IN PARTNERSHIP WITH:
Ecole des Mines de Nantes

Université Nantes

Activity Report 2015

Project-Team TASC

Theory, Algorithms and Systems for Constraints

IN COLLABORATION WITH: Laboratoire d'Informatique de Nantes Atlantique (LINA)

RESEARCH CENTER
Rennes - Bretagne-Atlantique

THEME
Architecture, Languages and Compilation

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Creation of the Project-Team: 2011 January 01

Keywords:

Computer Science and Digital Science:

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6.1. - Mathematical Modeling
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Other Research Topics and Application Domains:

4.1. - Fossile energy production
4.2. - Renewable energy production
8.3. - Urbanism and urban planning

1. Members

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2. Overall Objectives

2.1. Objectives of the team

2.1.1. Origin and Current Situation

Constraint programming emerges in the eighties and develops at **the intersection of Artificial Intelligence and Operations Research**, of Computer Science and Mathematics. Multidisciplinary by nature it keeps on using knowledge from various topics such as discrete mathematics, theoretical computer science (graph theory, combinatorics, algorithmic, complexity), functional analysis and optimization, IT and software engineering. Constraint programming was identified in 1996 by the ACM as a *strategic topic for Computer Science*. The turn of the century has seen the development of optimization technology in the industry (with notably Ilog, IBM, Dash and more recently Microsoft, http://code.msdn.microsoft.com/solverfoundation, Google and Dynadec) and the corresponding scientific field, at the border of Constraint Programming, Mathematical Programming, Local Search and Numerical Analysis. Optimisation technology is now assisting public sector, companies and people to some extent for making decisions that use resources better and match specific requirements in an increasingly complex world. Indeed, computer aided decision and optimization is becoming one of the cornerstones for providing assistance to all kinds of human activities.

Today, with the preeminence of optimization technology in most industrial sectors, we argue that quick and ad hoc solutions, often used today, cannot support the long-term development of optimization technology and its broad diffusion. We also argue that there should be a much more direct link between mathematical results and their systematic reuse in the main fields of optimization technology.

2.1.2. General Challenges

In spite of its importance, computer aided decision and optimization suffers from a number of fundamental weaknesses that prevent from taking advantage of its full potential and hinder its progress and its capacity to deal with more and more complex situations. This can be mostly blamed on the diversity of actors, which are:

- Spread out in distinct scientific communities, each with its own focus:
  - On the one hand, computer science for providing languages, modelling tools and libraries. While focusing on providing flexible and powerful programming paradigm that can be easily deployed and maintained on modern architectures, it does not address the central question of how to come up in a systematic way with efficient methods for optimization and decision problems.
  - On the other hand, applied mathematics for the theory part. The focus is to come up with powerful abstractions that allow understanding the structure of a class of problems, independently of its practical and systematic uses in modern software components.
- Spread out in distinct technological communities, each independently pushing its own solving paradigm like constraint programming, linear and integer programming, continuous optimization, constraint-based local search (e.g., COMET). To some extent, most of these techniques exploit in different ways the same mathematical results, that are manually adapted to fit the main way to proceed of a given technology.

Thus, a first challenge encountered by constraint programming is the design of computer systems implementing **in a transparent way** effective solving techniques.

- Ideally, the user must be able to **describe his problem in a high level modelling language** without being concerned with the underlying solving mechanisms used. Such systems must also be independent both from any computer programming language and from any resolution engine.
- In order to assists user, systems must also offer **digital knowledge base in problem solving** that make available state of the art models and heuristics for large set of well identified problems.
- Lastly, the user must have the ability to interpret the returned solutions, in particular within the context of **over constrained problems where it is necessary to partly relax some constraints**, and that in the most realistic possible way.

A second challenge resides in the **speed of resolution especially in the context of large-scale data**. One has to adapt techniques such as generic consistency algorithms, graph algorithms, mathematical programming, meta-heuristics and to integrate them within the framework of constraint programming. This integration generates new questions such as the design of incremental algorithms, the automatic decomposition or the automatic reformulation of problems.

Finally a third challenge deals with the use of constraint programming in the context of **complex industrial problems**, especially when both discrete and continuous aspects are present. Complexity has multiple causes such as:

- the combination of temporal and spatial aspects, of continuous and discrete aspects,
- the dynamic character of some phenomena inducing a modification of the constraints and data during time,
- the difficulty of expressing some physical constraints, e.g. load balancing and temporal stability,
- the necessary decomposition of large problems inducing significant solution performance losses.

3. Research Program

3.1. Overview

Basic research is guided by the challenges raised before: to classify and enrich the models, to automate reformulation and resolution, to dissociate declarative and procedural knowledge, to come up with theories and tools that can handle problems involving both continuous and discrete variables, to develop modelling tools and to come up with solving tools that scale well. On the one hand, **classification aspects** of this research are integrated within a knowledge base about combinatorial problem solving: the global constraint catalog (see http://sofdem.github.io/gccat/). On the other hand, **solving aspects** are capitalized within the constraint solving system CHOCO. Lastly, within the framework of its activities of valorisation, teaching and of partnership research, the team uses constraint programming for solving various concrete problems. The challenge is, on one side to increase the visibility of the constraints in the others disciplines of computer science, and on the other side to contribute to a broader diffusion of the constraint programming in the industry.

3.2. Fundamental Research Topics

This part presents the research topics investigated by the project:

- Global Constraints Classification, Reformulation and Filtering,
- Convergence between Discrete and Continuous,
- Dynamic, Interactive and over Constrained Problems,
- Solvers.

