R&D Project Report

Franco-Japanese research collaboration on constraint programming

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ABSTRACT

Constraint programming is an emergent technology that allows modeling and solving various problems in many areas such as artificial intelligence, computer programming, computer-aided design, computer graphics, and user interfaces. In this report, we recount the recent activities of research collaboration on constraint programming conducted by the authors and other researchers in France and Japan. First, we outline our joint research projects on constraint programming and then present the backgrounds, goals, and approaches of several research topics treated in the projects. Second, we describe the two Franco-Japanese Workshops on Constraint Programming (FJCP), which we held in Japan in October 2004 and in France in November 2005. We conclude with future prospects for collaboration between French and Japanese researchers in this area.

KEYWORDS
Constraint programming, constraint logic programming, speculative computation, multi-agent systems, constraint hierarchies, global optimization

1 Introduction

Constraint programming is an emergent technology that allows modeling and solving various problems in many areas such as artificial intelligence, computer programming, computer-aided design, computer graphics, and user interfaces. It allows declarative specification of problems with constraints that express relationships among objects. Additionally, it enables automatic maintenance of solutions to the specified problems by using constraint solvers.

Received March 7, 2006; Revised March 31, 2006; Accepted April 3, 2006.
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DOI: 10.2201/NiiPi.2006.3.6

Constraint programming has its primary origin in logic programming. In the mid-1980s, constraint logic programming was developed as a generalization of logic programming by integrating constraints [1]. In that development, France and Japan played important roles. In France, significant achievements were made in constraint logic programming languages such as Prolog III [2]. In Japan, a national project called the Fifth Generation Computer Systems founded the Institute for New Generation Computer Technology (ICOT) in 1982 and conducted research on various aspects of logic programming including its constraint extension.

In this report, we recount the recent activities of research collaboration on constraint programming conducted by the authors and other researchers in France and Japan. We believe that ours is a unique collaboration between France and Japan in this research area. In fact, not only are we currently working in this area, but also some of us were involved in achievements in constraint logic programming around 1990 in these countries.

The rest of this report is organized as follows. In Section 2, we outline our joint research projects on constraint programming and then present the backgrounds, goals, and approaches of several research topics treated in the projects. In Section 3, we describe the two Franco-Japanese Workshops on Constraint Programming (FJCP), which we held in Japan in October 2004 and in France in November 2005. In Section 4, we conclude with future prospects for collaboration between French and Japanese researchers in this area.

2 Joint research

This section first gives an overview of the history of our joint research and then describes the outlines of our three main research topics.

2.1 Overview

Our joint research dates back to the year 2002. From June to August of that year, Codognet served as a visiting professor at the National Institute of Informatics (NII). He collaborated with Satoh and Hosobe in studying the use of speculative computation in constraint processing (see Subsection 2.2 for details).

Since 2004, we have been conducting several joint research projects. The most general project is called SCooP, which stands for Soft and Continuous Constraint Programming. This project is being conducted under the memorandum of understanding (MOU) that was signed between the Laboratoire d'Informatique de Nantes Atlantique (LINA) and NII. This project treats constraint programming related to soft constraints and continuous constraints in a wide sense, covering the broad range of our research interests. Therefore, we regard most research collaboration between LINA and NII as activities within this SCooP project. NII provides researchers involved in the MOU-related projects with opportunities to visit their counterpart organizations. This has allowed some of the authors to visit LINA or NII to further the progress of the SCooP project.

Our first project that treated a more concrete research topic was titled "Continuous Soft Constraint Programming for Graphical Interface Applications." The aim of this project was to develop new methods that use global optimization and its related techniques to handle the framework of soft constraints called constraint hierarchies (see Subsections 2.3 and 2.4). Benhamou and Satoh applied for the project to be included in the Japan-France Integrated Action Program (SAKURA), conducted by the French Leading Agency for International Mobility (Égide) and the Japan Society for the Promotion of Science (JSPS); this project was accepted and funded by the program from 2004 to 2005. (Therefore, we often call this project simply "the SAKURA project.") The fund mainly supported our short-term trips from France to Japan or vice versa.

In 2004, we were also supported by the NII joint research project "A Study on Speculative Constraint Processing in Multi-Agent Systems," which allowed Ceberio to stay at NII for the month of October 2004. She joined Satoh and Hosobe in extending our previous method of speculative constraint processing (see Subsection 2.2).

The University of Nantes provided Hosobe with an opportunity to serve as an "enseignant invité" (invited professor) at LINA for two months from early May 2005. He collaborated with Benhamou and Jermann in studying research topics related to the SCooP and SAKURA projects.

We were also supported by NII's Research Center for Testbeds and Prototyping (RCTP) from early 2004 to March 2006. This was complementary to the other support, in that RCTP supported us mainly in preparing software and hardware needed to conduct our joint research.

