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Activity Report 2014

Project-Team TASC

Theory, Algorithms and Systems for Constraints

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

RESEARCH CENTER
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THEME
Architecture, Languages and Compilation

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Project-Team TASC

Keywords: Constraints, Artificial Intelligence, Inference, Operations Research, Numerical Methods, Knowledge

Creation of the Project-Team: 2011 January 01.

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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 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 2014 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 *city development planning with evaluation of energy impacts* (SUSTAINS project).
- *Optimizing electricity production* in the context of the Gaspard Monge call program for Optimisation and Operation Research. We extract global constraints from daily energy production temporal series issued from all productions plants of EDF.

5. New Software and Platforms

5.1. Platforms

5.1.1. CHOCO

Participants: Nicolas Beldiceanu, Jean-Guillaume Fages, Xavier Lorca [correspondant], Thierry Petit, Charles Prud'Homme [main developer], Rémi Douence.

CHOCO is a Java discrete constraints library integrating within a same system *explanations*, *soft constraints* and *global constraints* (90000 lines of source code). In 2014 developments were focusing on the following aspects:

- For second consecutive year, CHOCO has participated at the MiniZinc Challenge, an annual competition of constraint programming solvers. In competition with 16 other solvers, CHOCO has won three 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 (v3.3.0, Dec. 17th) has the particularity to be promoted on Maven Central Repository. The major modifications were related to a simplification of the API but also improvement of the overall solver.
- A User Guide is now available: 164 pages describing how to use CHOCO, together with a new website.
- Finally, Charles Prud'homme and Jean-Guillaume Fages, the main contributors of CHOCO, have defended their Phd, publishing at the same time their work in the source code. In particular, an extension of CHOCO now provides support for constraints involving graph variables.

5.1.2. IBEX

Participants: Ignacio Araya, Clément Carbonnel, Gilles Chabert [correspondant], Benoit Desrochers, Luc Jaulin, Bertrand Neveu, Jordan Ninin, Ignacio Salas Donoso, Gilles Trombettoni.

IBEX (Interval-Based EXplorer) 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.

In 2014 the work on IBEX has focused on the following points.

- Global optimizer:
  - Rigorous mode in the global optimizer (certification of the feasibility of strict equality constraints for the minimum found). This includes Newton-based inflation iteration, Hansen test for underconstrained systems (see Global Optimization using Interval Analysis, E. Hansen, 1992).
  - Unconstrained local search algorithm (quasi-Newton method with trust regions).
  - Rejection test based on first-order conditions (see First Order Rejection Tests For Multiple-Objective Optimization, A. Goldsztejn et al. [42]).
  - Multiple selection technique in exploration (see A new multisection technique in interval methods for global optimization, L.G. Casado, Computing, 2000)
- Contractors:
  - Existentially-quantified constraints, (see Contractor Programming, [8]).
  - Mohc contractor, (see Exploiting Monotonicity in Interval Constraint Propagation, I. Araya et al., [41]).
  - Q-intersection, (see Q-intersection Algorithms for Constraint-Based Robust Parameter Estimation, C. Carbonnel et al., AAAI 2014, [27]).
  - Contractor based on pixel maps (started in Oct 2014, still in progress, see Using set membership methods for robust underwater robot localization, PhD, J. Sliwka).
- Miscellanous
  - Everyday code improvement (around 400 commits in 2014).
  - Symbolic processing features (symbol occurrence splitting, function construction from strings, progress in differentiation with vector/matrix operations).
  - numerous bug fixes (especially in the inner arithmetic routines).

5.1.3. Global Constraint Catalog

Participants: Nicolas Beldiceanu [correspondant], Mats Carlsson, Sophie Demassey, Helmut Simonis.

The global constraint catalog presents and classifies global constraints and describes different aspects with meta data. It consist of

1. a pdf version that can be downloaded from http://sofdem.github.io/gccat/ (at item *working version*) containing 431 constraints, 4070 pages and 1000 figures,
2. an on line version accessible from the previous address,
3. meta data describing the constraints (buton *PL* for each constraint, e.g., alldifferent.pl),
4. an online service (i.e, a *constraint seeker*) which provides a web interface to search for global constraints, given positive and negative ground examples.

This year developments were focusing on:

1. maintaining the content of the catalogue,
2. making more easy the navigation within the pdf version,
3. continuing the redesign of the figures using TikZ: 200 figures were converted and 100 figures remain to be converted, and adding new illustrations (150 figures).
4. updating the web version of the catalogue (see http://sofdem.github.io/gccat/).

5.1.4. AIUR

Participant: Florian Richoux [correspondant].

AIUR (Artificial Intelligence Using Randomness) is an AI for $StarCraft: BroodWar^{tm}$.

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 behaviors (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.

