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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
Programs, Verification and Proofs

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Project-Team TASC

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

Creation of the Project-Team: January 01, 2011 .

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.

2.2. Highlights of the Year

1. The IBEX library has been entirely re-factored from scratch to provide a more clean and easy-to-use interface as well as a more powerful engine and made available in December 2012 on multiple platforms (Linux, MacOs, Windows). Global optimization and system solving front-end algorithms have been tested on more than 500 benchmarks.
2. Significant advance on learning constraints models for highly structured problems was done in 2012. The system [19] is based on the global constraint catalog, providing the library of constraints that can be used in modeling, and the Constraint Seeker tool, which finds a ranked list of matching constraints given one or more sample call patterns. Surprisingly, the system often finds usable models even when working with a single, positive example.

3. Scientific Foundations

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://www.emn.fr/x-info/sdemasse/gccat/index.html). 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 350 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.

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 combinate the expressive power of global constraints with local search frameworks.

3.2.4. Solvers

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 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). 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.). Since 2009 year, due to the hiring of G. 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). 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 2012 the TASC team was involved in the following application domains:

- *Planning and replanning* in Data Centres (SelfXL 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 over a period of several years.

5. Software

5.1. CHOCO

Participants: Nicolas Beldiceanu, Alexis De Clerq, Sophie Demassey, Jean-Guillaume Fages, Narendra Jussien [correspondant], Arnaud Letort, Xavier Lorca [correspondant], Thierry Petit, Charles Prud'homme [correspondant], Remi Douence.

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

1. Since September 2011, we are working on a new version of the CHOCO solver. This implies a total refactoring of the source code in order to make it simpler to use and maintain. We introduce a new propagation engine framework that directly handle state-of-the-art techniques, such as *advisors*, *propagator groups*, *activity-based search* and *explanations*, to ensure a good level of efficiency, and plug a MiniZinc modeling language parser. An alpha release will be available by the beginning of 2013.
2. In the context of the new version of the CHOCO solver we design an *adaptive propagation engine* to enhance performance as well as a *solver independent language to write strategies* for controlling the new adaptive propagation engine. The adaptive propagation engine can both deal with variable-oriented propagation engines and constraint-oriented propagation engines. It is usually accepted that there is no best approach in general and modern constraint solvers therefore implement only one.
3. New scalable global constraints were provides both in the context of *graph constraints* (with also graph variables) and in the context of *scheduling constraints*. These constraints respectively allow to handle sparse graphs with up to 10000 vertices, and resource scheduling problems with up to one million tasks.
4. A new global constraint called *focus* for concentrating high cost values motivated by several concrete examples, such as resource constrained scheduling problems with machine rentals, was introduced.
5. The work on providing probability-based constraints to get light propagation filtering algorithm has been pursued. A particular focus has been put on calculating the probabilistic indicator for the bound-consistency propagator of an *alldifferent* constraint.

N. Beldiceanu, A. De Clerq, S. Demassey, J.-G. Fages, N. Jussien, A. Letort, X. Lorca, T. Petit, C. Prud'Homme and R. Douence have contributed in 2012. The link to the system and documentation is http://choco.emn.fr.

5.2. IBEX

Participants: Ignacio Araya, Anthony Baire, Gilles Chabert [correspondant], Rémi Douence, Bertrand Neveu, Gilles Trombettoni.

IBEX (Interval-Based EXplorer) is a C++ library for solving nonlinear constraints over real numbers (25000 lines of source code). The main feature of Ibex is its ability to build solver/paver strategies declaratively through the contractor programming paradigm.

Continuing last year work on the redesign of the architecture of IBEX, the IBEX library has been entirely re-factored from scratch to provide a more clean and easy-to-use interface as well as a more powerful engine.The development started in late 2011, the kernel has been completed in mid-2012 and almost all the functionalities of IBEX integrated in the new architecture. Global optimization and system solving front-end algorithms have been tested on more than 500 benchmarks. Installation scripts for a deployment on multiple platforms have also been done by an engineer of Inria (Anthony Baire). A first web site has been activated, with an on-line installation documentation, a programming tutorial (still under writing), and an API. An alpha release is now available for download. A first training course on IBEX 2.0 has been organized at ENSTA Bretagne, Brest, the 17-18th December with about 25 participants. Similar training courses will also occur in 2013.

An explorative study aimed at showing that the explicit representation of search trees can play a distinguished role in the field of numerical constraints was done this year. The idea was also to define a new high-level language to handle explicit search trees, in the fashion of quadtrees (that one can intersects, etc.). We have developed a prototype in Haskell to validate the approach and have illustrated it over different examples.