The rest of this section is focused on three specific topics treated in our joint research.

2.2 Speculative constraint processing

Multi-agent systems allow problem solving in which distributed multiple computational agents cooperate by communicating with each other. In most current research on multi-agent systems, communication between agents is usually assumed to be guaranteed, and agents that have sent queries to other agents typically need to stop computation until they receive the corresponding replies from the agents responsible for processing the queries. However, such an assumption is not always valid in environments such as the Internet, where communication is not guaranteed. For example, a message might be lost during communication between agents, or a reply might be delayed for a long time due to extremely slow communication. In addition, even if communication is guaranteed, a situation similar to unguaranteed communication might occur. For example, an agent processing a received query and trying to ask its owner about the query might stop the processing if the owner is away at that time.

To handle such situations in multi-agent systems, Satoh et al. proposed a method of speculative computation based on abduction [3]. In this method, which is formalized as an extension of logic programming, even if an agent needs to ask another agent for some information, it can speculatively continue computation by using a default hypothesis about the necessary information. This method takes advantage of the speculative computation by allowing the asking agent to use the result of the speculative computation when it receives the corresponding reply. This is done by checking the consistency of the reply with the default hypothesis. If the reply is consistent, the agent continues the current computation; otherwise, the agent performs alternative computation that corresponds to the reply.

However, the method of Satoh et al. is limited to master-slave multi-agent systems with only yes/no queries. To tackle the limitation of such queries, we developed a method of speculative constraint processing [4] by extending the previous method to introduce constraints. In this extended method, each query is associated with a constraint that can express more general information than yes/no. It allows an agent to ask another agent about a more complex query at one time, which enables more efficient communication than in the case of only yes/no queries. To handle such complex queries, we extended the previous method to handle an additional case in which the reply does not entail but is consistent with the default hypothesis. In this case, the extended method continues the computation using the default and simultaneously starts alternative computation as well. For this work [4], we received the Best Paper Award at the Sixth Pacific Rim International Workshop on Multi-Agents (PRIMA 2003).

Furthermore, we tackled another problem of the previous method: its limitation to the master-slave structure of multi-agent systems. As the first step for this purpose, we incorporated belief revision into speculative constraint processing [5]. In the previous method of speculative constraint processing, slave agents were assumed to send at most one final answer. However, this assumption is too strong when we consider more general multi-agent systems, since agents in such systems might want to revise previous answers or to add new answers (In fact, addition of new answers occurs naturally in computational agents based on logic programming, because they might derive such new answers from alternative computation paths). Therefore, we developed another method of speculative constraint processing by extending the previous one to handle revised answers and added answers. This extension also gives additional benefits—a slave agent can return to the master agent a tentative reply that has not been confirmed and also can return to the master agent a partial reply even when it has not yet finished all computation. Furthermore, even in such a case, the master agent can carry out computation that uses the results of speculative computation. Therefore, the master agent can perform computation more speculatively.

As for future work, we will cover more general forms of multi-agent systems, where every agent can perform speculative computation. To handle a more general multi-agent system, we need to guarantee the appropriate computation of the overall system by additionally considering communication paths among agents.

2.3 Global optimization approach to constraint hierarchies

Global optimization [6] is the discipline of solving constrained or unconstrained optimization problems with the goal of achieving the global minimum of the problem. An optimization problem is composed of an objective function (a mathematical expression, often nonlinear) along with a set of constraints (possibly empty, often nonlinear) that restricts the possible assignments for the variables that occur in the objective function. Solving an optimization problem consists of finding an assignment of the variables that minimizes the objective function. Such an assignment is a global minimum if no other assignment yields a smaller value of the objective function while satisfying the constraints.

A general framework for translating soft constraint satisfaction problems (CSPs) into global optimization problems was proposed in the first year of the SAKURA project. Basically, the framework associates a penalty function with each constraint, and applies a set of aggregators that combine the penalty functions into a global penalty. The *best* solution to the soft CSP corresponds to the assignment that minimizes the global penalty; this assignment can be achieved using global optimization techniques. The interest of this framework is that it can achieve solutions to soft CSPs corresponding to different soft solution criteria by changing the penalty functions and the aggregators.

However, exactly modeling constraint hierarchies within this framework seems to be impossible; indeed, the framework produces a single optimization problem, while a constraint hierarchy corresponds to a sequence of optimization problems, one for each level in the hierarchy.

In the second half of the SAKURA project, two specific global optimization approaches to constraint hierarchies were studied: the lexicographic optimization and the refining method.

A lexicographic optimization problem is an optimization problem whose objective is an ordered vector of functions $[f_1, \ldots, f_n]$. An assignment θ to the variables is a global optimum if any other assignment θ' such that $f_k(\theta) > f_k(\theta')$ also verifies $f_i(\theta) < f_i(\theta')$ for an $i < k$, i.e., the first functions in the objective are always preferred to the other ones. A constraint hierarchy solution based on any global comparator is a global optimum of a lexicographic optimization problem whose objective is the penalty of the different hierarchy levels.