AIUR is an open source program under GNU GPL v3 licence, written in C++ (18.000 lines of code). Source and documentations are available at github.com/AIUR-group/AIUR. AIUR finished 4$^{\text{th}}$ to $StarCraft^{tm}$ AI competitions organized at the conferences AIIDE 2014 and CIG 2014.

5.1.5. GHOST

Participant: Florian Richoux [correspondant].

GHOST (General meta-Heuristic Optimization Solving Tool) is a template C++11 library designed for $StarCraft: BroodWar^{tm}$, under the terms of the GNU GPL v3 licence and is about 7500 lines long. GHOST implements a meta-heuristic solver aiming to solve any kind of combinatorial and optimization RTS-related problems represented by a CSP/COP [36]. The solver handles dedicated geometric and assignment constraints in a way that is compatible with very strong real time requirements. The source code as well as documentation pages are available at github.com/richoux/GHOST.

This framework is a deep extension of an ad-hoc solver. Although GHOST has been developed recently (during Summer 2014), it got itself quickly noticed by a French video-game developing company. We are starting discussion about a technology transfer of GHOST.

6. New Results

6.1. Highlights of the Year

In the context of the MiniZinc Challenge and in concurrency with 16 other solvers, CHOCO has won three bronze medals in three out of four categories: free search, parallel search and Open class.

6.2. CHOCO

Participants: Jean-Guillaume Fages, Narendra Jussien, Xavier Lorca, Charles Prud'Homme.

- For second consecutive year, CHOCO has participated at the MiniZinc Challenge, an annual competition of constraint programming solvers. In concurrency with 16 other solvers, CHOCO has won three 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 (v3.3.0, Dec. 17th) has the particularity to be promoted on Maven Central Repository. The major modifications were related to a simplification of the API but also improvement of the overall solver.
- Within the context of the PhD thesis of Charles Prud'homme [15], a domain specific language that allows prototyping propagation engines was integrated within CHOCO, A paper appears at Constraints.
- Within the context of the PhD thesis of Charles Prud'homme [15], a generic strategy based on explanations for large neighborhood search was designed and integrated within CHOCO. A corresponding paper appears at Constraints [23].
- Within the context of the PhD thesis of Jean-Guillaume Fages, a documented package for graph variables was designed and integrated within CHOCO.

6.3. IBEX Solver

Participants: Gilles Chabert, Alexandre Goldsztejn, Bertrand Neveu, Gilles Trombettoni.

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)

6.4. Packing curved objects

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

The development of algorithms to pack curved objects has continued. The filtering algorithm developed in 2013 for generic objects shapes has been published in the CP 2014 conference. Based on this result, we have started the design of a generic (nonlinear) packing solver in 2014. The strategy for packing is directly inspired from a successful approach recently proposed by our project partners (see On solving mixed shapes packing problems by continuous, T. Martinez et al., first BRICS countries congress on Computational Intelligence). It makes use of a stochastic optimization algorithm (CMA-ES) with a fitness function that gives a violation cost and equals zero when objects are all packed. We have generalized their approach by replacing the ad-hoc formulas (for measuring the overlapping between two objects) with an automatic calculation based on our filtering algorithm. The solver is done and the experiments have started.

6.5. Robustness and scheduling

Participants: Nicolas Beldiceanu, Mats Carlsson, Alban Derrien, Arnaud Letort, Thierry Petit, Stéphane Zampelli.

- *Robustness in the Context of the Cumulative Constraint*: This research [33] investigates cumulative scheduling in uncertain environments, using constraint programming. We get a new declarative characterization of robustness, which preserves solution quality which allow adding constraints to the main problem. In this context we adapt the 2013 sweep based algorithm in order to scale and handle several thousand of activities. We highlight the significance of our framework on a crane assignment problem with business constraints.
- *Characterization of Relevant Intervals in the Context of Energetic Reasoning*: Energetic Reasoning (ER) is a powerful filtering algorithm for the Cumulative constraint. Unfortunately, ER is generally too costly to be used in practice. One reason of its bad behavior is that many intervals are considered as relevant, although most of them should be ignored. In the literature, heuristic approaches have been developed in order to reduce the number of intervals to consider, leading to a loss of filtering. We provide a sharp characterization that allows to reduce the number of intervals by a factor seven without any loss of filtering [38].
- *Fix Point over a Conjunction of Scheduling Constraints*: This research introduces a family of synchronized sweep-based filtering algorithms for handling scheduling problems involving resource and precedence constraints. The key idea is to filter all constraints of a scheduling problem in a synchronized way in order to scale better. In addition to normal filtering mode, the algorithms can run in greedy mode, in which case they perform a greedy assignment of start and end times. The filtering mode achieves a significant speed-up over the decomposition into independent cumulative and precedence constraints, while the greedy mode can handle up to 1 million tasks with 64 resource constraints and 2 million precedences. These algorithms were implemented in both CHOCO and SICStus [21].