5.3. CHOCO-IBEX

Participants: Gilles Chabert [correspondant], Charles Prud'homme [correspondant].

Work has been done to provide an interface for connecting the CHOCO and the IBEX libraries in order to handle problems where we both have continuous and discrete variables. This interface allows to filter continuous domains from CHOCO with the IBEX engine as well as to check for unsatisfiability or entailment. It also manages reification variables. This interface has been tested on a toy problem and seems to work as expected. Some glue code (on both sides) is still missing to handle reificiation and should be integrated in a short term. The interface should be ready for usage with the next version of CHOCO (3.0).

5.4. Global Constraint Catalog

Participants: Nicolas Beldiceanu [correspondant], Mats Carlsson, 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://www.emn.fr/z-info/sdemasse/gccat/ (at item *last working version*) containing 406 constraints, 3397 pages and 758 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 focussing on:

1. maintaining the catalogue,
2. making the *core global constraints* (10 constraints) more accessible to a wider audience:
   - for this purpose examples with their corresponding pictures have been systematically provided for showing all solutions for an example of each core global constraint.
   - in addition a set of about 30 exercises with their corrections have been done for half of the core global constraints.
3. a redesign of all the 758 figures of the catalog has been undertaken in autumn 2012 using TikZ (in December 2012 312 figures were redesigned).
4. adding constraints related to sequences that we found relevant for learning constraints from electricity production curves.

N. Beldiceanu, M. Carlsson (SICS, Sweden) and H. Simonis (4C, Ireland) have contributed in 2012. The link to the global constraint catalog is http://www.emn.fr/z-info/sdemasse/gccat/.

6. New Results

6.1. Constraint and Abstract Interpretation

Participants: Marie Pelleau, Charlotte Truchet, Fredéric Benhamou, Antoine Miné.

We apply techniques from Abstract Interpretation (AI), a general theory of semantic abstractions, to Constraint Programming (CP), which aims at solving hard combinatorial problems with a generic framework based on first-order logics. We highlight some links and differences between these fields: both compute fix-points by iteration but employ different extrapolation and refinement strategies; moreover, consistencies in Constraint Programming can be mapped to non-relational abstract domains.

- In a first step, we redefine all the components of CP on abstract domains, instead of the usual cartesian, domain-specific domains (boxes or integer sets), obtaining a generic method that can be specified for any of the AI abstract domains.
- In a second step, we then use the correspondences between AI and CP to build an abstract constraint solver that leverages abstract interpretation techniques (such as relational domains) to go beyond classic solvers. We present encouraging experimental results obtained with our prototype implementation, called AbSolute. In particular, AbSolute is able to solve problems on both discrete and continuous variables.

The work is done in collaboration with Antoine Miné.

A corresponding paper *A constraint solver based on abstract domains* [26] will appear at the 14th International Conference on Verification, Model Checking, and Abstract Interpretation (VMCAI'13).

6.2. Analytic Combinatorics and Lazy Filtering

Participants: Jérémie du Boisberranger, Danièle Gardy, Xavier Lorca, Charlotte Truchet.

The ANR Boole project (2009-2013) aims at quantifying different formats of boolean formulas, including SAT of constraints. Within the project, we have started a collaboration with Danièle Gardy, UVSQ, expert in analytic combinatorics and average-case study of algorithms. The goal of the collaboration was to quantify, within a high level probabilistic model, how often the bound-consistency propagator of an *alldifferent* constraint is likely to do something (or nothing). During year 2012, a particular focus has been put on calculating the probabilistic indicator, with an accepted publication at Analco 2013 (to appear). Further research include implementing and testing different possible uses for this indicator. A post-doc, Vincent Armant, has been recruited on the Boole project for this.

The corresponding paper *When is it worthwhile to propagate a constraint? A probabilistic analysis of* alldifferent [29] was accepted for publication at the ANALCO 13th Meeting on Analytic Algorithmics and Combinatorics (Analco 2013).

6.3. Learning Constraint Models

Participants: Nicolas Beldiceanu, Naina Razakarison, Helmut Simonis.

We designed a system which generates finite domain constraint models from positive example solutions, for highly structured problems. The system is based on the global constraint catalog, providing the library of constraints that can be used in modeling, and the constraint seeker tool, which finds a ranked list of matching constraints given one or more sample call patterns. We have tested the modeler with 230 examples, ranging from 4 to 6,500 variables, using between 1 and 7,000 samples. These examples come from a variety of domains, including puzzles, sports-scheduling, packing and placement, and design theory. Surprisingly, in many cases the system finds usable candidate lists even when working with *a single*, positive example.

