31st EACSL Annual Conference on Computer Science Logic

CSL 2023, February 13–16, 2023, Warsaw, Poland

Edited by

Bartek Klin

Elaine Pimentel

LIPIcs – Vol. 252 – CSL 2023 www.dagstuhl.de/lipics

Editors

Bartek Klin
University of Oxford, UK
bartek.klin@cs.ox.ac.uk

Elaine Pimentel
University College London, UK
e.pimentel@ucl.ac.uk

ACM Classification 2012
Theory of computation → Logic

ISBN 978-3-95977-264-8

Published online and open access by
Schloss Dagstuhl – Leibniz-Zentrum für Informatik GmbH, Dagstuhl Publishing, Saarbrücken/Wadern, Germany. Online available at https://www.dagstuhl.de/dagpub/978-3-95977-264-8.

Publication date
February, 2023

Bibliographic information published by the Deutsche Nationalbibliothek
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at https://portal.dnb.de.

Digital Object Identifier: 10.4230/LIPIcs.CSL.2023.0

ISBN 978-3-95977-264-8 **ISSN 1868-8969** **https://www.dagstuhl.de/lipics**

LIPIcs – Leibniz International Proceedings in Informatics

LIPIcs is a series of high-quality conference proceedings across all fields in informatics. LIPIcs volumes are published according to the principle of Open Access, i.e., they are available online and free of charge.

ISSN 1868-8969

https://www.dagstuhl.de/lipics

Contents

Invited Talks

Regular Papers

31st EACSL Annual Conference on Computer Science Logic (CSL 2023).
Editors: Bartek Klin and Elaine Pimentel
Leibniz International Proceedings in Informatics
LIPICS Schloss Dagstuhl – Leibniz-Zentrum für Informatik, Dagstuhl Publishing, Germany

Preface

This volume contains the papers presented at CSL 2023, the 31st meeting in the conference series Computer Science Logic (CSL), the annual conference of the European Association for Computer Science Logic (EACSL). CSL 2023 was held from 13th to 16th February 2023. It was organised at the University of Warsaw.

CSL started as a series of international workshops, and became an international conference in 1992. Previous instalments of CSL were held in Göttingen (2022, on-line), Ljubljana (2021, on-line), Barcelona (2020), Birmingham (2018), Stockholm (2017), Marseille (2016), Berlin (2015), Vienna (2014), Torino (2013), Fontainebleau (2012), Bergen(2011), Brno (2010), Coimbra (2009), Bologna (2008), Lausanne (2007), Szeged (2006), Oxford (2005), Karpacz (2004), Vienna (2003), Edinburgh (2002), Paris (2001), Munich (2000), Madrid (1999), Brno (1998), Aarhus (1997), Utrecht (1996), Paderborn (1995), Kazimierz (1994), Swansea (1993) and San Miniato (1992).

CSL is an interdisciplinary conference, spanning both basic and application-oriented research in mathematical logic and computer science. It is a forum for the presentation of research on all aspects of logic and its applications, including automated deduction and interactive theorem proving, constructive mathematics and type theory, equational logic and term rewriting, automata and games, game semantics, modal and temporal logic, logical aspects of computational complexity, finite model theory, computational proof theory, logic programming and constraints, lambda calculus and combinatory logic, domain theory, categorical logic and topological semantics, database theory, specification, extraction and transformation of programs, logical aspects of quantum computing, logical foundations of programming paradigms, verification and program analysis, linear logic, higher-order logic, and non-monotonic reasoning.