6.6. Global constraints

Participants: Nicolas Beldiceanu, Jean-Guillaume Fages, Xavier Lorca, Thierry Petit.

- Scalability becomes more and more critical to decision support technologies. In order to address this issue in Constraint Programming, we introduce the family of self-decomposable constraints. These constraints can be satisfied by applying their own filtering algorithms on variable subsets only. We introduce a generic framework which dynamically decompose propagation, by filtering over variable subsets. Our experiments over the cumulative constraint illustrate the practical relevance of self-decomposition [34].
- Consider a constraint on a sequence of variables functionally determining a result variable that is unchanged under reversal of the sequence. Most such constraints have a compact encoding via an automaton augmented with accumulators, but it is unknown how to maintain domain consistency efficiently for most of them. Using such an automaton for such a constraint, we derive an implied constraint between the result variables for a sequence, a prefix thereof, and the corresponding suffix. We show the usefulness of this implied constraint in constraint solving, both by local search and by propagation-based systematic search [25].
- Constraints over finite sequences of variables are ubiquitous in sequencing and timetabling. This led to general modelling techniques and generic propagators, often based on deterministic finite automata (DFA) and their extensions. We consider counter-DFAs (cDFA), which provide concise models for regular counting constraints, that is constraints over the number of times a regular-language pattern occurs in a sequence. We show how to enforce domain consistency in polynomial time for at-most and at-least regular counting constraints based on the frequent case of a cDFA with only accepting states and a single counter that can be increased by transitions. We also show that the satisfaction of exact regular counting constraints is NP-hard and that an incomplete propagator for exact regular counting constraints is faster and provides more pruning than existing propagators. Finally, by avoiding the unrolling of the cDFA used by cost regular, the space complexity is reduced[26].

6.7. Optimization

Participants: Salvador Abreu, Alejandro Reyes Amaro, Yves Caniou, Philippe Codognet, Daniel Diaz, Jean-Guillaume Fages, Xavier Lorca, Éric Monfroy, Florian Richoux, Louis-Martin Rousseau.

- The traveling salesman problem (TSP) is a challenging optimization problem for CP and OR that has many industrial applications. Its generalization to the degree constrained minimum spanning tree problem (DCMSTP) is being intensively studied by the OR community. In particular, classical solution techniques for the TSP are being progressively generalized to the DCMSTP. Recent work on cost-based relaxations has improved CP models for the TSP. However, CP search strategies have not yet been widely investigated for these problems. The contributions of this research are twofold. We first introduce a natural generalization of the weighted cycle constraint (WCC) to the DCMSTP. We then provide an extensive empirical evaluation of various search strategies. In particular, we show that significant improvement can be achieved via our graph interpretation of the state-of-the-art Last Conflict heuristic. The work was published in the Constraints journal, see the salesman and the tree: the importance of search in CP.
- In the context of nature inspired metaheuristics and its combination with CP, some new work were conducted in the field of ant colony to solve the software project scheduling problem [19], and in the field of the Manufacturing Cell Design Problem [29].
- We implement new algorithmic methods for constraint problems on massively parallel machines. In [18], we propose an extensive study of homogeneous multi-walk parallel scheme for meta-heuristics both with and without communication. The next step will be to look at heterogeneous portfolio approaches where different solvers are looking in parallel for a solution to a given problem.

6.8. Modelling

Participants: Broderick Crawford, Frédéric Lardeux, Éric Monfroy, Ricardo Soto.

- In the framework of conversion of CST set constraints to SAT instances, a filtering engine has been studied and implemented in order to reduce the size of the generated SAT instances.
- From the one hand, CSP is very expressive. On the other hand, SAT solvers can solve huge instances (millions of variables and clauses). We thus worked on the conversion of CSP set constraints into SAT instances [35]. We then focused on the Social Golfer Problem, in order to easily integrate usual improvements (such as symmetry breaking) using our framework [40].

6.9. AI for real time strategy games

Participants: Santiago Ontanon, Florian Richoux, Alberto Uriarte.

We continue to develop an artificial intelligence, AIUR, to play the real time strategy (RTS) game $StarCraft^{tm}$, using both machine learning and constraint-based techniques. AIUR finished 4^{th} over 18 finalists to the $StarCraft^{tm}$ AI competition organized at the conference AIIDE 2014, and 4^{th} over 13 finalists to the competition at CIG 2014. This year, we wrote an ad-hoc CSPsolver to deal with the wall-in optimization problem [36] for StarCraft, and generalized it as a framework enable to handle any kind of CSP/COPmodels representing a RTS-related problem. This framework, named GHOST, helps the user to implement his CSP/COPmodel before solving it with the ready-to-use, already-tuned embedded solver.

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Grants with Industry

7.1.1. 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 year project) is first to extract constraints from daily energy production temporal series issued from the 350 production plants of EDF, second to see how to use these constraints in order to reduce the combinatorial aspect of the daily production planning solving process. The work is based on the CP 2012 model seeker.