These research topics are in fact not independent. The work of the team thus frequently relates transverse aspects such as explained global constraints, Benders decomposition and explanations, flexible and dynamic constraints, linear models and relaxations of constraints.

3.2.1. Constraints Classification, Reformulation and Filtering

In this context our research is focused (a) first on identifying recurring combinatorial structures that can be used for modelling a large variety of optimization problems, and (b) exploit these combinatorial structures in order to come up with efficient algorithms in the different fields of optimization technology. The key idea for achieving point (b) is that many filtering algorithms both in the context of Constraint Programming, Mathematical Programming and Local Search can be interpreted as the maintenance of invariants on specific domains (e.g., graph, geometry). The systematic classification of global constraints and of their relaxation brings a synthetic view of the field. It establishes links between the properties of the concepts used to describe constraints and the properties of the constraints themselves. Together with SICS, the team develops and maintains *a catalog of global constraints*, which describes the semantics of more than 431 constraints, and proposes a unified mathematical model for expressing them. This model is based on graphs, automata and logic formulae and allows to derive filtering methods and automatic reformulation for each constraint in a unified way (see http://www.emn.fr/x-info/sdemasse/gccat/index.html). We consider hybrid methods (i.e., methods that involve more than one optimization technology such as constraint programming, mathematical programming or local search), to draw benefit from the respective advantages of the combined approaches. More fundamentally, the study of hybrid methods makes it possible to compare and connect strategies of resolution specific to each approach for then conceiving new strategies. Beside the works on classical, complete resolution techniques, we also investigate local search techniques from a mathematical point of view. These partly random algorithms have been proven very efficient in practice, although we have little theoretical knowledge on their behaviour, which often makes them problem-specific. Our research in that area is focused on a probabilistic model of local search techniques, from which we want to derive quantified information on their behaviour, in order to use this information directly when designing the algorithms and exploit their performances better. We also consider algorithms that maintain local and global consistencies, for more specific models. Having in mind the trade off between genericity and effectiveness, the effort is put on the efficiency of the algorithms with guarantee on the produced levels of filtering. This effort results in adapting existing techniques of resolution such as graph algorithms. For this purpose we identify necessary conditions of feasibility that can be evaluated by efficient incremental algorithms. Genericity is not neglected in these approaches: on the one hand the constraints we focus on are applicable in many contexts (for example, graph partitioning constraints can be used both in logistics and in phylogeny); on the other hand, this work led to study the portability of such constraints and their independence with specific solvers. This research orientation gathers various work such as strong local consistencies, graph partitioning constraints, geometrical constraints, and optimization and soft constraints. Within the perspective to deal with complex industrial problems, we currently develop meta constraints (e.g. *geost*) handling all together the issues of large-scale problems, dynamic constraints, combination of spatial and temporal dimensions, expression of business rules described with first order logic.

3.2.2. Convergence between Discrete and Continuous

Many industrial problems mix continuous and discrete aspects that respectively correspond to physical (e.g., the position, the speed of an object) and logical (e.g., the identifier, the nature of an object) elements. Typical examples of problems are for instance:

- *Geometrical placement problems* where one has to place in space a set of objects subject to various geometrical constraints (i.e., non-overlapping, distance). In this context, even if the positions of the objects are continuous, the structure of optimal configurations has a discrete nature.
- *Trajectory and mission planning problems* where one has to plan and synchronize the moves of several teams in order to achieve some common goal (i.e., fire fighting, coordination of search in the context of rescue missions, surveillance missions of restricted or large areas).
- *Localization problems in mobile robotic* where a robot has to plan alone (only with its own sensors) its trajectory. This kind of problematic occurs in situations where the GPS cannot be used (e.g., under water or Mars exploration) or when it is not precise enough (e.g., indoor surveillance, observation of contaminated sites).

Beside numerical constraints that mix continuous and integer variables we also have global constraints that involve both type of variables. They typically correspond to graph problems (i.e., graph colouring, domination in a graph) where a graph is dynamically constructed with respect to geometrical and-or temporal constraints. In this context, the key challenge is avoiding decomposing the problem in a discrete and continuous parts as it is traditionally the case. As an illustrative example consider *the wireless network deployment problem*. On the one hand, the continuous part consists of finding out where to place a set of antenna subject to various geometrical constraints. On the other hand, by building an interference graph from the positions of the antenna, the discrete part consists of allocating frequencies to antenna in order to avoid interference. In the context of convergence between discrete and continuous variables, our goals are:

- First to identify and compare typical class of techniques that are used in the context of continuous and discrete solvers.

- To see how one can unify and/or generalize these techniques in order to handle in an integrated way continuous and discrete constraints within the same framework.

3.2.3. Dynamic, Interactive and over Constrained Problems

Some industrial applications are defined by a set of constraints which may change over time, for instance due to an interaction with the user. Many other industrial applications are over-constrained, that is, they are defined by set of constraints which are more or less important and cannot be all satisfied at the same time. Generic, dedicated and explanation-based techniques can be used to deal efficiently with such applications. Especially, these applications rely on the notion of *soft constraints* that are allowed to be (partially) violated. The generic concept that captures a wide variety of soft constraints is the violation measure, which is coupled with specific resolution techniques. Lastly, soft constraints allow to combine the expressive power of global constraints with local search frameworks.