The corresponding paper *A Model Seeker: Extracting Global Constraint Models From Positive Examples* [19] was published at the 18th International Conference on Principles and Practice of Constraint Programming (CP 2012).

6.4. Scalable Resource Scheduling Constraints

Participants: Nicolas Beldiceanu, Mats Carlsson, Arnaud Letort.

Following up on our work on scalable placement constraints for rectangle and box packing, and initially motivated by multidimensional bin packing problems that arise in the context of data centers, we have focussed this year our work on scalable resource scheduling constraints.

First we came up with a sweep based algorithm for the *cumulative* constraint, which can operate in filtering mode as well as in greedy assignment mode. Given n tasks, this algorithm has a worst-case time complexity of $O(n^2)$. In practice, we use a variant with better average-case complexity but worst-case complexity of $O(n^2 \log n)$, which goes down to $O(n \log n)$ when all tasks have unit duration, i.e. in the bin-packing case. Despite its worst-case time complexity, this algorithm scales well in practice, even when a significant number of tasks can be scheduled in parallel. It handles up to 1 million tasks in one single cumulative constraint in both CHOCO and SICStus.

Second we generalize the previous sweep algorithm to directly handle multiple resources. Given n tasks and k resources, this algorithm has a worst-case time complexity of $O(k \cdot n^2)$ but scales well in practice. In greedy assignment mode, it handles up to 1 million tasks with 64 resources in one single constraint. In filtering mode, on our benchmarks, it yields a speed-up of about $k^{0.75}$ when compared to its decomposition into k independent *cumulative* constraints.

A first paper *A Scalable Sweep Algorithm for the cumulative Constraint* [24] was published at the 18th International Conference on Principles and Practice of Constraint Programming (CP 2012). A second paper *A Synchronized Sweep Algorithm for the k-dimensional cumulative Constraint* was accepted for publication at the 10th International Conference on Integration of AI and OR Techniques in Constraint Programming for Combinatorial Optimization Problems (CPAIOR 2013).

6.5. Reification of Global Constraints

Participants: Nicolas Beldiceanu, Mats Carlsson, Pierre Flener, Justin Pearson.

Being able expressing the negation of global constraints is something that is required in contexts such as testing the equivalence of two constraints models (see the PhD thesis of N. Lazaar) or in the context of learning constraints. Motivated by that, we introduce a simple idea for deriving reified global constraints in a systematic way. It is based on the observation that most global constraints can be reformulated as a conjunction of total function constraints together with a constraint that can be easily reified.

The corresponding paper *On the Reification of Global Constraints* [12] was published in the Constraints journal. A companion technical report [35] provides such reifications for 82% of the constraints of the global constraint catalog [36].

6.6. Optimization and Soft Problems

Participant: Thierry Petit.

Many optimization problems involve business constraints, which are complementary to an objective function that aggregates cost variables. These constraints involve the same cost variables. They are generally non linear. In the literature, several approaches were proposed for balancing constraints. We address the reverse concept, that is, concentrating high cost values in a restricted number of areas. This concept is motivated by several concrete examples, such as resource constrained scheduling problems with machine rentals. We present a new global constraint called *focus*. We provide a complete and optimum time complexity filtering algorithm for our constraint.

The corresponding paper *Focus : A Constraint for Concentrating High Costs* [27] was published at the 18th International Conference on Principles and Practice of Constraint Programming (CP 2012).

6.7. Consistency and Filtering

Participants: Nicolas Beldiceanu, Mats Carlsson, Gilles Chabert, Sophie Demassey, Thierry Petit, Jean-Charles Régin.

Following up on our work on efficient filtering algorithms for common conjunctions of widely used constraints (e.g., *among*, *alldifferent*, *linear constraint*, *inequalities constraints*) we provide:

1. An $O(n \log n)$ bound consistency filtering algorithm for the conjunction of an *alldifferent* and a *linear inequality* constraint. The $O(n \log n)$ complexity is equal to the complexity of the bound consistency algorithm of the *alldifferent* constraint.
2. A polynomial time bound consistency algorithm for the conjunction of *among* constraints where the variable and value domains are interval.

Motivated by the need to define more formally incomplete filtering algorithms we have proposed a new theoretical scheme for characterizing, comparing and classifying the intermediary levels of consistency of global constraints.

