

Introduction

Significant advances in computing power since the 1960s have led to a wealth of research on problem solving in fields such as operations research, numerical analysis, symbolic computing, scientific computing, artificial intelligence and programming languages. Constraint programming is a discipline that gathers, exploits and unifies ideas shared by all of these domains to tackle decision support problems.

Over the last 15 years, constraint programming has become a leading technology for modeling and solving real-life combinatorial problems. It has been successfully used in fields such as production planning, scheduling, timetabling, rostering, supply-chain management, product configuration, diagnosis, molecular biology, robotics, computer security and industrial process control. Moreover, in many application domains it is the technology of choice for solving highly complex problems.

Constraint programming is essentially a declarative paradigm: once the problem has been modeled as a constraint satisfaction problem, a constraint solver calculates a solution for it. The behavior of a constraint solver is guided by a strict separation of concerns, in which individual constraints are responsible for pruning the search space. It is the interaction between these individual behaviors that leads to an efficient search procedure by exploiting sophisticated search space exploration techniques and heuristics.

While the principles behind constraint programming are simple, its practical application can be quite complex. Real life problems are often computationally

Introduction written by Frédéric BENHAMOU, Narendra JUSSIEN and Barry O'SULLIVAN.

intractable, so intelligent algorithms and heuristics appropriate to the application domain being considered must be used. In addition, the ideal of fully declarative problem formulation that ensures an efficient search process has not yet been achieved. Constraint programming is therefore an active academic field of research: many research papers are presented not only in constraint programming conferences and journals but also within artificial intelligence and operations research fora.

This book presents trends in the field of constraint programming that not only try to improve the efficiency and utility of constraint-based methods, but also present a variety of important emerging application domains for constraint programming.

Purpose of this book

The International Conference on the Principles and Practice of Constraint Programming (CP) is the premier annual meeting dedicated to developments in the field of constraint programming. It is concerned with all aspects of computing with constraints, including algorithms, applications, environments, languages, models, and systems. Constraint programming is an ever-evolving field and each year the set of workshops that run alongside the conference represent the ongoing trends of the field. Very interesting insights, concepts and results are presented during these workshops.

The objective of this book is to complement the CP 2006 conference proceedings with a volume that reflects the current trends in the field as reflected by the workshop program, and collects these in a thematic way to provide a broad perspective on what is currently being studied in these areas. The organizers of each workshop have contributed either a single chapter reflecting the broad trends within the topic of their workshop, or a collection of short chapters presenting condensed versions of key contributions accompanied with an editorial comment.

The intended audience of this book comprises researchers and practitioners interested in all aspects of constraint programming. Research students should find the book useful as a guide to the topics that are considered to be at the cutting edge of constraint programming research.

Organization of the book

The book is organized into eight parts. Part I focuses on the past, present and future of constraint programming. This is the largest part of the book, comprising six chapters.

Chapter 1 is a transcript of a talk that Pascal Van Hentenryck delivered at CP 2006 when he was awarded the Association for Constraint Programming's Research Excellence Award. The chapter presents the experiences of one of CP's top researchers as he was involved in the development of a series of influential constraint programming systems.

Chapter 2 presents a synthesis of the first CP-Tools workshop, which collected together a variety of constraint programming systems, both commercial and non-commercial. The chapter also reports on two panel discussions: one focusing on technical awareness issues, the other considering future directions for the development of CP systems.

Chapter 3 presents a synthesis of the discussions held as part of the workshop on the subject of "The Next 10 Years of Constraint Programming". During this workshop, over 120 people participated in breakout discussions; each breakout group was chaired by a discussion leader who acted as a facilitator of the discussion. This chapter compiles reports of the major points raised during this event summarized by these discussion leaders.

The remainder of Part I presents chapters that reflect trends in constraint propagation and implementation (Chapter 4), a major component of all constraint reasoning tasks; a chapter on the relationships between satisfiability and constraint programming (Chapter 5); and finally, a chapter on trends in bioinformatics and constraint programming (Chapter 6).

