of Sevilla (Justo Puerto)
- University of Chile (Fernando Ordonez)

7. Dissemination

7.1. Teaching - Supervision - Juries

7.1.1. Supervision

PhD in progress : Luciano Porretta, “Models and methods for the study of genetic associations”, May 2011, Bernard Fortz

PhD in progress : Sezin Afsar,"Revenue Optimization and Demand Response Models using bilevel programming in smart grid systems”,October 2011 , Luce Brotcorne

PhD in progress : Martim Moniz, “Traffic engineering in Ethernet networks”, November 2012, Bernard Fortz and Luis Gouveia

PhD in progress : Bayrem Tounsi,"Gestion de rśeaux de services porte à porte pour le transport de marchandies ”, October 2012 , Luce Brotcorne

PhD in progress : Carlos Casorran, “A Mathematical Optimization Approach for Stack- elberg Solutions of Bimatrix Games", July 2013, Martine Labbé

PhD in progress : Fabio Sciamannini, “Exact algorithms for variants of the coloring problem”, September 2014, Bernard Fortz, Martine Labbé and Isabella Lari

PhD in progress : Jérôme De Boeck, “Decomposition methods for combinatorial optimization problems", Octobre 2015, Bernard Fortz

PhD in progress : Léonard Von Niederhausern, "Approches bi-niveau pour la tarification de services énergéiques ", Octobre 2015 , Luce Brotcorne

8. Bibliography

Publications of the year

Articles in International Peer-Reviewed Journals

[1] S. BINART, P. DEJAX, M. GENDREAU, F. SEMET. *A 2-stage method for a field service routing problem with stochastic travel and service times*, in "Computers and Operations Research", 2016, vol. 65, pp. 64-75, https://hal.archives-ouvertes.fr/hal-01223020

[2] Q. Q. B. BOTTON, B. FORTZ, L. GOUVEIA. *On the hop-constrained survivable network design problem with reliable edges*, in "Computers & operations research", 2015, vol. 64, pp. 159-167, SCOPUS: ar.j, https://hal.archives-ouvertes.fr/hal-01255247

[3] D. CATANZARO, M. LABBÉ, L. GOUVEIA. *Improved integer linear programming formulations for the job Sequencing and tool Switching Problem*, in "European Journal of Operational Research", 2015, Language of publication: en, https://hal.archives-ouvertes.fr/hal-01255516

[4] D. C. CATTARUZZA, N. ABSI, D. FEILLET. *Vehicle routing problems with multiple trips*, in "4OR: A Quarterly Journal of Operations Research", 2016, forthcoming, http://hal-emse.ccsd.cnrs.fr/emse-01250603

[5] T. R. L. T. CHRISTENSEN, M. LABBÉ. *A branch-cut-and-price algorithm for the piecewise linear transportation problem*, in "European Journal of Operational Research", 2015, vol. 245, n^{o} 3, pp. 645-655, SCOPUS: ar.j, https://hal.archives-ouvertes.fr/hal-01255518

[6] B. GENDRON, P.-V. KHUONG, F. SEMET. *Multilayer variable neighborhood search for two-level uncapacitated facility location problems with single assignment*, in "Networks", 2015, vol. 66, n^{o} 3, pp. 214-234, https://hal.archives-ouvertes.fr/hal-01223087

[7] R. LAHYANI, L. C. COELHO, G. LAPORTE, F. SEMET. *A multi-compartment vehicle routing problem arising in the collection of olive oil in Tunisia*, in "Omega", 2015, vol. 51, pp. 1-10, https://hal.archives-ouvertes.fr/hal-01223093

[8] R. LAHYANI, M. KHEMAKHEM, F. SEMET. *Rich vehicle routing problems: From a taxonomy to a definition*, in "European Journal of Operational Research", February 2015, vol. 241, n^{o} 1, pp. 1-14, https://hal.archives-ouvertes.fr/hal-01146605

Articles in Non Peer-Reviewed Journals

[9] S. AFSAR, L. BROTCORNE, P. MARCOTTE, G. SAVARD. *Achieving an optimal trade-off between revenue and energy peak within a smart grid environment*, in "Renewable Energy", March 2016, https://hal.inria.fr/hal-01230915

Invited Conferences

[10] B. FORTZ, E. GORGONE, D. PAPADIMITRIOU. *Computational strategies for a multi-period network design and routing problem*, in "EURO 2015", Glasgow, United Kingdom, July 2015, https://hal.inria.fr/hal-01261383

International Conferences with Proceedings

[11] L. MALTA, N. JOZEFOWIEZ, F. SEMET. *Models for Multimodal Freight Transportation Integrating Consolidation and Transportation Phases*, in "International Conference on Operations Research and Enterprise Systems", Lisbon, Portugal, SCITEPRESS, 2015, https://hal.archives-ouvertes.fr/hal-01223091

[12] D. PAPADIMITRIOU, B. FORTZ, E. GORGONE. *Lagrangian relaxation for the time-dependent combined network design and routing problem*, in "2015 IEEE International Conference on Communications, ICC 2015, London, United Kingdom, June 8-12, 2015", Londres, United Kingdom, 2015, pp. 6030-6036, Language of publication: en, https://hal.archives-ouvertes.fr/hal-01255245