7.2. Bilateral Contracts with Industry

7.2.1. 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. Partnerships and Cooperations

8.1. Regional Initiatives

8.1.1. 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.

8.1.2. EPOC

Participants: Nicolas Beldiceanu, Didier Lime, Gilles Madi Wamba, Jean-Marc Menaud, Olivier H. Roux.

Title: EPOC: Energy Proportional and Opportunistic Computing system.

Duration: 2014-2017.

Budget: founding for a PhD thesis.

Topic: an integrated approach combining time automata and constraint programming for modeling dynamic aspects of vm management in a data center.

8.2. National Initiatives

8.2.1. 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).

8.2.2. SUSTAIN

Participants: Charlotte Truchet, Bruno Belin.

Title: SUSTAINS.

Duration: 2010-2014.

Type: FUI.

Budget: 151400 Euros.

Others partners: Artefacto, Artelys, Areva TA, EPAMarne, LIMSI.

The SUSTAINS project (*Constraint-based Prototyping of Urban Environments*) aims at building decision support system for city development planning with evaluation of energy impacts. The project is focused on spatial allocation of typical units such as industrial areas, commercial areas and leaving areas with their respective appropriate infrastructure. Its integrates sustainability, transport and energy concerns.

8.2.3. 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). In 2013 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.

8.2.4. ANR INFRA-JVM

Participants: Xavier Lorca, Charles Prud'Homme.

Title: Towards a Java Virtual Machine for pervasive computing.

Duration: 2011-2015.

Type: **new project**.

Budget: 78000 Euros.

Others partners: Univ. Paris 6 (REGAL team), LaBRI (LSR team), IRISA (TRISKELL).

The INFRA-JVM project investigates how to enhance the design of Java virtual machines with new functionalities to better manage resources, namely resource reservation, scheduling policies, and resource optimization at the middleware level. TASC is concerned with this later aspect. The performance of CHOCO will be improved using the memory snapshot mechanism that will be developed.

8.3. European Initiatives

8.3.1. FP7 & H2020 Projects

The GRACeFUL project (Global systems Rapid Assessment tools through Constraint FUnctional Languages) from the H2020-FETPROACT track has been accepted and will start in January 2015 for a period of three year. The abstract of the project is given below.

The making of policies coping with Global Systems is a process that necessarily involves stakeholders from diverse disciplines, each with their own interests, constraints and objectives. People play a central role in such collective decision making and the quest for solutions to a problem generally intertwines its very specification. Simulators can assist in this process provided they employ adequate high-level modelling to separate the political question from the underlying scientific details. Domain-specific Languages (DSL) embedded in Functional Programming (FP) languages offer a promising way to implement scalable and verifiable simulators. But the use of simulators is essentially a trial-and-error process too tedious for execution in a group session. A paradigm shift is needed towards active problem solving where stakeholders' objectives can be taken along from the very beginning. Constraint Programming (CP) has demonstrated to enable such a shift for e.g. managed physical systems like water and power networks. This project lays the base for a DSL aimed at building scalable Rapid Assessment Tools for collective policy making in global systems. This can be achieved through foundational scientific work at different levels: from the high-level, political modelling, adapting the social discipline of Group Model Building (as used in business organizations), through visual forms of CP as well as gamification aspects, down to the needs for a host language, combining CP and FP. Special emphasis is put on domain-specific constraints, constraint composition, and composable solvers and heuristics. Results are applied and validated for the problem case of Climate-Resilient Urban Design, but the ambition is a general framework applicable to many other systems. The case study is assessed by an external multi-disciplinary Advisory Board of Stakeholders that guides the specification process and evaluates needs and usability of the tools.

8.3.2. Collaborations in European Programs, except FP7 & H2020

8.3.2.1. PHC Ulysses

Participants: Charlotte Truchet, Florian Richoux, Alejandro Reyes.

Title: Development and estimation analysis of massively parallel local search approaches to the k-medoids problem.

Duration: 2014.

Type: **new project**.

Budget: 2500 Euros.

Others partners: 4C (Cork, Ireland).

The goal of this project is to develop parallel local search techniques for solving large instances of the k-medoids problem, a location problem with several applications, in particular in optical fiber networks deployment.

8.4. International Initiatives

8.4.1. Inria Associate Teams

8.4.1.1. TASCMELB

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

International Partner (Institution - Laboratory - Researcher):

NICTA (AUSTRALIE)

Duration: 2014 - 2016

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.

8.4.1.2. BANANAS

- Partners: Inria-Lorraine, PUCV (Chili), UTFSM (Chili), Univ. Angers (LERIA), Univ. Nantes (TASC).
- Duration: 2012-2014.
- Topics: Autonomous constraint solving, SMT solvers.
- Budget: 15 KEuros per year for the project.