The corresponding papers, *An $O(n \log n)$ Bound Consistency Algorithm for the Conjunction of an alldifferent and an Inequality between a Sum of Variables and a Constant, and its Generalization* [17], *The Conjunction of Interval* among *Constraints* [21] and *Intermediary Local Consistencies* [28] were published at the 20th European Conference on Artificial Intelligence (ECAI 2012) as well as at the 9th International Conference on Integration of AI and OR Techniques in Constraint Programming for Combinatorial Optimization Problems (CPAIOR 2012).

6.8. Automata and Matrix Models

Participants: Nicolas Beldiceanu, Mats Carlsson, Pierre Flener, Justin Pearson.

Matrix models are ubiquitous for constraint problems. Many such problems have a matrix of variables $\mathcal{M}$, with the same constraint C defined by a finite-state automaton $\mathcal{A}$ on each row of $\mathcal{M}$ and a global cardinality constraint gcc on each column of $\mathcal{M}$. We give two methods for deriving, by double counting, necessary conditions on the cardinality variables of the gcc constraints from the automaton $\mathcal{A}$. The first method yields linear necessary conditions and simple arithmetic constraints. The second method introduces the *cardinality automaton*, which abstracts the overall behaviour of all the row automata and can be encoded by a set of linear constraints. We also provide a arc-consistency filtering algorithm for the conjunction of lexicographic ordering constraints between adjacent rows of $\mathcal{M}$ and (possibly different) automaton constraints on the rows. We evaluate the impact of our methods in terms of runtime and search effort on a large set of nurse rostering problem instances.

The corresponding paper *On Matrices, Automata, and Double Counting in Constraint Programming* [11] was published in the Constraints journal.

6.9. Parallelization

Participants: Salvador Abreu, Yves Caniou, Philippe Codognet, Daniel Diaz, Florian Richoux.

During these last decades, many sequential algorithms for Constraint Satisfaction Problems (CSP) have been developed to be able to solve real problems from industry. However these problems become more and more complex and it remains important to treat them as fast as possible. Until the mid-2000's, one developed computers power by increasing CPU frequency. Nevertheless for about five years, this solution is not possible anymore since it asks too much energy (problem linked to heat dissipation issues), thus our machines architecture turns to be more and more multi-core oriented.

Nowadays we still have very few algorithms for constraint problems adapted to multi-core architecture. This year, we obtained very good results with the parallelization of meta-heuristic methods, reaching linear speed-ups over 8,192 cores on the *Costas Array Problem* [22], [23]. We also proposed in [20] two ways to perform smart cooperations between parallel local search processes, leading to very promising new approaches to solve constraint-based problems in parallel.

7. Bilateral Contracts and Grants with Industry

7.1. Ligéro

Participants: Sophie Demassey, Xavier Lorca.

Title: Ligéro.

Duration: 2009-2012.

Type: Regional research group

Budget: PhD founded by the project.

Others partners: LISA, IRCCyN (team SLP), LERIA (team MOA), LINA (team OPTI).

The goal of the project is to create an internationally visible regional research group putting together the key actors in the domain of Operations Research in the Pays de la Loire region.

7.2. CPER

Participant: Charles Prud'Homme.

Title: CPER.

Duration: 2010-2014.

Type: Regional research group.

Budget: 250000 Euros.

Others partners: EMN (team ATLANMOD), EMN (team ASCOLA), IRCCyN (team SLP).

Develop, promote and build up an eco-system around free software in the Pays de la Loire region. The TASC team is involved in the maintenance and development of the free constraint programming platform CHOCO.

7.3. UNIT

Participants: Nicolas Beldiceanu, Eliane Vacheret.

Title: UNIT.

Duration: 2011-2012.

Type: Developing teaching material.

Budget: 5000 Euros.

Others partners: EMN (CAPE).

Pedagogical material and software for learning constraints programming for non experts (integrated within the global constraint catalog).

7.4. FUI SUSTAINS

Participants: Charlotte Truchet, Bruno Belin.

Title: SUSTAINS.

Duration: 2010-2015.

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 focussed 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.

7.5. ANR BOOLE

Participants: Vincent Armant, Jérémie du Boisberranger, Xavier Lorca, Charlotte Truchet.

Title: BOOLE.

Duration: 2010-2015.

Type: open research program.

Budget: founding a PhD student and travels.