[13] D. PAPADIMITRIOU, B. FORTZ. *Robust cooperative monitoring problem*, in "Reliable Networks Design and Modeling (RNDM), 2015 7th International Workshop on", Munich, Germany, 2015, pp. 186-193, Language of publication: en, https://hal.archives-ouvertes.fr/hal-01255244

Conferences without Proceedings

[14] L. BROTCORNE, S. AFSAR, P. MARCOTTE, G. SAVARD. *Energy Pricing Problems for Demand Sideand Revenue Management*, in "INFORMS", Philadelphia, United States, November 2015, https://hal.inria.fr/hal-01260977

[15] L. BROTCORNE, E. ALEKSEEVA, S. LEPAUL. *A Bilevel Approach to Determine New Energy Service Prices*, in "EUROPT", Edinbourgh, United Kingdom, July 2015, https://hal.inria.fr/hal-01260970

[16] H. CALIK, B. FORTZ. *Location, allocation, and routing decisions in an electric car sharing system*, in "OR 2015", Vienna, Austria, September 2015, https://hal.inria.fr/hal-01261397

[17] D. C. CATTARUZZA, L. BROTCORNE, N. MITTON, T. RAZAFINDRALAMBO, F. SEMET. *A two-phase matheuristic for the multi-robot routing problem under connectivity constraints*, in "Congrès annuel de la société Française de Recherche Opérationnelle et d'Aide à la Décision (ROADEF)", Compiègne, France, February 2016, https://hal.inria.fr/hal-01256730

[18] D. CATTARUZZA, B. TOUNSI, L. BROTCORNE, F. SEMET. *A matheuristic for the packaging and shipping problem*, in "Odysseus 2015", Ajaccio, France, May 2015, https://hal.inria.fr/hal-01260041

[19] D. CATTARUZZA, B. TOUNSI, L. BROTCORNE, F. SEMET. *A matheuristic for the packaging and shipping problem*, in "Roadef 2015", Marseille, France, February 2015, https://hal.inria.fr/hal-01260049

[20] B. FORTZ, E. GORGONE, D. PAPADIMITRIOU. *Computational strategies for a multi-period network design and routing problem*, in "ROADEF 2015", Marseille, France, February 2015, https://hal.inria.fr/hal-01261366

[21] B. FORTZ, E. GORGONE, D. PAPADIMITRIOU. *Lagrangean Relaxation for the Generalized Multicommodity Capacitated Network Design Problem*, in "INOC 2015", Warsaw, Poland, May 2015, https://hal.inria.fr/hal-01261376

[22] S. GELAREH, R. NEAMATIAN MONEMI, F. SEMET. *Capacitated Hub Routing Problem in Hub-and-Feeder Network Design: Modeling and Solution Algorithm*, in "ODYSSEUS 2015 - Sixth International Workshop on Freight Transportation and Logistics", Ajaccio, France, May 2015, https://hal.archives-ouvertes.fr/hal-01222923

[23] M. M. MONIZ, B. FORTZ, L. GOUVEIA. *Optimal design of switched Ethernet networks implementing the multiple spanning tree protocol*, in "OR 2015", Vienna, Austria, September 2015, https://hal.inria.fr/hal-01261389

[24] D. PAPADIMITRIOU, B. FORTZ. *Cooperative Monitoring Problem in Presence of Traffic Uncertainty*, in "OR 2015", Vienna, Austria, September 2015, https://hal.inria.fr/hal-01261391

[25] B. TOUNSI, L. BROTCORNE, F. SEMET. *Multi-period stochastic packing and shipping model for online retail*, in "Roadef 2015", Marseille, France, February 2015, https://hal.inria.fr/hal-01260018

[26] B. TOUNSI, Y. HAYEL, L. BROTCORNE, D. QUADRI. *Programmation mathématique avec contrainte d'équilibre stochastique pour un problème de tarification de services de livraison* , in "Roadef 2015", Marseille, France, February 2015, https://hal.inria.fr/hal-01260135

[27] B. TOUNSI, Y. HAYEL, D. QUADRI, L. BROTCORNE. *Mathematical Programming with Stochastic Equilibrium Constraints applied to Optimal Last-mile Delivery Services*, in "7th International Network Optimization Conference", Varsovie, Poland, May 2015, 8 p. , https://hal.inria.fr/hal-01204647

Scientific Books (or Scientific Book chapters)

[28] H. CALIK, M. LABBÉ, H. YAMAN. *p-Center Problems*, in "Location Science", Springer International Publishing, 2015, pp. 79-92, Language of publication: en, https://hal.archives-ouvertes.fr/hal-01255517

[29] B. FORTZ. *Location Problems in Telecommunications*, in "Location Science", Springer International Publishing, 2015, pp. 537-554, Language of publication: en, https://hal.archives-ouvertes.fr/hal-01255246

Other Publications

[30] S. AFSAR, L. BROTCORNE, P. MARCOTTE, G. SAVARD. *Exact and Heuristic Methods for Energy Pricing Problem*, January 2016, working paper or preprint, https://hal.inria.fr/hal-01230919