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John Hooker (Ed.)

# Principles and Practice of Constraint Programming

24th International Conference, CP 2018  
Lille, France, August 27–31, 2018  
Proceedings

*Editor*  
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Carnegie Mellon University  
Pittsburgh, PA  
USA

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# Preface

This volume contains the proceedings of the 24th International Conference on the Principles and Practice of Constraint Programming (CP 2018) held August 27–31, 2018, in Lille, France. Detailed information about the CP 2018 conference can be found at <http://cp2018.a4cp.org>.

The CP conference is the annual international conference on all aspects of computing with constraints including theory, algorithms, environments, languages, models, systems, and applications such as decision-making, resource allocation, scheduling, configuration, and planning. The organizers of CP 2018 made a particular effort to build bridges to related fields that may provide new applications for CP. This theme was reflected in invited plenary talks, tutorials, a panel session, and seven themed tracks in addition to the main technical track: Applications; CP and Data Science; CP and Music; CP and Operations Research; CP, Optimization, and Power System Management; Multiagent and Parallel CP; and Testing and Verification. Each track had its own track chair(s) and Program Committee to ensure that the papers would be peer reviewed by experts in the relevant field.

The 114 submitted papers were allocated to tracks specified by the author(s). Each paper received at least three reviews. A total of 395 reviews were provided by Program Committee members, and 44 by external reviewers. The review process in each themed track was managed by the respective track chair, while papers submitted to the Main Technical Track were assigned to a senior Program Committee member, who conducted the discussion for that paper. The senior Program Committee consisted of seven prominent researchers from the CP community as well as the 11 track chairs and the conference program chair. Authors had an opportunity to respond to the initial reviews. Following this, the senior Program Committee conducted an intense asynchronous online discussion of the papers via EasyChair over an 11-day period, involving the regular Program Committee members as needed.

The reviewing process was double blind, meaning that authors and reviewers were anonymous to each other throughout the review process. In addition, Program Committee members indicated potential conflicts of interest by selecting from a list of submitting authors those with whom they had professional relationships. This prevented members from seeing the reviews or participating in the discussion of any papers with which they had a conflict of interest. In addition, papers submitted by track chairs to their own track were transferred to other track chairs, who managed the review process and obtained reviewers as necessary from the relevant Program Committees. The final deliberations of the senior Program Committee were conducted so as to respect all conflict-of-interest restrictions.

The senior Program Committee selected 50 papers for presentation at the conference, resulting in an acceptance rate of 44%. The committee also awarded the Best Paper Prize to Emmanuel Hebrard and George Katsirelos for their paper, “Clause Learning and New Bounds for Graph Coloring.” This paper was presented in a plenary

session, along with a presentation by the recipient of the ACP Doctoral Research Award. In addition, the authors of six outstanding papers were offered an opportunity to publish a longer version in *Constraints* rather than in the conference proceedings, and three accepted this offer. Because the longer versions would not appear in time for the conference, the original conference versions of the papers were posted on the conference website along with this proceedings volume. Abstracts of these papers appear at the end of the volume.

The first day of the conference was allocated to four workshops and the Doctoral Program. The workshops were the International Workshop on Graphs and Constraints, the Second Workshop on Progress Towards the Holy Grail, Constraints and AI Planning, and the 17th International Workshop on Constraint Modelling and Reformulation. The Doctoral Program afforded 26 participating students an opportunity to present their work, meet one-on-one with a senior researcher, and attend invited talks targeted to the experiences of a PhD student.

The main conference program featured three invited talks that described opportunities to apply CP technology in related fields. Srinivas Bollapragada, Chief Scientist at General Electric's Global Research Center, presented industrial scheduling problems that have heretofore been addressed by operations research methods. James Cussens, Senior Lecturer in Computer Science at the University of York, showed how CP can contribute to machine learning. Malte Helmert, Head of the AI Research Group at the University of Basel, discussed the role of constraints in automated planning. In addition, the program included several hour-long tutorials that showed how to formulate problems for modelling and solution software systems in related fields. Finally, a plenary panel session discussed opportunities for collaboration between the CP and automated planning communities.

A conference is a more complicated affair than is often thought, presenting literally hundreds of issues that must be resolved for a successful event. Our thanks go to Conference Chairs Gilles Audemard and Christophe Lecoutre for securing financial support and making the many necessary arrangements. In addition, we thank Publicity Chair George Katsirelos, Workshop Chair Sébastien Tabary, and Doctoral Program Chairs Anastasia Paparrizou and Nadjib Lazaar for their service.