Others partners: Univ. de Versailles Saint-Quentin, Univ. Caen, Univ. Paris 8, Univ. Aix-Marseille, Univ. Paris Nord, Univ. Paris 11, ENS Paris.

Défi: Probabilistic method for combinatorial problems.

The work of TASC focuses on the use of probabilistic methods to avoid waking systematically global constraints for nothing. The goal is to provide probabilistic models for the consistency of global constraints such as *alldifferent* or *nvalue*. We compute the probability of a constraint to be still consistent after fixing one of its variables and provide an approximation that can be computed in constant time. The PhD of J. du Boisberranger is co-supervised with D. Gardy from Univ. de Versailles Saint-Quentin.

7.6. ANR NetWMS2

Participants: Nicolas Beldiceanu, Gilles Chabert.

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

Duration: 2011-2014.

Type: cosinus research program, **new project**.

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).

7.7. ANR INFRA-JVM

Participants: Xavier Lorca, Charles Prud'Homme.

Title: Towards a Java Virtual Machine for pervasive computing.

Duration: 2011-2013.

Type: **new project**.

Budget: 78000 Euros.

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

The INFRA-JVM project will investigate 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.

7.8. EDF

Participants: Nicolas Beldiceanu, Helmut Simonis.

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 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 model seeker [19].

7.9. Google

Participants: Jean-Guillaume Fages, Xavier Lorca, Jean-Charles Régin, Louis Martin Rousseau.

Within the context of a Google grant involving Jean-Charles Régin from Nice University, Louis-Martin Rousseau from Polytechnique Montreal and Xavier Lorca and Jean-Guillaume Fages from TASC the following work on graph constraints has been undertaken.

In constraint programming, specific syntax for expressing unweighted circuit constraints in a graph have been proposed already since the first CP systems were developed. Most current CP systems contain a constraint to model unweighted circuits, although the associated filtering algorithm may be quite different for each system. Weighted circuit constraints are less common in CP systems, as the weights and the circuit are typically handled separately. However, several filtering algorithms have been proposed in the literature that can be applied to the weighted circuit constraint. Currently, no professional CP system offers any of these algorithms. Thus, solving problems that contain weighted circuit constraints remains a challenge for constraint programming. One of the main contributions of our work is to expand the reach of constraint programming solvers to complex routing problems. We will propose more effective filtering algorithms for the weighted circuit constraint that are guided by the resolution of real world instances and not only by benchmarking.

8. Partnerships and Cooperations

8.1. Regional Initiatives

1. The goal of Ligéro is to create an internationally visible regional research group putting together the key actors in the domain of Operations Research in the Pays de la Loire region.
2. A regional grant from the Région Pays de la Loire for inviting in Nantes a senior researcher was obtained end of 2012 (6 months in 2013 and 2014 for Helmut Simonis) on *learning generic constraint models*.

8.2. National Initiatives

1. Cooperation with J.-C. Régin from Univ. Nice on efficient graph filtering algorithms.
2. Cooperation with A. Miné from ENS Paris on abstract domains by M. Pelleau and C. Truchet.

8.3. European Initiatives

8.3.1. Collaborations with Major European Organizations

SICS, Computer Systems Laboratory (Sweden)

Global Contraint Catalog, scalable global constraints.

4C, (Ireland)

Learning constraint models.

Uppsala University, (Sweden)

Automata and constraints.

8.4. International Initiatives

8.4.1. Inria International Partners

- SICS, Sweden: Work on the *global constraint catalog* and on *scalable constraints* with Mats Carlsson.
- Uppsala University, Sweden: Work on automata and dedicated filtering algorithms for some constraint patterns with the ASTRA group of Pierre Flener.
- École Polytechnique de Montreal, Canada: Work on graph constraints with Louis Martin Rousseau.
- JFLI, Japan: Work with Philippe Codognet.

8.5. International Research Visitors

8.5.1. Visits of International Scientists

Helmut Simonis (4C): work on model learning and work on learning constraints in the context of EDF, one month.

8.5.1.1. Internships

- Naina Razakarison (internship of ENS Cachan in summer 2012 on learning generic models).
- Mohamed Kebe (internship of Clermont University in summer 2012 on reformulations of the *cumulative* constraint).

8.5.2. Visits to International Teams

- N. Beldiceanu, 4C Cork Ireland: work on *learning generic models* and work on *learning constraints in the context of EDF* with H. Simonis.
- N. Beldiceanu, Uppsala University and SICS: work on *automata and constraints* with P. Flener and J. Pearson and on *learning generic models* with M. Carlsson.