8.4.2. Inria International Partners

8.4.2.1. Informal International Partners

- SICS, Sweden.
- Uppsala University, Sweden.
- 4C, Ireland.
- Univ. Austral de Chile, Valparaiso, Chile.

8.4.3. Participation In other International Programs

Ulysse (cooperation with 4C, Cork, Ireland).

8.5. International Research Visitors

8.5.1. Visits of International Scientists

- Mats Carlsson (SICS, Sweden), *Automata constraints* (5 days).
- Philippe Codognet (Japanese-French Laboratory for Informatics at the University of Tokyo, Japan), *Prediction models of local search speed-up* (15 days).
- Pierre Flener, (Uppsala University, Sweden), *Automata constraints* (5 days).
- Justin Pearson, (Uppsala University, Sweden), *Automata constraints* (5 days).
- Helmut Simonis, (Insight Centre for Data Analytics, University College Cork, Ireland), *Learning constraint models* (3 months).

8.5.2. Visits to International Teams

8.5.2.1. Sabbatical programme

Thierry Petit is currently visiting the Foisie School of business of WPI (Worcester Polytechnic Institute, Massachusetts, USA), collaborating with Andrew C. Trapp on optimization problems, since July, 2014.

8.5.2.2. Research stays abroad

- Nicolas Beldiceanu, 4C Cork Ireland: work on *learning generic models* and work on *learning constraints in the context of EDF* with Helmut Simonis (two weeks).
- Nicolas Beldiceanu, Uppsala University and SICS: work on *automata and constraints* with Pierre Flener and Justin Pearson and Mats Carlsson (one month).
- Éric Monfroy, Univ. Austral de Chile, Valparaiso, Chile: work with Ricardo Soto.
- Florian Richoux visited the Japanese-French Laboratory for Informatics at the University of Tokyo, to work with Philippe Codognet on massively parallel combinatorial optimization algorithms and to start collaborations on Game AI, with Ruck Thawonmas from Ritsumeikan University (from the 1st of April till the 31st of August).

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. Scientific events organisation

9.1.1.1. general chair, scientific chair

- Gilles Chabert: Organization of a workshop on constraints, intervals and geometry in Mine de Nantes on June 2014 (http://ibex-lib.org/workshop-23-06-14).
- Éric Monfroy: Co-chair of the ACM SAC CSP. tracks 2014 and 2015.
- Thierry Petit: Chairman of the 10th Edition of JFPC conference, June 11-13 2014, Angers, JFPC 2014.

9.1.1.2. member of the organizing committee

- Éric Monfroy: Member of the organizing committee of JFPC 2014.

9.1.2. Scientific events selection

9.1.2.1. member of the conference program committee

- Nicolas Beldiceanu: Member of the senior program committee of CP 2014.
- Nicolas Beldiceanu: Member of the program committee of CPAIOR 2014.
- Nicolas Beldiceanu: Member of the program committee of CPAIOR 2015.
- Nicolas Beldiceanu: Member of the program committee of IJCAI 2015.

- Xavier Lorca: Member of the program committee of JFPC 2015 (in Bordeaux).
- Xavier Lorca: Member of the program committee of IJCAI 2015.
- Éric Monfroy: Member of the program committee of EvoCOP 2015.
- Thierry Petit: Member of the program committee of CPAIOR 2014.
- Thierry Petit Member of the program committee of IEEE-ICTAI 2014 (Special track on SAT-CSP).
- Thierry Petit Member of the program committee of ECAI 2014.
- Charles Prud'homme: Member of the program committee of JFPC 2014.
- Florian Richoux: Member of the Program Committee of LION 9.
- Florian Richoux: Member of the Program Committee of SAC 15.
- Florian Richoux: Member of the program committee of JFPC 2014.
- Charlotte Truchet: Member of the program committee of ParSearchOpt 2014.
- Charlotte Truchet: Member of the program committee of JFPC 2014.

9.1.2.2. reviewer

- Nicolas Beldiceanu reviewer at AAAI 2014.
- Gilles Chabert reviewer at SIAM Journal of Scientific Computing.

9.1.3. Journal

9.1.3.1. member of the editorial board

- Nicolas Beldiceanu, Constraints (Springer).
- Thierry Petit, Constraints (Springer).
- Florian Richoux, Encyclopedia of Computer Graphics and Games (Springer).

9.1.3.2. reviewer

- Xavier Lorca: Reviewer for Constraints (Springer).
- Éric Monfroy: Reviewer for IEEE TEC (Elsevier).
- Éric Monfroy: Reviewer for Information Sciences (Elsevier).
- Florian Richoux reviewer at journal IEEE Transactions on Computational Intelligence and AI in games.
- Florian Richoux reviewer at Annals of Mathematics and Artificial Intelligence, Springer.