3.2.4. Solvers

- *Discrete solver* Our theoretical work is systematically validated by concrete experimentations. We have in particular for that purpose the CHOCO constraint platform. The team develops and maintains CHOCO initially with the assistance of the laboratory e-lab of Bouygues (G. Rochart), the company Amadeus (F. Laburthe), and others researchers such as N. Jussien and H. Cambazard (4C, INP Grenoble). Since 2008 the main developments are done by Charles Prud'homme and Xavier Lorca. The functionalities of CHOCO are gradually extended with the outcomes of our works: design of constraints, analysis and visualization of explanations, etc. The open source CHOCO library is downloaded on average 450 times each month since 2006. CHOCO is developed in line with the research direction of the team, in an open-minded scientific spirit. Contrarily to other solvers where the efficiency often relies on problem-specific algorithms, CHOCO aims at providing the users both with reusable techniques (based on an up-to-date implementation of the global constraint catalogue) and with a variety of tools to ease the use of these techniques (clear separation between model and resolution, event-based solver, management of the over-constrained problems, explanations, etc.).
- *Continuous solver* Since 2009 year, due to the hiring of Gilles Chabert, the team is also involved in the development of the continuous constraint solver IBEX. These developments led us to new research topics, suitable for the implementation of discrete and continuous constraint solving systems: portability of the constraints, management of explanations, incrementality and recalculation. They partially use aspect programming (in collaboration with the Inria ASCOLA team).
- *Constraint programming and verification* Constraint Programming has already had several applications to verification problems. It also has many common ideas with Abstract Interpretation, a theory of approximation of the semantics of programs. In both cases, we are interested in a particular set (solutions in CP, program traces in semantics), which is hard or impossible to compute, and this set is replaced by an over-approximation (consistent domains / abstract domains). Previous works (internship of Julie Laniau, PhD of Marie Pelleau, collaboration with the Abstract Interpretation team at the ENS and Antoine Miné in particular) have exhibited some of these links, and identified some situations where the two fields, Abstract Interpretation and Constraint Programming, can complement each other. It is the case in real-time stream processing languages, where Abstract Interpretation techniques may not be precise enough when analyzing loops. With the PhD of Anicet Bart, we are currently working on using CP techniques to find loop invariants for the Faust language, a functional sound processing language.

This work around the design and the development of solvers thus forms the fourth direction of basic research of the project.

4. Application Domains

4.1. Introduction

Constraint programming deals with the resolution of decision problems by means of rational, logical and computational techniques. Above all, constraint programming is founded on a clear distinction between, on the one hand the description of the constraints intervening in a problem, and on the other hand the techniques used for the resolution. The ability of constraint programming to handle in a flexible way heterogeneous constraints has raised the commercial interest for this paradigm in the early nighties. Among his fields of predilection, one finds traditional applications such as computer aided decision-making, scheduling, planning, placement, logistics or finance, as well as applications such as electronic circuits design (simulation, checking and test), DNA sequencing and phylogeny in biology, configuration of manufacturing products or web sites, formal verification of code.

4.2. Panorama

In 2015 the TASC team was involved in the following application domains:

- *Replanning* in industrial timetabling problems in a Labcom project with Eurodécision.
- *Planning and replanning* in Data Centres taking into account energy consumption in the EPOC (Energy Proportional and Opportunistic Computing system) project.
- *Packing complex shapes* in the context of a warehouse (NetWMS2 project).
- Building decision support system for *resilient city development planning wrt climat change* (GRACeFUL project).
- *Optimizing electricity production* in the context of the Gaspard Monge call program for Optimisation and Operation Research in the context of electricity production. In 2015 we were focussing on the systematic reformulation of time-series constraints for MIP solvers. This was done in order to integrate time-series constraints in existing integer linear programming models for electricity production.

5. Highlights of the Year

5.1. Highlights of the Year

5.1.1. Awards

1. The PhD thesis of Jean-Guillaume Fages about *the use of graph structure in constraint programming* got the following awards:
   - PhD thesis award by the French association for AI.
   - Doctoral research award by the Association for Constraint Programming.
2. The paper of the PhD student Anicet Bart (*Verifying a Real-Time Language with Constraints*, Anicet Bart, Charlotte Truchet and Eric Monfroy [29]) got the best paper award of the SAT/CSP track of the ICTAI 2015 conference.
3. The solver Choco3 got a bronze medal in the 2015 minizinc challenge.

BEST PAPER AWARD:

[29]
A. BART, C. TRUCHET, E. MONFROY. *Verifying a Real-Time Language with Constraints*, in "27th IEEE International Conference on Tools with Artificial Intelligence", Vietri sul Mare, Italy, 2015, https://hal.archives-ouvertes.fr/hal-01234188

6. New Software and Platforms

6.1. AIUR

(Artificial Intelligence Using Randomness)

FUNCTIONAL DESCRIPTION

The main idea is to be unpredictable by making some stochastic choices. The AI starts a game with a "mood" randomly picked up among 5 moods, dictating some behaviours (aggressive, fast expand, macro-game, ...). In addition, some other choices (productions, timing attacks, early aggressions, ...) are also taken under random conditions.

Learning is an essential part of AIUR . For this, it uses persistent I/O files system to record which moods are efficient against a given opponent, in order to modify the probability distribution for the mood selection. The current system allows both on-line and off-line learning.