Fundamental issues in constraint programming are addressed in Parts II-IV, each part presenting a collection of papers from three workshops: modeling and reformulation, symmetry breaking, and interval constraint reasoning. The chapters on modeling and reformulation (Part II) address different aspects of the importance of modeling in constraint programming. Other complex issues associated with the constraint modeling problem arise when symmetries are present in the problem being solved. This issue is discussed in detail in Part III. Of course, not all constraint models are specified using finite domains. In Part IV we are given a flavor of the depth and rigor associated with continuous constraint modeling and solving.

Part V presents a selection of papers from the workshop on local search techniques in constraint programming. Local search, while incomplete, has been shown to be a key approach to problem solving that has the capability to tackle real-life problems that are too large for systematic solvers. The development of new local search algorithms continues to provide a very rich and practical domain for cutting-edge constraint programming research.

The importance of reasoning about preferences and soft constraints is considered in Part VI. Solving constraint satisfaction problems involving costs

continues to be a very important and productive area of research, as reflected in the introduction to this part.

The two final parts of the book (Parts VII and VIII) focus on two important application domains for constraint programming: software verification, testing and analysis, and graphical applications, respectively. Software verification, testing and analysis is becoming more important with the emergence of safety critical systems and the high level of investment in the development of complex technical systems. Graphical applications provide a rich domain for exploiting constraints technology since it brings together human-computer interaction, visual problem solving, and hybrid finite and infinite domain constraint systems. Even though graphical applications of constraints date back to the 1960s, there remain significant challenges in this area.

Acknowledgements

This book would not have been possible without the coordinated efforts of many people. Firstly, we would like to express our thanks to the organizers of each of the CP 2006 workshops, all of whom participated in this project. Secondly, we would like to thank the individual authors of each of the parts, chapters and chapter sections. It is their scientific contributions to the future of constraint programming that we have set out to show-case in this book. Thirdly, the individual workshops would not have been possible without their hard working programme committees, who enabled the peer-review process that ensures scientific excellence.

Finally, we would like to record a very special mention of two special events that took place during the CP 2006 conference: the workshop on CP-Tools and the workshop on “The Next 10 Years of Constraint Programming”. These events enabled the industrial and research communities of constraints researchers and users to come together and take stock of what has been achieved by the community over the last decade, and to reflect upon where our community needs to go over the next 10 years. It was clear from the attendance at both events that these were welcomed and highly regarded.