9.2. Teaching - Supervision - Juries

9.2.1. 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, IPIPIP project, 12h, L1, Mines Nantes, France.

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

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

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

Licence: Gilles Chabert, Numerical methods, 15h, L3, Mines Nantes, France.

Licence: Gilles Chabert, Supervisions of projects, 66h, L3, Mines Nantes, France.

Gilles Chabert, Member of the selection commitee for a position of associate professor at ISTIA (Angers University).

Master: Xavier Lorca, Head of the major of the Master in Engineering, Computer Science for Decision Support, M2, Mines Nantes, France.

Master: Xavier Lorca, Graph Theory, Algorithms, 22h, M1, Mines Nantes, France.

Master: Xavier Lorca, Artificial Intelligence and Constraint Programming, 22h, M2, Mines Nantes, France.

Master: Xavier Lorca, IT System and Software Development, 45h, M2, Mines Nantes, France.

Master: Xavier Lorca, Decision support sytems, 45, M2, Mines Nantes, France.

Master: Xavier Lorca, Supervisions of projects, L2, M1, M3, Mines Nantes, France.

Licence: Éric Monfroy, Responsible of the L2 in Computer Science, Nantes University, France.

Licence and Master: Éric Monfroy, Responsible of the pole "Fondements Théoriques", CS Department, Nantes University, France.

Licence: Éric Monfroy, Algorithm 2, 16h, L2, Nantes University, France.

Licence: Éric Monfroy, Logic, 40h, L2, Nantes University, France.

Licence: Éric Monfroy, Language theory, 96h, L3, Nantes University, France.

Licence: Éric Monfroy, Computer architecture, 40h, L3, Nantes University, France.

Master: Éric Monfroy, supervision of 5 M2-MIAGE students (alternants), M2, Nantes University, France.

Master: Éric Monfroy, seminar about problem modelisation (ORO Master), 2, M2, Nantes University, France.

Master: Thierry Petit, Director of the Combinatorial Optimization degree, GIPAD, M2, Mines Nantes, France.

Master: Thierry Petit, Director of the Artificial Intelligence and Constraint Programming degree, GIPAD, M2, Mines Nantes, France.

Master: Thierry Petit, Discrete optimization, 9h, M2, Mines Nantes, France.

Master: Thierry Petit, Constraint Programming in CHOCO, 20h, M2, Mines Nantes, France.

Licence: Thierry Petit, Data structures, 20h, L2, Mines Nantes, France.

Licence: Thierry Petit, Java Programming, 40h, L2, Mines Nantes, France.

Licence: Thierry Petit, HMI, 13h, L2, Mines Nantes, France.

Licence: Thierry Petit, FIL project supervisor, 12h, L2, Mines Nantes, France.

Licence: Thierry Petit, IPIPIP project, 12h, L1, Mines Nantes, France.

Licence: Thierry Petit, Introduction to Constraint Programming, 4h, L2, Worcester Polytechnic Institute, USA.

Master: Florian Richoux, Constraint Programming, 12h, M2, University of Nantes, France.

Master: Florian Richoux, Prediction of Parallel Speed-ups for Las Vegas Algorithms, 2h, M2, University of Tokyo, Japan.

Licence: Florian Richoux, Design Patterns in Object-Oriented Programming, 86h, L3, University of Nantes, France.

Licence: Florian Richoux, Algorithm and Data Structures, 45h, L2, University of Nantes, France.

Licence: Charlotte Truchet, Algorithms and Programming, 46h, L1, University of Nantes, France.

Master: Charlotte Truchet, Local Search, 10h, M2, Mines Nantes.

E-learning

Pedagogical resources: Nicolas Beldiceanu, global constraint course, exercises (available in two fomats: pdf and interactivly on the web) M2, http://imedia.emn.fr/global_constraints_course/

9.2.2. Supervision

PhD: Bruno Belin, Interactive conception of sustainable urban environments with constraints, Nantes University, November 27, 2014, Charlotte Truchet, Marc Christie, Fréderic Benhamou.

PhD: Jean-Guillaume Fages, Graph Theory in Constraint Programming, Theory and application to several graph covering problems, Nantes University, October 23, 2014, Xavier Lorca, Nicolas Beldiceanu.

PhD: Charles Prud'homme, Controlling Propagation and Search within a Constraint Solver, Nantes University, February 28, 2014, Xavier Lorca, Narendra Jussien, Rémi Douence.

PhD in progress: Anicet Bart, Mixed Constraint Solving, October 2014, Charlotte Truchet, Éric Monfroy.

PhD in progress: Alban Derrien, Constraint propagation with limited time complexity, October 2012, Thierry Petit, Nicolas Beldiceanu.

PhD in progress: Gilles Madi Wamba, Integrating time automata and constraint programming for modeling vm assignment in a data centre, October 2014, Nicolas Beldiceanu. Didier Lime, Oliver H. Roux.