The quality of a conference program relies on the hard work of many reviewers. CP 2018 is indebted to 117 members of eight Program Committees, some of whom served on multiple committees. We also thank the track chairs for recruiting their Program Committees and managing the review process in their tracks; they include Meinolf Sellmann (Applications), Michele Lombardi and Tias Guns (CP and Data Science), Charlotte Truchet (CP and Music), David Bergman and André Ciré (CP and Operations Research), Bhagyesh Patil (CP, Optimization, and Power System Management), Ferdinando Fioretto and William Yeoh (Multiagent and Parallel CP), and Arnaud Gotlieb and Nadjib Lazaar (Testing and Verification). Special thanks go to the senior Program Committee for moderating discussions and making the tough final decisions.

Finally, we are grateful to our financial sponsors, which include *Artificial Intelligence*, Association for Constraint Programming, Association Française pour la Programmation par Contraintes, Centre de Recherche en Informatique de Lens, Centre

National de la Recherche Scientifique, Cosling, European Association for Artificial Intelligence, Horizontal Software, Huawei, N-SIDE, ROADEF, Siemens, and Université d'Artois.

June 2018

John Hooker

# Workshops and Tutorials

## Workshops

### Constraints and AI Planning

|                  |                                         |
|------------------|-----------------------------------------|
| Christopher Beck | University of Toronto, Canada           |
| Michael Cashmore | King's College, London, UK              |
| Malte Helmert    | University of Basel, Switzerland        |
| Gilles Pesant    | École Polytechnique de Montréal, Canada |

### International Workshop on Graphs and Constraints

|                 |                                   |
|-----------------|-----------------------------------|
| Stefan Mengel   | CRIL, Université d'Artois, France |
| Florent Capelli | Université de Lille               |

### Second Workshop on Progress Towards the Holy Grail

|                |                                  |
|----------------|----------------------------------|
| Eugene Freuder | University College Cork, Ireland |
|----------------|----------------------------------|

### 17th International Workshop on Constraint Modelling and Reformulation

|             |                              |
|-------------|------------------------------|
| Kevin Leo   | Monash University, Australia |
| Alan Frisch | University of York, UK       |

## Tutorials

### Xpress Mosel Tutorial: Modelling and Solving Optimization Problems with Various Solvers

|                  |              |
|------------------|--------------|
| Sébastien Lannez | FICO, France |
|------------------|--------------|

### Automated Modeling with Conjure and Savile Row

|                   |                               |
|-------------------|-------------------------------|
| Özgür Akgün       | University of St. Andrews, UK |
| Peter Nightingale | University of St. Andrews, UK |

### MiniZinc: An Expressive Extensible Modelling Language

|               |                                    |
|---------------|------------------------------------|
| Peter Stuckey | University of Melbourne, Australia |
| Guido Tack    | Monash University, Australia       |

### Model-Based Optimization: Principles and Trends

|               |                              |
|---------------|------------------------------|
| Robert Fourer | Northwestern University, USA |
|---------------|------------------------------|

### Machine Learning for SAT Solvers

|               |                                |
|---------------|--------------------------------|
| Jia Hui Liang | University of Waterloo, Canada |
|---------------|--------------------------------|

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## **Abstracts of Invited Talks**

# Potential Applications of CP in Industrial Scheduling

Srinivas Bollapragada

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**Abstract.** Scheduling and planning algorithms have the potential to realize significant gains in key industrial sectors such as rail, aviation, power, oil & gas, and healthcare. Improving system level efficiencies even by one percent can save billions of dollars per year in each of these sectors. For example, increasing the average speed of trains by one mile per hour saves the rail industry \$2.5 billion per year. This talk will describe some of our optimization algorithms based industrial applications that saved hundreds of millions of dollars for our customers.

# Towards the Holy Grail in Machine Learning

James Cussens

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**Abstract.** The holy grail in machine learning—like that in CP—is that the user merely states the (machine learning) problem and the “system” solves it for them. In the Bayesian approach the user would state what they know as a prior distribution and then a posterior distribution is “learned” by conditioning on the observed data. Point estimates, expectations, predicted values and so on can then be extracted from this posterior.

The reality of machine learning is rather different (witness “gradient descent by grad student” in deep learning!) but progress towards this holy grail is happening right now with the development of probabilistic programming languages like `stan`. I will argue that the CP community has a contribution to make here. In particular, where the discrete structure of probabilistic model has to be learned (rather than just the continuous parameters of a given model) CP has much to offer. Constraints are also the natural choice when we wish to provide the user with a flexible and expressive language in which to declare any domain knowledge. I will use a number of examples of how CP is already being used in machine learning, including (but not restricted to) my own work on using integer programming to learn the structure of Bayesian networks.

# Constraints at the Heart of Classical Planning

Malte Helmert

University of Basel, Switzerland  
malte.helmert@unibas.ch

**Abstract.** The last two decades have seen significant advances in domain-independent planning. Besides improved scalability through better planning algorithms, several breakthroughs have been made in the theoretical understanding of classical planning heuristics. This talk discusses the critical role that constraints play in the modern theory of classical planning heuristics and presents the new opportunities and challenges brought about by a constraint-based view of classical planning.

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