Inria International program
Associate Team final report
BANANAS: *Automated design and autonomous control of hybrid solver cooperations*

Associate Team acronym: BANANAS

Period of activity: 2012 — 2014

Principal investigator (Inria): Christophe Ringeissen, CASSIS project team, Inria Nancy Grand-Est

Principal investigator (partner): Carlos Castro, Departamento de Informática, Universidad Técnica Federico Santa María (UTFSM), Avenida Espana 1680, Valparaíso, Chile

Other participants:

In the original proposal we indicate Eric Monfroy as principal investigator from UTFSM, and some other participants: Jorge Amaya from CMM and Fréderic Saubion's group from the university of Angers. Since the beginning of the project, the configuration has significantly changed. Eric Monfroy is back to the university of Nantes, where the very fruitful cooperation with Frédéric Saubion is continued. This explains the inclusion in 2013 of two *new* academic partners:

- PUCV (*Escuela de Ingeniería Informática de la Pontificia Universidad Católica de Valparaíso*): Broderick Crawford and Ricardo Soto are professors at PUCV. They have done their PhDs respectively at UTFSM and at the university of Nantes.
- Université de Nantes, LINA, projet TASC: Eric Monfroy who spent seven years at UTFSM came back to France for the academic year 2012/13, by retrieving his professor position at the university of Nantes.

1 Overview of the activities

During the last decades, impressive improvements have been achieved to solve complex combinatorial optimization problems. These problems are generally issued from real world applications and they involve more and more data and constraints. In order to tackle large scale instances and intricate problem structures, sophisticated solving techniques have been developed, combined, and hybridized to provide efficient solvers. A common idea to get more efficient and robust algorithms consists in combining several resolution paradigms in order to take advantage of their respective assets.

However, solvers or hybridizations of solvers become more and more complex: the user must select or design various solving and hybridization strategies and tune numerous parameters. To tackle this problem, Autonomous Search is a very attractive approach for designing adaptive systems with the capability of improving its solving performance by selecting and adapting its search strategies to the problem at hand. The main goal of the project is to apply the Autonomous Search approach to hybrid solver cooperations, by automating the selection and the cooperation of solvers, by tuning the cooperation parameters, and by adapting the cooperation during solving.

Our project is structured into three directions according to some different types of solvers we have identified in the initial proposal:

Direction 1 solvers as black boxes

Direction 2 solvers as autonomous systems

Direction 3 abstraction of solvers

2 Scientific achievements

Foundations of autonomous search : In the context of our collaboration, we have published a textbook on autonomous search [20], which describes the state of the art of autonomous and adaptive techniques for constraint programming. This work has been achieved by two members of the team (E. Monfroy and F. Saubion) and include some chapters written by members of our team.

In this trend, our work focus on the autonomous management of of tree-based (complete) solvers and metaheuristics (incomplete) solving techniques, which are typically the two main approaches for solving constraint satisfaction and optimisation problems.

2.1 Autonomous Cooperative Solvers for CSP

2.1.1 Context

The main goal concerning Constraint Satisfaction Problems is to determine a value assignment for variables satisfying a set of constraints, or otherwise, to conclude that such an assignment does not exist (the set of constraints is unsatisfiable). In the Constraint Programming resolution process, it is known that the order in which the variables are assigned have a significant impact in terms of computational cost.

2.1.2 Results

In our work we propose different ways for guiding the classical Constraint Programming resolution process. The idea is to exploit the search process features to dynamically adapt a Constraint Programming solver changing the enumeration strategy in use when another strategy looks more promising in order to solve a Constraint Satisfaction Problem at hand (Set Covering, Sudoku, Robotic manipulation, Scheduling of software projects). Regarding this issue, our approach uses Autonomous Search principles where a system should be able to replace its internal components, when exposed to changing external forces and opportunities, in order to obtain better results. The replacement is performed depending on a quality rank, which is computed by means of a choice function-based Hyperheuristic, where its parameters are fine-tuned by a Metaheuristic (Genetic Algorithm or Particle Swarm) which trains the choice function carrying out a sampling phase. We perform extensive experiments on several benchmarks which show the effectiveness of our approach. Additionally, we published some papers using metaheuristics (Ant Colony Optimization and Cultural Algorithms) to solve combinatorial problems (Sudoku and Scheduling).

Related papers can be found in [8], [32], [27], [28], [39], [15], [16], [5], [26], [33], [10], [31], [6], [12], [4], [13], [9], [14], [11], [7], [34].

2.2 Automatic Selection of Search Operators

2.2.1 Context

In order to efficiently apply solvers to optimization problems, there are many choices that need to be done. Firstly, the design of the general skeleton of the solver includes the modeling of the problem, the data structures, the definition of the basic solving operators... These components can be considered as the structural parameters of the solvers that define the basic skeleton of its operational architecture. However, once the structure is defined, a difficult and crucial task remains: how to control the general computation process? This control is usually embedded in a set of behavioral parameters that can be related to the data structures or to the computation steps.