- Contact: Florian Richoux
- URL: https://github.com/AIUR-group/AIUR

6.2. CHOCO

SCIENTIFIC DESCRIPTION

For fourth consecutive year, CHOCO has participated at the MiniZinc Challenge , an annual competition of constraint programming solvers. Since then, in concurrency with 16 other solvers, CHOCO has won two silver medals and four bronze medals in three out of four categories (Free search, Parallel search and Open class). Five versions have been released all year long, the last one (v3.3.3, Dec. 22th) has the particularity to be promoted on Maven Central Repository. The major modifications were related to an improvement of the overall solver (efficiency, stability and robustness) but also a simplification of the API. As an example, more flexibility has been injected to the search loop, a central concept of the solver.

FUNCTIONAL DESCRIPTION

CHOCO is a Free and Open-Source Software dedicated to Constraint Programming. It is a Java library written under BSD 4-clause license (700 classes, 134K lines of code). It aims at describing hard combinatorial problems in the form of Constraint Satisfaction Problems and solving them with Constraint Programming techniques. The user models its problem in a declarative way by stating the set of constraints that need to be satisfied in every solution. Then, CHOCO solves the problem by alternating constraint filtering algorithms with a search mechanism. In addition to native explanations system, soft constraints and global constraints, the library is, in practice, open, easy to integrate and to tweak. A User Guide is now available: 164 pages describing how to use CHOCO, together with responsive online support (forums and mailing-lists).

- Participants: Charles Prud'homme, Nicolas Beldiceanu, Jean-Guillaume Fages, Xavier Lorca, Thierry Petit and Rémi Douence
- Partner: Ecole des Mines de Nantes
- Contact: Charles Prud'homme
- URL: http://www.choco-solver.org/

6.3. GCCat

Global Constraint Catalog

KEYWORDS: Constraint Programming - Global constraint - Catalogue - Graph - Automaton - Transducer - First order formula - meta-data - ontology - symmetry - counting -

FUNCTIONAL DESCRIPTION

This global constraint catalog presents a catalogue of global constraints where each constraint is explicitly described in terms of graph properties and/or automata and/or first order logical formulae with arithmetic. When available, it also presents some typical usage as well as some pointers to existing filtering algorithms. This year we were preparing a second volume of the catalog focused on time-series constraints. It presents a restricted set of finite transducers used to synthesise structural time-series constraints described by means of a multi-layered functions composition scheme. Second it provides the corresponding synthesised catalogue of structural time-series constraints where each constraint is explicitly described in terms of automata with accumulators.

- Participants: Nicolas Beldiceanu, Mats Carlsson, Sophie Demassey and Helmut Simonis
- Contact: Nicolas Beldiceanu
- URL: http://sofdem.github.io/gccat/gccat/index.html

6.4. GHOST

General meta-Heuristic Optimization Solving Tool
FUNCTIONAL DESCRIPTION

GHOST, i.e. General meta-Heuristic Optimization Solving Tool, is a template C++ library designed for StarCraft:BroodWartm. GHOST implements a meta-heuristic solver aiming to solve any kind of combinatorial and optimization RTS-related problems represented by a csp /cop. The solver handles dedicated geometric and assignment constraints in a way that is compatible with very strong real time requirements.

- Contact: Florian Richoux
- URL: http://github.com/richoux/GHOST

6.5. IBEX

pour le calcul ensembliste (calcul numérique garanti avec propagation rigoureuse d'incertitudes)
KEYWORD: Constraint Programming
SCIENTIFIC DESCRIPTION

In 2014 the development on IBEX has focused on the following points:

Rejection test based on first-order conditions (see First Order Rejection Tests For Multiple-Objective Optimization, A. Goldsztejn et al. [42]).

Q-intersection (see Q-intersection Algorithms for Constraint-Based Robust Parameter Estimation, C. Carbonnel et al., AAAI 2014)
FUNCTIONAL DESCRIPTION

IBEX is a C++ library for solving nonlinear constraints over real numbers. The main feature of Ibex is its ability to build solver/paver strategies declaratively through the contractor programming paradigm. It also comes with a black-box solver and a global optimizer.

- Participants: Ignacio Araya, Gilles Chabert, Bertrand Neveu, Ignacio Salas Donoso and Gilles Trombettoni
- Partners: ENSTA - Ecole des Ponts ParisTech
- Contact: Gilles Chabert
- URL: http://www.ibex-lib.org/

7. New Results

7.1. IBEX

The development of the Ibex library has continued. The main developments in 2015 are:

- the complete refactoring of the multi-heap internal structure used for search space exploration in the global optimizer
- the creation of a new module for explicit set (or pavings) manipulation/algebra with full documentation and tutorial

7.2. NetWMS2

New advances have been made in the context of packing curved objects. The packing algorithm developed in 2014 have been published in ICJAI'15, along with new features. The calculation of the *penetration depth* (a classical measure of violation cost for overlapping objects) has also been extended to the case of parametric curves (like, e.g., Bezier curves) and new experiments have been conducted with our solver for this new type of objects.