9. Dissemination

9.1. Scientific Animation

- Nicolas Beldiceanu:
  - Head of the Inria TASC team and LINA TASC team.
  - Program co-chair of CPAIOR 2012.
  - Member of the program committee of ROADEF 2012.
  - Member of the program committee of CP 2012.
  - Co-chair of BPPC 2012.
  - Member of the program committee of ECAI 2012.
  - Member of the program committee of CPAIOR 2013.
  - Member of the program committee of CP 2013.
  - Reviewer for IJCAI 2013.
  - Reviewer in 2012 for the Constraints Journal.
  - Invited talk in August 2012 on the topic of *a model seeker* by the Department of Information Technology, Uppsala University, Sweden.
- Fréderic Benhamou:
  - Vice-President for Research of Nantes University, France.
- Gilles Chabert:

  - Reviewer for CPAIOR 2012.
  - Reviewer for ACM-SAC 2012.
  - Reviewer in 2012 for the Constraints Journal.
  - Reviewer in 2012 for the RAIRO Journal.
  - Invited by the department of mathematics of Uppsala University, Sweden in the context of the international workshop on interval analysis and set-membership methods.
- Sophie Demassey:
  - Member of the program committee of CPAIOR 2012.
- Jean-Guillaume Fages:
  - Reviewer in 2012 for the Constraints Journal.
  - Invited an Inria Rocquencourt by the constraint team for a seminar on *Using Graph Variables in Constraints Programming*.
- Narendra Jussien:
  - Head of the computer science department at EMN.
  - Conference and program co-chair of CPAIOR 2012.
  - Member of the program committee of CP 2012.
  - Member of the program committee of LION 7.
  - Member of the program committee of RIVF 2012.
  - Member of the program committee of ROADEF 2012.
  - Member of the program committee of ACM-SAC 2012.
  - Reviewer in 2012 for the AI Journal.
  - Reviewer in 2012 for the TPLP.
  - Reviewer in 2012 for the Constraints Journal.
  - Director of the series *Operations Research and Constraint Programming* from ISTE/Wiley.
- Xavier Lorca:
  - Member of the program committee of JFPC 2012.
  - Member of the program committee of JFPC 2013.
  - Member of the program committee of IJCAI2013.
  - Reviewer for CPAIOR 2012.
  - Reviewer in 2012 for the Constraints Journal.
  - Reviewer in 2012 for the RAIRO Journal.
- Florian Richoux:
  - Organizer and member of the program committee of the session *Large Scale Parallelism* of LION 7.
- Thierry Petit:
  - Co head of the LINA TASC team.
  - Conference co-chair of CPAIOR 2012.
  - Member of the program committee of CPAIOR 2012.
  - Member of the program committee of Cocomile 2012.
  - Reviewer in 2012 for CP 2012.
  - Reviewer in 2012 for the Constraints Journal.
  - Reviewer in 2012 for EJOR.

  - Reviewer in 2012 for CPL.
  - Member of the program committee of CP 2013.
  - Invited talk on the topic of *constraints on sequences of variables, balancing and focus constraints* at the 8èmes Journèes Francophones de Programmation par Contraintes (JFPC 2012), Toulouse, France.
- Charlotte Truchet:
  - Program Chair of JFPC 2013.
  - Member of the program committee of ECAI 2012.
  - Invited at the NII (National Institute for Informatics) and JFLI (Japanese-French LAboratory for Informatics) in Tokyo: work on *parallel constraint solving* with H. Hosobe at NII and with P. Codognet at JFLI.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Master: N. Beldiceanu, Constraint (Master ORO), 26h, M2, Nantes University, France.

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

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

Licence: N. Beldiceanu, Imperative Programming, 12h, L3, Mines de Nantes, France.

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

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

Licence: G. Chabert, Simulation and parameter estimation, 18h, L3, Mines de Nantes, France.

Licence: G. Chabert, Numerical integration, 15h, L3, Mines de Nantes, France.

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

Licence: J.-G. Fages, Graphs and Algorithms, 28h, L2, Mines de Nantes, France.

Master: J.-G. Fages, Constraints Programming, 12h, M2, Mines de Nantes, France.

Master: J.-G. Fages, Project, 20h, M2, Mines de Nantes, France.

Licence: J.-G. Fages, Imperative Programming, 4h, L1, Mines de Nantes, France.

Master: N. Jussien, Constraint, 12h, M2, Mines de Nantes, France.