All these parameters should then be tuned, depending on the problem at hand. People now acknowledge that specific problems require specific setup in order to obtain satisfactory performance. In other words, when it comes to solving a given problem, all practitioners know that parameter setting is in fact the Achille's heel of many solvers.

We have firstly focus our attention on evolutionary algorithms (EA) and local search methods (LS) for solving constraint satisfaction and optimisation problems. Parameter setting in EAs appears actually as a major issue that has deserved much attention during recent years, and research is still very active nowadays. This is actually not limited to EAs, being also investigated in the operation research and constraint programming communities, where the current amount of solving technologies that are included in efficient solvers require a huge expertise to be fully used. Indeed, the efficiency is strongly related to the way the Exploration versus Exploitation (EvE) dilemma is addressed, determining the ability of the EA to escape from local optima in order to sparsely visit interesting areas, while also being able to focus on the most promising ones, thus reaching global solutions.

The algorithms are abstracted as processes that apply a solving operator at each basic step of the search. Therefore our purpose is then to provide automated selection process for managing these operators in order to get acceptable performance on wide range of problem instances.

2.2.2 Results

- **Foundations of autonomous search :** We have published a textbook on autonomous search [20], which describes the state of the art of autonomous and adaptive techniques for constraint programming. This work has been achieved by two members of the team (E. Monfroy and F. Saubion).

- **An autonomous controller for EA :** A controller as been developed for EAs and experimented on classic satisfiability problems. It may be plugged into any EA very easily and allows the users to design high level solving strategies. This work has been achieved in cooperation with the Austral University of Chile (Valdivia) [17]. We have also written a book chapter on this topic [25, 18].

- **Autonomous Local Search :** We have developed new performance measure and operator evaluation mechanism for LS algorithms. This work has been done in cooperation with the Austral University of Chile (Valdivia) [46, 45, 44]. We have extended our work to constraint satisfaction problems in [43].

- **Dynamic Island Models :** Island Models have been introduced in order to better manage diversity in population based algorithms and provide a natural abstraction for dividing the population into several subsets (the islands). An independent EA is then ran on each of these islands. We propose to use island models as a new method for improving parameter settings by running different configurations of the solver on different islands. Another immediate advantage of such models is that they facilitate the parallelization of EAs. This work has been presented in [1].

  We recently have investigated new models in order to consider more complex - non stationnary - operators in [2, 19]. This formal framework will be useful to devise and compare new control mechanisms based on reinforcement learning techniques. In collaboration with the Austral University of Chile (Valdivia), we are also investigating the ability of our model to learn dependencies between operators in changing scenarios. We have thus developed a methodology, as well as suitable criteria, in order to evaluate adaptive control policies [21].

2.3 Applications

Using our techniques we focus on the resolution of a theoretical problem: Set Covering Problem [42], and the following industrial problems: Nurse Rostering [37], Manufacturing Cell Design Problems [40][41], Optimal Design of Architectures for Water Distribution Tanks and Reservoirs [35]. Set covering problem is a classical problem in computer science and complexity theory. It has many applications, such as airline crew scheduling problem, facilities location problem, vehicle routing, assignment problem. All of them are related to Chilean industry and development.

3 Production

BANANAS allowed us to make significant advances in the context of solver cooperations design. During the period 2012—2014, the funding has been used to perform 7 visits in Chile, and 5 visits in France. Let us mention the following highlights that benefited from the support of the associate team.

1. Publication of a textbook on Autonomous Search [20].

2. Conference and journal papers on the use of Autonomous Search in hybrid solver cooperations (cf. list of publications given below).

3. A joint workshop was held in Chile in December 2012. It involved BANANAS and the partners of the project AutoEvol funded by ECOS-Sud: Jorge Maturana, Frédéric Lardeux, and Frédéric Saubion. It was the opportunity to present the project to Jorge Maturana who is a former student from UTFSM who did a PhD at the University of Angers (2005-2009), supervised by Frédéric Saubion. He is now Full-time professor at the Computer Science Institute in Austral University, Valdivia, Chile.

4. International School on Rewriting (ISR 2014), organized by Carlos Castro at UTFSM, with the participation of several French researchers: Claude Kirchner, Hélène Kirchner, Pierre-Moreau (as lecturers) and Christophe Ringeissen (as organizing committee member).

   Even if rewriting does not play anymore a central role in the BANANAS project, most of its members are still interested in applying rewriting techniques and rule-based formalisms to develop constraint solvers. Actually, BANANAS is the continuation of previous bilateral projects (between France and Chile, since 2003) on the interactions between Rewriting and Constraint Programming. We believe that he organization of ISR 2014 in Valparaíso may help to attract in the near future Latin American students on rewriting and automated deduction in Nancy.