We deal with the problem of packing two-dimensional objects of quite arbitrary shapes including in particular curved shapes (like ellipses) and assemblies of them. This problem arises in industry for the packaging and transport of bulky objects which are not individually packed into boxes, like car spare parts. There has been considerable work on packing curved objects but, most of the time, with specific shapes; one famous example being the circle packing problem. There is much less algorithm for the general case where different shapes can be mixed together. A successful approach has been proposed recently by Martinez et al. and the algorithm we propose here is an extension of their work. Martinez et al. use a stochastic optimization algorithm with a fitness function that gives a violation cost and equals zero when objects are all packed. Their main idea is to define this function as a sum of $\binom{n}{2}$ elementary functions that measure the overlapping between each pair of different objects. However, these functions are ad-hoc formulas. Designing ad-hoc formulas for every possible combination of object shapes can be a very tedious task, which dramatically limits the applicability of their approach. We generalize the approach by replacing the ad-hoc formulas with a numerical algorithm that automatically measures the overlapping between two objects. Then, we come up with a fully black-box packing algorithm that accept any kind of objects.

7.3. Time-Series Constraints

We describe a large family of constraints for structural time series by means of function composition. These constraints are on aggregations of features of patterns that occur in a time series, such as the number of its peaks, or the range of its steepest ascent. The patterns and features are usually linked to physical properties of the time series generator, which are important to capture in a constraint model of the system, i.e. a conjunction of constraints that produces similar time series. We formalise the patterns using finite transducers, whose output alphabet corresponds to semantic values that precisely describe the steps for identifying the occurrences of a pattern. Based on that description, we automatically synthesise automata with accumulators, as well as constraint checkers. The description scheme not only unifies the structure of the existing 30 time-series constraints in the Global Constraint Catalogue, but also leads to over 600 new constraints, with more than 100,000 lines of synthesised code.

7.4. New Global Constraints

This year we introduce new generic global constraints that can be respectively used to reformulate a number of constraints where the formulation become easy once some tuples are sorted, and to express temporal relation between two sequence of intervals.

- Some constraint programming solvers and constraint modelling languages feature the *sort*(L, P, S) constraint, which holds if S is a nondecreasing rearrangement of the list L, the permutation being made explicit by the optional list P. However, such sortedness constraints do not seem to be used much in practice. We argue that reasons for this neglect are that it is impossible to require the underlying sort to be stable, so that *sort* cannot be guaranteed to be a total-function constraint, and that L cannot contain tuples of variables, some of which form the key for the sort. To overcome these limitations, we introduce the *stable-keysort* constraint, decompose it using existing constraints, and propose a propagator. This new constraint enables a powerful modelling idiom, which we illustrate by elegant and scalable models of two problems that are otherwise hard to encode as constraint programs.
- The constraint was initially motivated by an application where the objective is to generate a video summary, built using intervals extracted from a video source. In this application, the constraints used to select the relevant pieces of intervals are based on Allen's algebra. The best state-of-the-art results are obtained with a small set of ad hoc solution techniques, each specific to one combination of the 13 Allen's relations. Such techniques require some expertise in Constraint Programming. This is a critical issue for video specialists. We design a generic constraint, dedicated to a class of temporal problems that covers this case study, among others. ExistAllen takes as arguments a vector of tasks, a set of disjoint intervals and any of the 213 combinations of Allen's relations. ExistAllen holds if and only if the tasks are ordered according to their indexes and for any task at least one relation is satisfied, between the task and at least one interval. We design a propagator that achieves bound-consistency in O(n+m), where n is the number of tasks and m the number of intervals. This propagator is suited to any combination of Allen's relations, without any specific tuning. Therefore, using our framework does not require a strong expertise in Constraint Programming. The experiments, performed on real data, confirm the relevance of our approach.

7.5. Controlling the Generation of Solutions

The following two results deal with controlling the generation of solutions to a constraint problem.

- The *focus* constraint expresses the notion that solutions are concentrated. In practice, this constraint suffers from the rigidity of its semantics. To tackle this issue, we propose three generalizations of the FOCUS constraint. We provide for each one a complete filtering algorithm. Moreover, we propose mathematical programming (ILP) and constraint programming decompositions.
- There are significant motivations for considering alternate solutions to a problem. As expressed by renowned statistician George Box *The most that can be expected from any model is that it can supply a useful approximation to reality: all models are wrong; some models are useful.*. Multiple solutions alone, however, are not sufficient to guarantee anything of value. If they are nearly identical nothing is gained. While most frameworks in the literature consider diversity between solutions through mathematical distances, this paper proposes alternative distance measures represented by global constraints. It introduces a constraint programming framework for optimization problems, able to generate sets of nearly-optimal solutions that are diverse. With respect to over-constrained problems, the framework can be specialized in order to generate solution sets where constraint violations are diverse.

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

8.1.1. Labcom TransOp

Participants: Charles Prud'Homme, Xavier Lorca.

Title: TransOp.

Duration: 2014-2016.

Type: **new project**.

Budget: 300000 Euros.

Others partners: Eurodécision.

The goal of the project is to handle robustness in the context of industrial timetabling problems with constraint programming using CHOCO. The project is managed by Xavier Lorca.

8.2. Bilateral Grants with Industry

8.2.1. Gaspard Monge

Participants: Nicolas Beldiceanu, Helmut Simonis.

Title: Gaspard Monge 2.

Duration: 2014.

Type: **continuation of 2012,2013 project**.

Budget: 6000 Euros.

Others partners: EDF.

Within the context of the Gaspard Monge call program for Optimisation and Operation Research we work with EDF on the research initiative on *Optimization and Energy*. The goal of the project (continuation of last years projects) is to provide a systematic reformulation of time-series constraints in term of linear constraints that can be used in a MIP solver.

9. Partnerships and Cooperations

9.1. Regional Initiatives

9.1.1. SmartCat

Participants: Eric Monfroy, Charlotte Truchet.