Achieving the exact theoretical solution to a lexicographic optimization problem is difficult in practice, due to the approximation of real numbers by floating points in computers. Hence, we have defined a new notion of an interval global optimum, achievable by interval global optimizers. However, the interval global optimum is, in general, not guaranteed to include the real global optimum. We are still working on this theoretical aspect.

The refining method, already used in the constraint hierarchy community [7], is a way to obtain the solutions of a constraint hierarchy corresponding to a global comparator. It consists of finding, at each iteration, the assignments that minimize current hierarchy level penalty function; these assignments are searched in the solution set resulting from previous level computation. Hence, at the first iteration the retained assignments are the ones that minimize f_1, among which only those that minimize f_2 are retained at the second iteration, and so on. This method transforms a constraint hierarchy into a sequence of optimization problems. It may be a way to overcome the theoretical difficulties of interval lexicographic optimization, but the problem of storing the solution sets between iterations also introduces some practical difficulties.

In the near future, we expect to propose a first practical implementation of a global optimization approach to constraint hierarchies with well-defined theoretical properties.

2.4 Graph-based approach to constraint hierarchies

The locally-predicate-better (LPB) solutions to a constraint hierarchy basically satisfy maximal consistent subsets of constraints in each hierarchy level. In order to compute those subsets, a maximum matching-based algorithm, called `GR` in this paper, was proposed [8]. The algorithm relies on the assumption that each constraint can fix exactly one variable, hence constraints can be matched with variables and inconsistencies appear as matching conflicts when several constraints compete in matching the same variable. In such a case, to satisfy the constraint hierarchy definitions, the constraints with highest priority should be matched first. The `GR` algorithm is the most general method proposed in the constraint hierarchy community to achieve LPB solutions.

However, several similar graph-based or flow-based algorithms have been proposed in other communities. In the constraint programming community, a maximum matching-based algorithm decomposes a CSP into its over-, well-, and under-constrained parts. Well- and under-constrained parts do not require the use of priorities since no constraint conflicts occur in these parts. In the geometric constraint community, flow-based algorithms are used to identify well- or over-constrained subsets. One interest of these algorithms is that they can handle multi-output constraints, i.e., constraints that fix several variables. For instance, the equality between two points in 2D fixes two variables, the x and y coordinates of the point, simultaneously.

During the SAKURA project, we studied the applicability of these graph- and flow-based methods to constraint hierarchies. This has allowed us to design a novel flow-based algorithm that subsumes algorithm `GR`, since it imposes no restrictions on the constraints in the constraint hierarchy. We are now devising the theoretical properties of this algorithm and implementing a prototype version.

In the near future, we will propose a new definition of constraint hierarchy solutions that better fits the users' expectations in 3D graphic environments. Intuitively, this definition combines local and global comparators in order to satisfy exactly as many constraints as possible, and then minimize the violation of the remaining ones. This new definition will be achievable using a graph-based algorithm followed by an optimization process. Applications are expected in the field of virtual reality.

3 FJCP Workshops

This section describes the two Franco-Japanese Workshops on Constraint Programming, which we held in Japan in 2004 and in France in 2005.

3.1 First workshop

Late in 2003, the Embassy of France in Japan proposed that we should organize a workshop to enhance collaboration between France and Japan on constraint programming. Accepting that proposal, we set up an organizing committee that consisted of Benhamou, Codognet, Hosobe, Jermann, Satoh, and Ueda.

The workshop was realized as the 1st Franco-Japanese Workshop on Constraint Programming (FJCP 2004) [9], which took place at NII in Tokyo from October 25th to 27th, 2004. It was sponsored by the Embassy of France in Japan as well as LINA, and was also supported by the NII joint research project led by Ueda.

The workshop gathered approximately 30 participants from France and Japan. The program was composed of 24 technical talks, covering both theoretical and practical aspects of constraint programming as well as several applications of constraint technology, in addition to an invited talk given by Krzysztof R. Apt on a rule-based approach to constraint programming.

3.2 Second workshop

Following the success of FJCP 2004, the 2nd Franco-Japanese Workshop on Constraint Programming (FJCP

2005) [10] was held at the Port aux Rocs Hotel in Le Croisic, a charming village on the Atlantic coast close to Nantes, from November 14th to 16th, 2005. The organizers of the first workshop organized this second workshop with the sponsorship from LINA, the University of Nantes, and the French Association for Constraint Programming, and also with the support of the NII joint research project led by Ueda.

The workshop brought together approximately 30 participants from France and Japan. It was composed of 20 technical talks, ranging over various aspects and applications of constraint programming as in the previous workshop, in addition to an invited talk presented by Mats Carlsson on global constraints.