The conference received 93 abstracts of which 75 were followed up by full-paper submissions. The programme committee selected 34 papers for presentation at the conference. Each paper was reviewed by at least three members of the programme committee, with the help of external reviewers. The submission and reviewing process, programme committee discussion, and author notifications were all handled by the Easychair conference management system. In addition to the contributed papers, there were five invited talks, by: Claudia Faggian (Université Paris Cité, France), Nina Gierasimczuk (Danish Technical University, Denmark), Dale Miller (Inria Saclay, France), Michał Pilipczuk (University of Warsaw, Poland) and Davide Sangiorgi (University of Bologna, Italy). We thank the invited speakers for their stimulating talks and papers, which greatly contributed to the success of the conference. One of the major regular events at CSL conferences is the presentation of the Ackermann Award: the annual EACSL award for an outstanding dissertation in the area of logic in computer science. The recipients of the award are selected by jury from a field of international nominees, and the recipients receive their award at a ceremony at which they give a prize lecture on their dissertation. This year, the jury elected to give the Ackermann Award 2022 to Alexander Bentkamp for his thesis "Superposition for Higher-Order Logic" defended at Vrije Universiteit Amsterdam (The Netherlands) under the supervision of Jasmin Blanchette, Uwe Waldmann, and Wan Fokkink. The award was presented during the conference. The citation for the award is included in the proceedings.

A significant event at CSL 2023 was the presentation of the Helena Rasiowa Award, named after the eminent Polish mathematician and logician Helena Rasiowa (1917 – 1994) whose work had an essential impact on the emerging field of logic in computer science. The

31st EACSL Annual Conference on Computer Science Logic (CSL 2023).
Editors: Bartek Klin and Elaine Pimentel
Leibniz International Proceedings in Informatics
LIPICS Schloss Dagstuhl – Leibniz-Zentrum für Informatik, Dagstuhl Publishing, Germany

Helena Rasiowa Award, presented for the first time at CSL 2022, is given to the best paper, as decided by the programme committee, that is written solely by students or to which students were the main contributors. There was a strong field of candidates for this award edition, with 10 of the accepted papers eligible. From these, the programme committee selected Hiromi Tanaka as the recipient of the 2023 Helena Rasiowa Award, for his paper "Tower-Complete Problems in Contraction-Free Substructural Logics". Hiromi Tanaka is a PhD student at the Keio University under the supervision of Tatsuya Kashiwabata.

CSL 2023 also had three affiliated workshops: Fixpoints in Computer Science (FICS), Logic Mentoring Workshop (LMW), and Schwentickfest.

We are very grateful to all the members of the CSL 2023 programme committee and external reviewers for their careful and efficient evaluation of the papers submitted. We would like to thank also the members of the organisation committee Lorenzo Clemente, Wojciech Czerwiński, Radosław Piórkowski, from the University of Warsaw, for taking care to ensure a smooth-running and enjoyable conference. It was as always a pleasure to work with Thomas Schwentick/Maribel Fernandez who, as the EACSL presidents until 2022/from 2023, provided excellent guidance. The proceedings of CSL 2023 are published as a volume in the LIPIcs series. We thank Michael Wagner, Michael Didas and all the Dagstuhl/LIPIcs team for their ongoing support and for the high quality preparation of these proceedings. Last, but not least, we are very grateful to the University of Warsaw for supporting the organisation of this conference.

Bartek Klin and Elaine Pimentel 25th November 2022

Program Committee Members

Matteo Acclavio (University of Luxembourg, Luxembourg)
Patricia Bouyer-Decitre (LSV, CNRS & ENS Paris-Saclay, France)
Agata Ciabattoni (TU Wien, Austria)
Diana Costa (University of Lisbon, Portugal)
Alejandro Díaz-Caro (Univ. N. de Quilmes & CONICET-Univ. de BA, Argentina)
Martín Escardó (University of Birmingham, UK)
Rajeev Goré (The Australian National University, Australia)
Giulio Guerrieri (Huawei Edinburgh Research Centre, UK)
Shin-ya Katsumata (National Institute of Informatics, Japan)
Delia Kesner (Université Paris Cité, France)
Sandra Kiefer (Max Planck Institute for Software Systems, Germany)
Bartek Klin (University of Oxford, UK, co-chair)
Naoki Kobayashi (The University of Tokyo, Japan)
Stepan Kuznetsov (Steklov Mathematical Institute of RAS, Russia)
Martin Lück (Leibniz Universität Hannover, Germany)
Meena Mahajan (The Institute of Mathematical Sciences, HBNI, India)
Filip Murlak (University of Warsaw, Poland)
Daniele Nantes (University of Brasília, Brazil)
Elaine Pimentel (UCL, UK, co-chair)
Paolo Pistone (University of Bologna, Italy)
Ana Sokolova (University of Salzburg, Austria)
Lutz Straßburger (Inria Saclay – Île-de-France, France)
Pascal Schweitzer (TU Darmstadt, Germany)
Martin Zimmermann (Aalborg University, Denmark)
Yoni Zohar (Bar Ilan University, Israel)