Title: Online optimization for chemical reactions.

Others partners: CEISAM.

The SmartCat project, started in 2015 on regional fundings, aims at developing an intelligent automatised tool for online chemistry. Contrarily to the traditional batch chemistry, where reactants are mixed in a glass, online chemistry consists in having a flow of reactants in a tube, possibly passing through ovens are pressure control mechanisms. This way, the reaction happens continuously and it can produce much more products within a system of reasonable size. SmartCat integrates a controller for which intelligent tools need to be developed. These tools will analyse the product of the reaction and adapt the conditions (stoechiometry, pressure, temperature, catalysis) in order to optimise the yield. TASC contributes to this project by developing these methods, based on local search techniques.

9.1.2. Atlanstic

Participants: Raphael Chenouard, Laurent Granvilliers, Christophe Jermann, Frédéric Lardeux, Éric Monfroy, Frédéric Saubion.

Title: Atlanstic project about problem modelisation, conversion, and transformation.

Duration: 2014-2015.

Budget: 8000 Euros.

Others partners: LERIA, IRCYNN.

Topic: modelling and model transformation.

9.1.3. Search

Participants: Nicolas Galvez, Éric Monfroy, Frédéric Saubion.

Title: Hybrid Algorithms for Search Based Software Engineering.

Others partners: LERIA.

Topic: hybrid algorithms for search.

9.2. National Initiatives

9.2.1. IBEX

Participants: Ignacio Araya, Clément Carbonnel, Gilles Chabert, Benoit Desrochers, Luc Jaulin, Bertrand Neveu, Jordan Ninin, Gilles Trombettoni.

Title: Development of IBEX.

Others partners: ENSTA Bretagne, ENPC PariTech, Lirmm, LAAS, University Federico Santa Maria, Chile.

Development of IBEX (see Section 6.3).

9.2.2. ANR NetWMS2

Participants: Gilles Chabert, Ignacio Salas Donoso, Nicolas Beldiceanu.

Title: Networked Warehouse Management Systems 2: packing with complex shapes.

Duration: 2011-2014.

Type: cosinus research program.

Budget: 189909 Euros.

Others partners: KLS Optim and CONTRAINTES (Inria Rocquencourt).

This project builds on the former European FP6 Net-WMS Strep project that has shown that constraint-based optimisation techniques can considerably improve industrial practice for box packing problems, while identifying hard instances that cannot be solved optimally, especially in industrial 3D packing problems with rotations, the needs for dealing with more complex shapes (e.g. wheels, silencers) involving continuous values. This project aims at generalizing the geometric kernel *geost* for handling non-overlapping constraints for complex two and three dimensional curved shapes as well as domain specific heuristics. This will be done within the continuous solver IBEX, where discrete variables will be added for handling polymorphism (i.e., the fact that an object can take one shape out of a finite set of given shapes). A filtering algorithm has been devised in the case of objects described by nonlinear inequalities and is now under testing with the Ibex library. This work has been presented in a workshop on interval methods & geometry in ENSTA Bretagne.

9.3. European Initiatives

9.3.1. FP7 & H2020 Projects

Within the context of the First Future and Emerging Technologies (FET) Proactive projects under Horizon 2020 Framework Programme the GRACeFUL project started this year. From an application point of view the project develops scalable rapid assessment tools for collective policy making in global systems, and test these on climate-resilient urban design. From a technical point of view it provides domain specific languages that are embedded in functional programming and constraint programming languages. Within the project TASC is responsable for the constraint part.

9.4. International Initiatives

9.4.1. Inria Associate Teams not involved in an Inria International Labs

9.4.1.1. TASCMELB

Title: Synergy between Filtering and Explanations for Scheduling and Placement Constraints

International Partner (Institution - Laboratory - Researcher):

NICTA (Australia) - Optimisation Research Group (Optimisation) - Pascal van Hentenryck

Start year: 2014

See also: http://www.normalesup.org/~truchet/TASCMELB.html

In the context of Constraint Programming and SAT the project addresses the synergy between filtering (removing values from variables) and explanations (explaining why values were removed in term of clauses) in order to handle in a more efficient way correlated resource scheduling and placement constraints. It combines the strong point of Constraint Programming, namely removing value that leads to infeasibility, with the strong point of SAT, namely taking advantage from past failure in order to quickly identify infeasible sub-problems.

9.5. International Research Visitors

9.5.1. Visits of International Scientists

- One visit regarding time-series constraints of Mats Carlsson, Andreina Francisco Rodriguez Helmut Simonis, Pierre Flener and Justin Pearson in Nantes.
- One visit in Nantes of Andreas Schutt from NICTA in the context of the TASCMELB associated team.

9.5.1.1. Internships

- Master thesis : Ekaterina Arafailova (February-June 2015), *reformulation of automata with accumulators as linear programs*.
- Master thesis : Julien Fradin (February-June 2015), *extensions to the GHOST library*.
- Master thesis : Adrien Bodineau (January-April 2015), *extensions to the GHOST library*.
- Internship : Guillaume Legru (April-May 2015), *IA for combat games*.

9.5.2. Visits to International Teams

Three visits to Insight Cork, Centre for Data Analytics and to Uppsala University were done to continue the work with Helmut Simonis, Pierre Flener and Mats Carlsson on time-series constraints. An extra visit took place in Nantes. Two visits of Nicolas Beldiceanu and Charlotte Truchet in Melbourne to Peter Stuckey and Marck Wallace took place.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific events selection

10.1.1.1. Chair of conference program committees

- Nicolas Beldiceanu: Sixth International Workshop on Bin Packing and Placement Constraints.