4 Conclusions and future prospects

In this report, we recounted our research collaboration between France and Japan in the area of constraint programming. We have been conducting several joint research projects of different kinds. The Soft and Continuous Constraint Programming (SCooP) project is the general framework for collaboration between the Laboratoire d'Informatique de Nantes Atlantique (LINA) and the National Institute of Informatics (NII) in this area. By contrast, our SAKURA project, funded by the French Leading Agency for International Mobility (Égide) and the Japan Society for the Promotion of Science (JSPS), treated a more concrete research topic. In addition to the joint research, we held two workshops, one in 2004 and the other in 2005, to enhance collaboration between French and Japanese researchers working on constraint programming.

We are continuing and expanding this Franco-Japanese research collaboration on constraint programming. We are currently setting up a new research project as a successor to the SAKURA project. Although we focused the SAKURA project mainly on constraint solving, we will cover the modeling aspect of constraint programming in the new project. Also, we expect to invite researchers in other areas to the next project in order to explore new application areas of constraint programming. In addition to the joint research, we wish to continue the Franco-Japanese Workshops on Constraint Programming (FJCP) in order to help to provide opportunities for further research collaboration between France and Japan.

Acknowledgments

We would like to thank Makoto Yokoo for his continuous cooperation in our activities.

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Frédéric Benhamou is a Full Professor of Computer Science at the University of Nantes. He is the Head of the Computer Science Research Institute of Nantes (LINA) and of the ICT Research Institute AtlanSTIC.

His main scientific contributions are in the area of CLP and Interval Constraint Solving. He co-edited one of the first books on Constraint Logic Programming, was the invited editor of four journal special issues and is the (co-) author of numerous scientific articles and of survey articles in the Encyclopedia of Optimization and the Handbook on Constraint Programming.

In 2006, he was conference chair and program chair of CP 2006, the major international annual conference on constraint programming. He also organized and sat on the program committee of a number of international events, including two Franco Japanese workshops on Constraint Programming, one in Tokyo in 2004 and one in Le Croisic in 2005.

He was also involved in various international projects including a Japanese AITEC grant in 1995 and a Sakura project in 2004.

Martine CEBERIO

Martine Ceberio received her doctoral degree from the University of Nantes, France, in 2003. After graduating, she joined the University of Texas at El Paso, where she is still now, as an Assistant Professor in Computer Science.

Her research interests include constraint programming, global optimization, interval computations, and multi-criteria decision making. Her current projects include working on Protein-Ligand Docking (NSF-funded), in a global computing environment, where the contribution of constraint solving and decision techniques to scheduling and distributing the processes, as well as deciding which docking to consider, is explored.

Philippe CODOGNET

Philippe Codognet is working since September 2003 as Attaché for Science and Technology at the French Embassy in Japan (Tokyo), on leave from University of Paris 6.

After receiving a PhD in Computer Science from University of Bordeaux and working at Thomson-CSF (now Thales) Research Lab in Paris, he joined the French National Institute for Computer Science (INRIA) as senior researcher. After a sabbatical leave at Sony Computer Science Laboratory in Paris in 1997/8, he joined University Pierre et Marie Curie (Paris 6) in September 1998, as full professor. His researches focused on programming languages, artificial intelligence, logic, multi-agent systems and virtual reality. Over 70 publications in international journals and conferences are detailing his researches.

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His research interests include constraint programming, user interfaces, information visualization, and interactive graphics. He was presented with the Takahashi Award in 2003 by the Japan Society for Software Science and Technology.

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His research is mainly focused on geometric constraint solving, involving investigations in geometric reasoning, interval propagation, preference handling and graph algorithms, with applications in CAD and robotics.

Ken SATOH

Ken Satoh was born in 1959. He joined Fujitsu Laboratories in 1981 and he received Doctor of Science from University Tokyo in 1993. He became an associate professor in Hokkaido University in 1995 and he has been a professor in National Institute of Informatics (NII) and Sokendai since 2001.

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Kazunori Ueda received his doctoral degree from the University of Tokyo in 1986. After working for the Japanese Fifth Generation Computer Systems (FGCS) project at NEC and ICOT, he joined Waseda University in 1993, where he is Professor in Computer Science.

His research interests include design and implementation of programming languages, concurrent and constraint programming, and constraint-based program analysis. His recent project is LMNtal, a programming language based on hierarchical graph rewriting. He has acted as Area Editor of the Journal of Logic Programming, Theory and Practice of Logic Programming, and New Generation Computing. He is Editor-in-Chief of Computer Software, the journal of Japan Society for Software Science and Technology (JSSST) since 2004. He was awarded IBM Japan Science Prize (computer science area) in 1993 for his research on concurrent logic programming languages.