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

PhD in progress: Nicolás Sebastián Gálvez Ramírez, CP for Software Engineering, November 2014, Éric Monfroy, co-tutelle with Chile also involving Carlos Castro, Frédéric Saubion.

PhD in progress: Alejandro Reyes Amaro, New parallel algorithms for combinatorial optimization, October 2013, Florian Richoux, Éric Monfroy.

9.2.3. Juries

- Nicolas Beldiceanu, Member of the committee of the HdR of Xavier Lorca, Elément de flexibilité et d'efficacité en programmation par contraintes, (Nantes University, November 6, 2014).
- Nicolas Beldiceanu, Member of the committee of the HdR of Thierry Petit, Concilier expressivité et éfficacité en programmation par contraintes, (Nantes University, December 4, 2014).
- Nicolas Beldiceanu, Member of the PhD committee of the thesis of Jean-Guillaume Fages, Graph Theory in Constraint Programming, Theory and application to several graph covering problems, (Nantes University, October 23, 2014).
- Fréderic Benhamou, Member of the PhD committee of the thesis of Bruno Belin, Interactive conception of sustainable urban environments with constraints, (Nantes University, November 27, 2014).
- Gilles Chabert, Member of the PhD committee of the thesis of Aymeric Bethencourt, Interval Analysis for swarm localization. Application to underwater robotics. (ENSTA Bretagne, September 30, 2014).
- Xavier Lorca, Member of the PhD committee of the thesis of Jean-Guillaume Fages, Graph Theory in Constraint Programming, Theory and application to several graph covering problems, (Nantes University, October 23, 2014).
- Xavier Lorca, Member of the PhD committee of the thesis of Charles Prud'homme, Controlling Propagation and Search within a Constraint Solver, (Nantes University, February 28, 2014).
- Charlotte Truchet, Member of the PhD committee of the thesis of Bruno Belin, Interactive conception of sustainable urban environments with constraints, (Nantes University, November 27, 2014).

- Éric Monfroy, Member of the HDR committee of the Habilitation thesis of Xavier Lorca, Elément de flexibilité et d'efficacité en programmation par contraintes, (Nantes University, November 6, 2014).
- Éric Monfroy, Member of the HDR committee of the Habilitation thesis of Adrien Goeffon, Modèles d'abstraction pour la résolution de problèmes combinatoires, (Angers University, November 17, 2014).
- Éric Monfroy, Member of the HDR committee of the Habilitation thesis of Thierry Petit, Concilier expressivité et éfficacité en programmation par contraintes, (Nantes University, December 4, 2014).
- Éric Monfroy, Member of the PhD committee of the thesis of Xavier Dupont, (Caen University, December 18, 2014).
- Éric Monfroy, Member of the Magister committee of the Magister thesis of N. Galvez, (UTFSM, Chile, November 19, 2014).

9.3. Popularization

- A user guide is now available for CHOCO: 164 pages describing how to use CHOCO, together with a new website, see http://www.choco-solver.org. The next topics on the way will include:
  - Dealing with strong consistencies.
  - Designing an even more efficient free search strategy.
  - Providing a light explanation framework.
- Within the context of the global constraint catalog:
  - On-line interactive exercises completed (see http://imedia.emn.fr/global_constraints_course/).
  - Effort for providing more TikZ illustrations has been continued (about 1000 figures are currently available and 60 figures remain to be redesigned to TikZ) by Nicolas Beldiceanu.
  - Reorganization of the production of the pdf version (and enhancing look and navigation within the pdf) by Mats Carlsson.
  - Update of the web version (see http://sofdem.github.io/gccat/) by Sophie Demassey.
- A strong effort has also been made in 2014 to improve the dissemination of IBEX and the collaboration of programers. This includes:
  - Course on IBEX by Gilles Chabert at MACS 2015.
  - Creation of a new web site, see http://www.ibex-lib.org/.
  - Documentation writing (low-level interval arithmetic operations, contractors), see http://www.ibex-lib.org/doc/.
  - Migration of the code from SVN+sourceforge to github (github.com/ibex-team/ibex-lib).
  - Support via the new forum (http://ibex-lib.org/forum).
  - Bug/issue tracking system, private wiki for developers.
  - Introduction of Travis for continuous integration.
- Within the context of *Artificial Intelligence and real time strategy games*,
  - Interview by Inria Bretagne of F. Richoux on his work about Game AI, see emergences.inria.fr/emergences-2014/newsletter-n30/L30-STARCRAFT.
  - F. Richoux has been invited to write a short article about his work about Game AI in the "Bulletin de l'Association Française pour l'Intelligence Artificielle". It should appear on January 2015.
- Presentation at the workshop les femmes dans le monde académique by Charlotte Truchet.
- A the 2014 edition of the Fête de la Science (Nantes University):
  - One talk on *Challenges around optimizations problems* was given by Xavier Lorca.