10.1.1.2. Member of the conference program committees

- Nicolas Beldiceanu: Member of the senior program committee of CP 2015.
- Nicolas Beldiceanu: Member of the program committee of CP 2016.

- Nicolas Beldiceanu: Member of the senior program committee of CPAIOR 2015.
- Nicolas Beldiceanu: Member of the senior program committee of CPAIOR 2016.
- Nicolas Beldiceanu: Member of the program committee of IJCAI 2015.
- Xavier Lorca: Member of the program committee of IJCAI 2015.
- Xavier Lorca: Member of the program committee of CP 2015.
- Xavier Lorca: Member of the program committee of ROADEF 2015.
- Xavier Lorca: Member of the program committee of ROADEF 2016.
- Eric Monfroy: Track chair de ACM-SAC 2015 CSP track.
- Eric Monfroy: Member of the program committee of Evocop 2015.
- Eric Monfroy: Member of the program committee of Evocop 2016.
- Eric Monfroy: Member of the program committee of IJCAI 2015.
- Eric Monfroy: Member of the program committee of ICTAI 2015, special track on SAT and CSP.
- Eric Monfroy: Member of the program committee of JFPC 2015.
- Florian Richoux: Member of the program committee of LION 9.
- Florian Richoux: Member of the program committee of SAC 2015.
- Florian Richoux: Journé Jeux Vidéo and Intelligence Artificielle 2015.

10.1.1.3. Reviewer

- Nicolas Beldiceanu, reviewer at CPAIOR 2015.
- Nicolas Beldiceanu, reviewer at CP 2015.
- Nicolas Beldiceanu, reviewer at CPAIOR 2016.
- Nicolas Beldiceanu reviewer at AAAI 2016.
- Florian Richoux reviewer at IEEE Transactions on Comp. Int. and AI in Games.
- Florian Richoux reviewer at AIIDE 2015 (Artificial Intelligence and Interactive Digital Entertainment).
- Florian Richoux reviewer at Artificial Intelligence in Adversarial Real-Time Games worshop associated to AIIDE 2015.

10.1.2. Journal

10.1.2.1. Member of the editorial boards

- Nicolas Beldiceanu, Constraints (Springer).
- Thierry Petit, Constraints (Springer).
- Florian Richoux, Encyclopedia of Computer Graphics and Games (Springer).
- Charlotte Truchet, blog Binaire of lemonde.

10.1.2.2. Reviewer - Reviewing activities

- Xavier Lorca reviewer at AIJ.
- Xavier Lorca reviewer at Constraints (Springer).
- Xavier Lorca reviewer at RAIRO.

10.1.3. Invited talks

- Florian Richoux*Feedback on IA competitions in the context of games*. Workshop PFIA 2015, Jeux Vidéo and IA, July 2015, Inria Rennes (France).
- Florian Richoux*Antagonist IA for Win That War !*, workshop PFIA 2015, Jeux Vidéo and IA, July 2015, Inria Rennes (France).

10.1.4. Leadership within the scientific community

Xavier Lorca is the co-head of the OR and Constraints working group.

10.1.5. Research administration

Within the forthcoming research unit *UMR LS2N* Xavier Lorca is the co-head of the cluster *Data Science and Decision* that group together seven research teams.

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Master: Nicolas Beldiceanu, Constraint (Master ORO), 30h, M2, Nantes University, France.

Master: Nicolas Beldiceanu, Logic Programming, 32h, M2, Mines Nantes, France.

Master: Nicolas Beldiceanu, Gipad end project, 8h, M2, Mines Nantes, France.

Licence: Nicolas Beldiceanu, Programming with Java, 42h, L3, Mines Nantes, France.

Licence: Nicolas Beldiceanu, Automata, 12h, L3, Mines Nantes, France.

Licence: Nicolas Beldiceanu, IPIPIP project, 12h, L1, Mines Nantes, France.

Licence: Gilles Chabert, Variational calculus, 12h, L3, Mines Nantes, France.

Licence: Gilles Chabert, Numerical methods, 21h, L3, Mines Nantes, France.

Master: Gilles Chabert, Project Supervision, L3, Master 1 and Master2, Mines Nantes, France.

Master: Gilles Chabert, Non-linear optimization, 20h, M1, Mines Nantes, France.

Master: Gilles Chabert, Non-linear optimization, 24h, M1, Nantes University, France.

Master: Gilles Chabert, Non-linear programming, 20h, M2, Mines Nantes, France.

Licence: Xavier Lorca, Software engineering and miscellaneous , 30h, Mines Nantes, France.

Master: Xavier Lorca In charge of the organisation of the Gipad specialty (coordinating 12 modules of 45h each).

Master: Xavier Lorca Gipad (Graph and Algorithms, Artificial Intelligence and Constraint Programming, Decision Analytics, Data Visualisation, Architecture of Computer System and Software), 100h, Mines Nantes, France.

Licence, Master: Eric Monfroy, Head of the computer science department, Nantes University, France.

Licence: Eric Monfroy, Logic, L2 Nantes University, France.

Licence: Eric Monfroy, Computer Architecture, L3 Nantes University, France.

Licence: Eric Monfroy, Computability theory and foundations, L3 Nantes University, France.