31st EACSL Annual Conference on Computer Science Logic (CSL 2023).
Editors: Bartek Klin and Elaine Pimentel
Leibniz International Proceedings in Informatics
LIPICS Schloss Dagstuhl – Leibniz-Zentrum für Informatik, Dagstuhl Publishing, Germany

External Reviewers

Beniamino Accattoli
Shaull Almagor
Pablo Barenbaum
Victoria Barrett
Nicolas Behr
Ulrich Berger
Steffen van Bergerem
Yves Bertot
Achim Blumensath
James Brotherston
Florian Bruse
Andrei Bulatov
Davide Catta
Ranald Clouston
Bob Coecke
Liron Cohen
Fredrik Dahlqvist
Anupam Das
Laure Daviaud
Anuj Dawar
Bérénice Delcroix-Oger
Antonin Delpeuch
Arnaud Durand
Cristina Feier
Giulio Fellin
Christian Fermüller
Nathanaël Fijalkow
Robert Freiman
Moses Ganardi
Herman Geuvers
Guido Gherardi
Dan Ghica
Iris van der Giessen
Alessandro Di Giorgio
Erich Grädel
Jim de Groot
Victor Gutierrez-Basulto
Albert Gutowski
Anselm Haak
Amar Hadzihasanovic
Tuomas Hakoniemi
Miika Hannula
Valentina Harizanov
Masahito Hasegawa
Lauri Hella
Jelle Hellings
Loic Helouet
Federico Holik
Ahmed Irfan
Jules Jacobs
Ismaël Jecker
Christian Johansen
Matthieu Josuat-Vergès
Jean Christoph Jung
Jens Keppeler
Marie Kerjean
Stefan Kiefer
Emanuel Kieronski
Yuichi Komorida
Cynthia Kop
Eryk Kopczynski
Andre Kornell
Denis Kuperberg
Timo Lang
Graham Leigh
Moritz Lichter
Etienne Lozes
Tim Lyon
Ian Mackie
Yasir Mahmood
Octavio Malherbe
Makai Mann
Nicolas Markey
Dan Marsden
Guillaume Massas
Filip Mazowiecki
Damiano Mazza
Alexandre Miquel
Marianela Morales Elena
Sean Moss
Carlos Olarte
Paulo Oliva
Federico Olmedo
Benedikt Pago
Pierre-Marie Pédrot
Robin Piedeleu
Diogo Poças
Femke van Raamsdonk
Luca Reggio
Fabian Reiter
Mark Reynolds
Daniel Rogozin
Claudio Sacerdoti Coen
Ken Sakayori
Alessio Santamaria
Yury Savateev
Sylvain Schmitz
Monika Seisenberger
Ying Sheng
A V Sreejith
B Srivathsan
Isar Stubbe
Martin Sulzmann
S P Suresh
Grégoire Sutre
Eugenia Ternovska
Lê Thành Dũng Nguyễn
Neil Thapen
Riccardo Treglia
Pierre Vandenhove
Gabriele Vanoni
Daniele Varacca
Lionel Vaux Auclair
Daniel Ventura
Marcos Villagra
Dominik Wehr
Thorsten Wißmann
Chuangjie Xu
Marc Zeitoun

31st EACSL Annual Conference on Computer Science Logic (CSL 2023).
Editors: Bartek Klin and Elaine Pimentel
Leibniz International Proceedings in Informatics
LIPICS Schloss Dagstuhl – Leibniz-Zentrum für Informatik, Dagstuhl Publishing, Germany

The Ackermann Award 2022

By Jean Goubault-Larrecq and Thomas Schwentick
For the Jury of the EACSL Ackermann Award

The 18th Ackermann Award was presented at CSL'23 in Warsaw, Poland. The 2022 Ackermann Award was open to any PhD dissertation on any topic represented at the annual CSL and LICS conferences that were formally accepted by a degree-granting institution in fulfilment of the PhD degree between 1 January 2020 and 31 December 2021. The Jury received eleven nominations for the 2022 Award. The candidates came from a number of different countries around the world. The institutions at which the nominees obtained their doctorates represent different countries in Europe, Asia and North America.