Master: N. Jussien, Constraint, 3h, M1, Mines de Nantes, France.

Licence: N. Jussien, Discrete mathematics, 12h, L3, Mines de Nantes, France.

Licence: A. Letort, Project, 15h, L1, Mines de Nantes, France.

Licence: A. Letort, Operation Research, 15h, L3, Mines de Nantes, France.

Master: X. Lorca, Head of the major of the Master in Engineering, Computer Science for Decision Support, M2, 30h, Mines de Nantes, France.

Master: X. Lorca, Algorithms and Complexity, 20h, M1, Mines de Nantes, France.

Master: X. Lorca, Data Warehouse and Data Analysis, 20h, M1, Mines de Nantes, France.

Master: X. Lorca, Graph Theory, Algorithms, 20h, M1, Mines de Nantes, France.

Master: X. Lorca, Business Intelligence, 20h, M2, Mines de Nantes, France.

Master: X. Lorca, IT System and Software Development, 20h, M2, Mines de Nantes, France.

Master: X. Lorca, Implementation Project, 20h, M2, Mines de Nantes, France.

Master: T. Petit, Combinatorial Optimization GIPAD, 17.5h, M2, Mines de Nantes, France.

Master: T. Petit, GIPAD project, 25h, M2, Mines de Nantes, France.

Master: T. Petit, Internship of Mohamed Kebe, 25h, M2, University of Clermont, France.

Licence: T. Petit, Imperative Programming, 22.5h, L2, Mines de Nantes, France.

Licence: T. Petit, Object Programming, 9h, L2, Mines de Nantes, France.

Licence: T. Petit, Synthesis, 5h, L2, Mines de Nantes, France.

Licence: T. Petit, Programming project, 8h, L2, Mines de Nantes, France.

Licence: T. Petit, Data structures, 27.5h, L2, Mines de Nantes, France.

Licence: F. Richoux, Design Patterns in Object-Oriented Programming, 96h, L3, University of Nantes, France.

Licence: F. Richoux, Introduction to Computer Science, 36h, L1, University of Nantes, France.

Licence: C. Truchet, C2i, 64h, L1, University of Nantes, France.

Licence: C. Truchet, Algorithms and Programming, 140h, L1, University of Nantes, France.

Licence: C. Truchet, Web, 36h, L1, University of Nantes, France.

Master: C. Truchet, Computer sound design, 24h, M2, University of Nantes, France.

9.2.2. Supervision

PhD: Marie Pelleau, Abstract domains in constraint programming, Nantes University, November 29 2012, Charlotte Truchet, Fréderic Benhamou, Pascal van Hentenryck.

PhD: Alexis De Clerq, Cumulative scheduling with overloads: global constraints and decompositions, Nantes University, October 29 2012, Thierry Petit, Narendra Jussien, Nicolas Beldiceanu.

PhD: Aurélien Merel, Biobjective railway infrastructure capacity assessment by hybrid column generation, Nantes University, October 31 2012, Sophie Demassey, Xavier Gandibleux.

PhD in progress: Arnaud Letort, Scalable scheduling constraints, October 2010, Nicolas Beldiceanu.

PhD in progress: Bruno Belin, Interactive conception of sustainable urban environments with constraints, September 2011, Charlotte Truchet, Marc Christie, Fréderic Benhamou.

PhD in progress: Jean Guillaume Fages, Graph Theory in Constraint Programming, Theory and application to several graph covering problems, October 2011, Xavier Lorca, Nicolas Beldiceanu.

PhD in progress: Charles Prud'Homme, Constraint Propagation and search strategies Management in Modern Constraint Solvers, October 2011, Xavier Lorca, Narendra Jussien, Rémi Douence.

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

9.2.3. Juries

- N. Beldiceanu, Member of the PhD committee of the thesis of Alexis De Clerq (Univ. Nantes, October 29, 2012).
- F. Benhamou, Member of the PhD committee of the thesis of Marie Pelleau (Univ. Nantes, November 29, 2012).
- Narendra Jussien, Member of the PhD committee of the thesis of Alexis De Clerq (Univ. Nantes, October 29, 2012).
- Narendra Jussien, Reviewer of the PhD thesis of Caroline Maillet (Univ. Toulouse, April 25, 2012).
- T. Petit, Member of the PhD committee of the thesis of Alexis De Clerq (Univ. Nantes, October 29, 2012).
- Charlotte Truchet, Member of the PhD committee of the thesis of Marie Pelleau (Univ. Nantes, November 29, 2012).