Master: Eric Monfroy, Modelling with constraints, (Master ORO), M1, Nantes University, France.

Licence: Florian Richoux, Algorithm and data structures, L2, Nantes University, France.

Licence: Florian Richoux, Object programming and design patterns, L3, Nantes University, France.

Licence: Florian Richoux, Operation Research, exercises and practice, L3, Nantes University, France.

Master: Florian Richoux, Machine Learning, exercises and practice (Master ATAL), M1, Nantes University, France.

Master: Florian Richoux, Constraint programming (Master ORO), M1, Nantes University, France.

Licence: Charlotte Truchet, 192h, L1, Nantes University, France.

10.2.2. Supervision

PhD : Alban Derrien, Cumulative scheduling in constraint programming (energetic characterization of reasoning and robust solutions), Mines Nantes, November 27 2015, Thierry Petit and Nicolas Beldiceanu.

PhD in progress : Ignacio Salas Donoso, Packing curved shapes, May 2013, Gilles Chabert and Nicolas Beldiceanu.

PhD in progress : Gilles Madi Wamba, Mixing constraint programming and behavioural models to manage energy consumption in data centre, October 2014, Nicolas Beldiceanu and Didier Lime.

PhD in progress : Alejandro Reyes Amaro, Toward autonomous parallel algorithms for constraint-based problems, October 2014, Eric Monfroy and Florian Richoux.

PhD in progress : Anicet Bart, Solving mixed constraints, application to the management of mobile sensors, October 2014, Eric Monfroy and Charlotte Truchet.

PhD in progress : Ekaterina Arafailova, Functional constraints, September 2015, Nicolas Beldiceanu and Rémi Douence.

PhD in progress : Nicolas Galvez, Hybrid Algorithms for Search Based Software Engineering, December 2014, Eric Monfroy with Frédéric Saubion from Angers University and C. Castro from UTFSM Valparaiso, Chili.

PhD in progress : Léopold Houdin, Set-based algorithms for characterizing limit cycles in bio-inspired robotics, October 2015, Frédéric Boyer, Gilles Chabert, Alexandre Goldsztejn.

Master thesis : Ekaterina Arafailova (February-June 2015), *reformulation of automata with accumulators as linear programs*, Nicolas Beldiceanu.

Master thesis : Julien Fradin (February-June 2015), *extensions to the GHOST library*, Florian Richoux.

Master thesis : Adrien Bodineau (January-April 2015), *extensions to the GHOST library*, Florian Richoux.

Internship : Guillaume Legru (April-May 2015), *IA for combat games*, Florian Richoux.

10.2.3. Juries

- Nicolas Beldiceanu, Member of the committee of the PhD of Alban Derrien, Cumulative scheduling in constraint programming (energetic characterization of reasoning and robust solutions), Mines Nantes, November 27 2015.
- Nicolas Beldiceanu, Member of the committee of the PhD of Haykel Boukadida, Automatic creation of video summarisation with constraint programming, Rennes University, December 4 2015.
- Xavier Lorca, Member of the committee of the PhD of Alban Derrien, Cumulative scheduling in constraint programming (energetic characterization of reasoning and robust solutions), Mines Nantes, November 27 2015.
- Xavier Lorca, Member of the committee of the PhD of Nebras Gharbi, Compression and parallelisation in CSP, Lens University, December 4 2015.
- Xavier Lorca, Member of the committee of the PhD of Mohammed Rezgui, Parallelism in constraint programming, Nice University, July 7 2015.
- Eric Monfroy, Member of the committee of the PhD of Roberto Amadini, Portfolio Approaches in Constraint Programming, Bologna University, June 4 2015.
- Thierry Petit, Member of the committee of the PhD of Alban Derrien, Cumulative scheduling in constraint programming (energetic characterization of reasoning and robust solutions), Mines Nantes, November 27 2015.

10.3. Popularization

- A the 2015 edition of the Fête de la Science (Nantes University):
  - A workshop around *Software for sound processing in the context of the R2D2 robot* was given by Charlotte Truchet.

- – One talk on *Travel to the land of dreams : lands, monsters and fairies* was given by Nicolas Beldiceanu.
  - – Two sessions discussing and answering questions around the work of professor and researcher in computer science with young persons (18 years old) was spent by Nicolas Beldiceanu and Florian Richoux.
- Charlotte Truchet wrote an article regarding *women in computer science*.
- Interview for the WebTV FranceLive on AI and games in November 2015 by Florian Richoux.
- Interview for Nantes University regarding the collaboration of Florian Richoux with Facebook in summer 2015.
- Interview of Florian Richoux in the Thinkovery magazine (number 3, April-May-June 2015) regarding Artificial Intelligence in Games.
- Interview of Florian Richoux in Rue89 in March 2015 regarding works of Google DeepMind around the Atari game.

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Major publications by the team in recent years

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Doctoral Dissertations and Habilitation Theses

[11] A. DERRIEN. *Cumulative scheduling in constraint programming : energetic characterization of reasoning and robust solutions*, Ecole des Mines de Nantes, November 2015, https://tel.archives-ouvertes.fr/tel-01242789

Articles in International Peer-Reviewed Journals

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A. BART, C. TRUCHET, E. MONFROY. *Verifying a Real-Time Language with Constraints*, in "27th IEEE International Conference on Tools with Artificial Intelligence", Vietri sul Mare, Italy, 2015, https://hal.archives-ouvertes.fr/hal-01234188.

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