Contributors

Anbulagan, L&C/NICTA and CSL/ANU, Australia; Carlos **Ansótegui**, DIEI, University of Lleida, Spain; Bonny **Banerjee**, Computer Sc. & Eng., Ohio State Univ, USA; Pedro **Barahona**, Universidade Nova de Lisboa, Portugal; Roman **Barták**, Charles University, Czech Republic; J. Christopher **Beck**, University of Toronto, Canada; Frédéric **Benhamou**, LINA/University of Nantes, France; Bruno **Berstel**, ILOG, MPI, France; Christian **Bessiere**, LIRMM/CNRS, France; Benjamin **Blanc**, CEA/LIST, France; María L. **Bonet**, LSI, Universitat Politècnica de Catalunya, Spain; Lucas **Bordeaux**, Microsoft Research, UK; Ondřej **Čeppek**, Charles University and Institute of Finance and Administration, Czech Republic; B. **Chandrasekaran**, Computer Sc. & Eng., Ohio State Univ, USA; Yannick **Chevalier**, IRIT, France; Najah **Chridi**, LORIA-UHP, France; Marc **Christie**, LINA/University of Nantes, France; Alessandro **Dal Palù**, Univ. Parma, Matematica, Italy; Nicolas **Delanoue**, ISTIA/LISA, France; Yves **Deville**, UCLouvain, Belgium; Alastair **Donaldson**, University of Glasgow, UK; Agostino **Dovier**, Univ. Udine, DIMI, Italy; Pierre **Dupont**, UCLouvain, Belgium; François **Fages**, INRIA Rocquencourt, France; Alan M. **Frisch**, University of York, UK; Ian **Gent**, University of St. Andrews, UK; Arnaud **Gotlieb**, IRISA/INRIA, France; Peter **Gregory**, University of Strathclyde, UK; Youssef **Hamadi**, Microsoft Research, UK; Ivan **Heckman**, University of Toronto, Canada; Fred **Hemery**, CRIL, France; Michael **Heusch**, LINA/University of Nantes, France; Hiroshi **Hosobe**, NII, Japan; Daisuke **Ishii**, Waseda University, Japan; Erwan **Jahier**, CNRS/VERIMAG, France; Luc **Jaulin**, ENSIETA/E3I2, France; Peter **Jeavons**, Oxford University Computing Laboratory, UK; Chris **Jefferson**, Oxford University, UK; Philippe **Jégou**, LSIS / UPCAM 3, France; Christophe **Jermann**, LINA/University of Nantes, France; Narendra **Jussien**, EMN/LINA, France; Tom **Kelsey**, University of St. Andrews, UK; Mounira **Kourjeh**, IRIT, France; Sébastien **Lagrange**, ISTIA/LISA, France; Michel **Leconte**, ILOG, France; Christophe **Lecoutre**, CRIL, France; Jordi **Levy**, IIIA, CSIC, Spain; Chu Min **Li**, LaRIA – University of Picardie Jules Verne, France; Steve **Linton**, University of St. Andrews, UK; Felip **Manyà**, DIEI, University of Lleida, Spain; Joao **Marques-Silva**, University of Southampton, UK; Kim **Marriott**, Monash University, Australia; Bernadette **Martínez-Hernández**, University of York, UK; Pedro **Meseguer**, IIIA/CSIC, Spain; Deepak **Mehta**, University College Cork, Ireland; Claude **Michel**, I3S (UNSA/CNRS), France; Laurent **Michel**, CSE, University of Connecticut, USA; Ian **Miguel**, University of St Andrews, UK; Yehuda **Naveh**, IBM Haifa Research Lab, Israel; Samba Ndojeh **Ndiaye**, LSIS/UPCAM 3, France; Robert **Nieuwenhuis**, Technical University of Catalonia, Spain; Jean-Marie **Normand**, LINA/University of Nantes, France; Barry **O’Sullivan**, 4C – University College Cork, Ireland; Gilles **Pesant**, Polytechnique Montréal, Canada; Karen **Petrie**, Oxford University, UK; Duc Nghia **Pham**, SAFE/NICTA, Australia; Steve **Prestwich**,

4C – University College Cork, Ireland; Patrick **Prosser**, Glasgow University, UK; Jean-François **Puget**, ILOG, France; Pascal **Raymond**, CNRS/VERIMAG, France; Jean-Charles **Régin**, ILOG, Sophia-Antipolis, France; Andrea **Roli**, DEIS – University of Bologna, Italy; Francesca **Rossi**, University of Padua, Italy; Abdul **Sattar**, SAFE/NICTA and IIS/Griffith University, Australia; Pierre **Schaus**, UCLouvain, Belgium; Thomas **Schiex**, INRA Toulouse, France; Christian **Schulte**, KTH/ICT/ECS, Sweden; Meinolf **Sellmann**, Brown University, USA; John **Slaney**, L&C NICTA and CSL/ANU, Australia; Barbara M. **Smith**, 4C – University College Cork, Ireland; Christine **Solnon**, LIRIS, France; Sébastien **Sorlin**, LIRIS, France; Peter **Stuckey**, University of Melbourne, Australia; Cyril **Terrioux**, LSIS / UPCAM 3, France; Kazunori **Ueda**, Waseda University, Japan; M.R.C. **Van Dongen**, University College Cork, Ireland; Pascal **Van Hentenryck**, Brown University, USA; Laurent **Vigneron**, LORIA-UN2, France; Mark **Wallace**, Monash University, Australia; Toby **Walsh**, NICTA – University of New South Wales, Australia; Wanxia **Wei**, University of New Brunswick, Canada; Sebastian **Will**, ALU Freiburg, Bioinformatics, Germany; Roland **Yap**, National University of Singapore, Singapore; Stéphane **Zampelli**, UCLouvain, Belgium; Harry **Zhang**, University of New Brunswick, Canada.