9.3. Popularization

- Within the context of the global constraint catalog, some effort was done to provide more explanations for the core global constraints, namely:

  - provide for all core global constraints some small examples where one can see, also graphically, all solutions.
  - provide a set of 30 exercises with their detailed solution for half of the core constraints (*alldifferent*, *cycle*, *cumulative*, *element*, *nvalue*).
- Within the context of the new release of the library IBEX a course was given by G. Chabert mid december to about 22 participants in ENSTA Bretagne.

10. Bibliography

Major publications by the team in recent years

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[2] N. BELDICEANU, M. CARLSSON, S. DEMASSEY, E. PODER. *New Filtering for the cumulative constraint in the context of non-overlapping rectangles*, in "Annals of Operations Research", 2010, p. 1-20 [*DOI :* 10.1007/s10479-010-0731-0], http://hal.archives-ouvertes.fr/hal-00485563/en/.

[3] 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, p. 180-194, http://hal.archives-ouvertes.fr/hal-00481558/en/.

[4] N. BELDICEANU, P. FLENER, X. LORCA. *Combining tree Partitioning, Precedence, and Incomparability Constraints*, in "Constraints", 2008, vol. 13, n^{o} 4, p. 459-489 [*DOI :* 10.1007/s10601-007-9040-x], http://hal.archives-ouvertes.fr/hal-00481533/en/.

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[7] H. CAMBAZARD, N. JUSSIEN. *Identifying and exploiting problem structures using explanation-based constraint programming*, in "Constraints", 2006, vol. 11, n^{o} 4, p. 295-313 [*DOI :* 10.1007/s10601-006-9002-8], http://hal.archives-ouvertes.fr/hal-00293899/en/.

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[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, p. 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

Articles in International Peer-Reviewed Journals

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[12] N. BELDICEANU, M. CARLSSON, P. FLENER, J. PEARSON. *On the Reification of Global Constraints*, in "Constraints", 2012, vol. 17, n^{o} 4, http://dx.doi.org/10.1007/s10601-012-9132-0.

Invited Conferences

[13] T. PETIT. *Problèmes d'optimisation sur des séquences*, in "8èmes Journèes Francophones de Programmation par Contraintes (JFPC'12)", Toulouse, France, 2012, p. 3–3.

[14] H. SIMONIS, N. BELDICEANU. *Building global constraint models from positive examples*, in "21th International Symposium on Mathematical Programming (ISMP'12)", Berlin, Germany, august 2012.

[15] H. SIMONIS, N. BELDICEANU. *A Model Seeker: Extracting Global Constraint Models From Positive Examples*, in "2013 INFORMS Computing Society Conference", Santa Fe, USA, january 2013, to appear.

International Conferences with Proceedings

[16] I. ARAYA, G. TROMBETTONI, B. NEVEU, G. CHABERT. *Upper Bounding in Inner Regions for Global Optimization under Inequality Constraints*, in "GLOBAL OPTIMIZATION WORKSHOP 2012", Natal, Brazil, 2012, p. 25-29, http://hal.inria.fr/hal-00733860.

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[19] N. BELDICEANU, H. SIMONIS. *A Model Seeker: Extracting Global Constraint Models from Positive Examples*, in "18th International Conference on Principles and Practice of Constraint Programming (CP'12)", Quebec City, Canada, M. MILANO (editor), Lecture Notes in Computer Science, Springer-Verlag, october 2012, vol. 7514, p. 141–157, http://link.springer.com/chapter/10.1007/978-3-642-33558-7_13.

[20] Y. CANIOU, D. DIAZ, F. RICHOUX, P. CODOGNET, S. ABREU. *Performance Analysis of Parallel Constraint-Based Local Search*, in "17th ACM SIGPLAN Symposium on Principles and Practice of Parallel Programming (PPoPP'12)", New Orleans, LA, USA, ACM Press, 2012, poster paper.

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[29] J. DU BOISBERRANGER, D. GARDY, X. LORCA, C. TRUCHET. *When is it worthwhile to propagate a constraint? A probabilistic analysis of alldifferent*, in "ANALCO 13th Meeting on Analytic Algorithmics and Combinatorics", New Orleans, Louisiana, USA, january 2013, to appear.

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[31] N. BELDICEANU, P. FLENER, J.-N. MONETTE, J. PEARSON, H. SIMONIS. *Some Research Challenges and Remarks on CP*, in "Position Papers on the Future of Constraint Programming", Quebec City, Canada, october 2012.

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