– A session discussing and answering questions around the work of professor and researcher in computer science with young persons (18 years old) was spent by N. Beldiceanu.

10. Bibliography

Major publications by the team in recent years

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[2] N. BELDICEANU, M. CARLSSON, E. PODER, R. SADEK, C. TRUCHET. *A Generic Geometrical Constraint Kernel in Space and Time for Handling Polymorphic k-Dimensional Objects*, in "13th International on Principles and Practice of Constraint Programming (CP'07) 13th International on Principles and Practice of Constraint Programming (CP'07)", Brown États-Unis, 2007, vol. 4741, pp. 180-194, http://hal.archives-ouvertes.fr/hal-00481558/en/

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[4] C. BESSIERE, R. DEBRUYNE. *Theoretical Analysis of Singleton Arc Consistency and Its Extensions"*, in "Artificial Intelligence", 01 2008, vol. 172, n^o 1, pp. 29-41, http://hal-lirmm.ccsd.cnrs.fr/lirmm-00230949/en/

[5] C. BESSIERE, T. PETIT, B. ZANUTTINI. *Making Bound Consistency as Effective as Arc Consistency*, in "IJCAI'09", 2009, http://hal-lirmm.ccsd.cnrs.fr/lirmm-00382609/en/

[6] H. CAMBAZARD, N. JUSSIEN. *Identifying and exploiting problem structures using explanation-based constraint programming*, in "Constraints", 2006, vol. 11, n^o 4, pp. 295-313 [*DOI :* 10.1007/S10601-006-9002-8], http://hal.archives-ouvertes.fr/hal-00293899/en/

[7] G. CHABERT, N. BELDICEANU. *Sweeping with Continous Domains*, in "16th International Conference on Principles and Practice of Constraint Programming (CP'10)", St Andrews, Scotland, D. COHEN (editor), Lecture Notes in Computer Science, Springer-Verlag, 2010, vol. 6308, pp. 137-151

[8] G. CHABERT, L. JAULIN. *Contractor Programming*, in "Artificial Intelligence", 2009, vol. 173, pp. 1079-1100 [*DOI :* 10.1016/J.ARTINT.2009.03.002], http://hal.archives-ouvertes.fr/hal-00428957/en/

[9] F. HERMENIER, X. LORCA, J.-M. MENAUD, G. MÜLLER, J. LAWALL. *Entropy: a Consolidation Manager for Clusters*, in "International conference on Virtual execution environments", 2009, https://hal.inria.fr/hal-01102354v1

[10] J.-M. NORMAND, A. GOLDSZTEJN, M. CHRISTIE, F. BENHAMOU. *A Branch and Bound Algorithm for Numerical MAX-CSP*, in "LNCS The 14th International Conference on Principles and Practice of Constraint Programming", Australie, 09 2008, vol. 5202/2008, pp. 205-219, Best student paper award [*DOI :* 10.1007/978-3-540-85958-1_14], http://hal.archives-ouvertes.fr/hal-00481180/en/

Publications of the year

Doctoral Dissertations and Habilitation Theses

[11] B. BELIN. *Interactive design of sustainable cities with constraints solving*, Université de Nantes, November 2014, https://hal.archives-ouvertes.fr/tel-01095433

[12] J.-G. FAGES. *On the use of graphs within constraint-programming*, Ecole des Mines de Nantes, October 2014, https://tel.archives-ouvertes.fr/tel-01085253

[13] X. LORCA. *Éléments de flexibilité et d'efficacité en programmation par contraintes*, Université de Nantes, November 2014, Habilitation à diriger des recherches, https://hal.archives-ouvertes.fr/tel-01096401

[14] T. PETIT. *Concilier Expressivité et Efficacité en Programmation par Contraintes* , Université de Nantes, December 2014, Habilitation à diriger des recherches, https://hal.archives-ouvertes.fr/tel-01095608

[15] C. PRUD'HOMME. *Controlling propagation and search within a constraint solver*, Ecole des Mines de Nantes, February 2014, https://tel.archives-ouvertes.fr/tel-01060921

Articles in International Peer-Reviewed Journals

[16] I. ARAYA, G. TROMBETTONI, B. NEVEU, G. CHABERT. *Upper Bounding in Inner Regions for Global Optimization under Inequality Constraints*, in "Journal of Global Optimization", October 2014, vol. 60, n° 2, pp. 145-164, https://hal-enpc.archives-ouvertes.fr/hal-01061701

[17] N. BELDICEANU, P. FLENER, J.-N. MONETTE, J. PEARSON, H. SIMONIS. *Toward sustainable development in constraint programming*, in "Constraints", April 2014, 11 p. [*DOI :* 10.1007/s10601-013-9152-4], https://hal.inria.fr/hal-01086761

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