5. Nicolás Gálvez, who did his master thesis with Carlos Castro is now starting a PhD in co-tutelle between UTFSM and the university of Angers. He will be supervised by Carlos Castro, Frédéric Saubion and Eric Monfroy. The subject of this thesis will be related to the application of search techniques developed in this project (adaptive constraint programming techniques as well as adaptive metaheuristics) to software engineering problems. This recent trend of SBSE (Search Based Software Engineering) appears actually as a very promising application area for our algorithms. In particular, we will collaborate with members of the DAASE project (Dynamic Adaptive Automated Software Engineering), with whom we have already relationship (e.g., Y. Hamadi at Microsoft Research Cambridge or N. Veerapen and G. Ochoa at University of Stirling).

6. Fruitful cooperations with new Chilean researchers working on constraint solving and constraint programming, namely Broderick Crawford and Ricardo Soto (PUCV), and Jorge Maturana (U. Valdivia). Ricardo Soto and Jorge Maturana did their PhDs in France, respectively in Nantes and in Angers. Broderick Crawford did a PhD with Carlos Castro at UTFSM, when Eric Monfroy was a researcher at UTFSM (from 2005 to 2012).

4 Future of the partnership

In the initial proposal, we divided the project into three directions. The first direction was dedicated to the study of autonomous solving for solvers seen as black boxes. Then, in a second direction, the idea was to open the black boxes in order to consider solvers also as autonomous systems. Now, we have a flatten point of view of the problem. In some sense, the two directions have been merged. A third direction was to consider abstract solvers together with a service composition approach to implement an autonomous system. This third direction is now viewed as a long-term project, where students can be easily involved.

As shown below, we are working on applying the ideas of autonomous search to the modeling problem, in order to guide the way a problem can be reduced in a efficient way with respect to the tools at hand. Therefore, our motivation is to lift our techniques from solving to modeling. Nevertheless, the design of autonomous system for constraint solving remains our priority. These two lines of research are discussed in the following.

- Adaptive Modeling

  One of the key feature of Constraint Programming at its beginning was "modeling": translating verbal problem statements into a formal description that can be read by a solver. During the last year of the project, we came back to this topic to integrate adaptive and autonomous modeling. On the one hand, CSP are declarative and expressive. On the other hand, SAT solvers can solve huge problems (millions of variables). We thus worked on the convertion of set constraints (CSP) into SAT instances, transforming a CSP model into a SAT model. To this end, we developed a technique based on rewrite rules that transform a CSP set constraint into Boolean variables and clauses. Since the size of the generated SAT instances increase rapidly, we also developed a set of rules to reduce the support of the sets before convertion; these rules are equivalent to a generalized arc consistency algorithm for sets. Hence, we obtain "good" SAT instances that are well suited for SAT solvers. The advantage of our method is that it is declarative and expressive (modeling with set constraints), less error-prone than directly writing SAT instances, the automatically generated SAT instances have similar caracteristics (in term of size and solving time) than hand-written (and tuned) instances, and the model can be solved by a SAT solver or a CSP solver [23]. In the future, we plan to make a kind of tool box of model transformers that could also be managed automatically to adapt models to the solvers, thus bringing autonomy at the level of models.

This line of research is the opportunity to study new reductions to SMT instead of reductions to SAT, and so applying SMT solvers, such as veriT developed in Nancy, instead of SAT solvers. This topic allows us to consider a large scope of techniques and solvers developed by different communities: Constraint Programming, Artificial Intelligence, Operational Research, and also Automated Reasoning.

- Adaptive Solving

  We are focusing on the design and implementation of an autonomous search system for constraint programming involving adaptive enumeration and adaptive propagation able to achieve efficient solving processes without the need of user expertise in tuning. To this aim, we are working on the following sub-goals that need to be further investigated:

  1. Design and implementation of a component for performing adaptive enumeration including a choice function and a rank generator supported by database techniques.
  2. Design and implementation of a component for performing adaptive propagation involving different local consistencies and supported by the modern architecture for Autonomous Search.
  3. Integration of both components (adaptive enumeration and propagation) in a single unified framework to combine both adaptive techniques.
  4. Perform a large experimentation phase considering a large set of problems so as to determine which rank generators, choice functions, optimizers, and strategies exhibit the best solving processes.

  The achievement of these sub-goals involve master students, mainly on the Chilean side. In relation with master students, we study the use of Metaheuristic Algorithms for Combinatorial Problems and Engineering Applications and its possible hibridization with Constraint Programming. Among recent Metaheuristics, we are considering: particle swarm optimization, cuckoo search, firefly algorithm, bat algorithm, black hole, electromagnetism, gravitacional, harmony, biogeography-based optimization.

  Concerning specific application domains, as mentioned above, the thesis of Nicolás Gálvez will focus on software engineering problems, which appear as a very promising area for using such adaptive solving tools.

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