Again this year, EACSL Ackermann Award is sponsored by the association *Alumni der Informatik Dortmund e.V.*[1]

The topics covered a wide range of areas in Logic and Computer Science as represented by the LICS and CSL conferences. All submissions were of a very high quality and contained significant contributions to their particular fields. The jury wish to extend their congratulations to all the nominated candidates for their outstanding work.

The wide range of excellent candidates presented the jury with an excruciating task. After an extensive discussion, the jury decided to award the **2022 Ackermann Award** to:

- Alexander Bentkamp from Germany for his thesis

  Superposition for Higher-Order Logic

  approved by *Vrije Universiteit Amsterdam* in 2021.

Citation

Alexander Bentkamp receives the *2022 Ackermann Award* of the European Association of Computer Science Logic (EACSL) for his thesis

Superposition for Higher-Order Logic.

The thesis is in the domain of automated theorem proving. The mechanization of proofs is of growing importance in several areas of mathematics and computer science, and is already of paramount importance in ascertaining the correctness of critical software and hardware.

Mechanizing proofs has different meanings. In proof assistants, human guidance is required. With automated theorem provers, the computer finds proofs automatically. Already with first-order logic, this is an undecidable task, although one for which efficient tools exist, notably those based on so-called superposition procedures. It had been widely believed since the 1990s that superposition could not be extended much beyond first-order logic, and that higher-order logic would remain the realm of proof assistants for a long time.

In a series of breakthroughs, A. Bentkamp manages to extend superposition calculi to higher-order logic. He does this in three steps: by first extending superposition to the lambda-free fragment, then to the more expressive clausal fragment, and finally to full

[1] `https://www.cs.tu-dortmund.de/nps/en/Alumni/index.html`

31st EACSL Annual Conference on Computer Science Logic (CSL 2023).
Editors: Bartek Klin and Elaine Pimentel
Leibniz International Proceedings in Informatics
LIPICS Schloss Dagstuhl – Leibniz-Zentrum für Informatik, Dagstuhl Publishing, Germany

higher-order logic. In each case, he obtains sound and complete calculi: all higher-order theorems can be proved by his calculi, and only them. He also demonstrates that these calculi are several orders of magnitude more efficient than previous proposals, through his award-winning, Zipperposition-based implementations.

Background to the thesis

Automated theorem proving is one of the oldest fields of computer science logic. Herbrand and others laid out the bases of first-order theorem proving as early as 1930, the first automated first-order provers were created in the 1960s, and the highly efficient superposition calculi were devised in the 1990s by Bachmair and Ganzinger. Andrews and Huet were among the pioneers of automated higher-order logic theorem proving in the 1970s and 1980s. Before A. Bentkamp, the most common higher-order theorem proving procedures relied on translations to first-order logic, as first hinted by Robinson in 1970, and then following Kerber, Dougherty, and others, starting from the 1990s. However, the sophisticated recipes that modern first-order provers rely for efficient theorem proving, notably the use of term orderings, are essentially nullified by the various translations.

Extending superposition to higher-order calculi presented formidable challenges already for the so-called lambda-free fragment of higher-order logic, which is essentially first-order logic augmented with the possibility of applying variables to terms inside terms. For one, one may need to superpose inside variables, or even below, which seems untenable. One also requires term orderings that are monotonic and ground-total, as needed in standard approaches to superposition, and that runs in conflict with the need for variable applications. In more general fragments of first-order logic, additional difficulties accumulate, and notably the need to guess the shapes of formulae that should instantiate Boolean variables.

Contributions of the thesis

A. Bentkamp first considers the lambda-free fragment, and, in a first breakthrough, shows how to extend superposition with term orderings that may fail to be monotonic. He obtains calculi that are complete, even in the presence of redundancy criteria. The rules are familiar from superposition, but also surprising in some ways: some of them offer no guidance in some cases, but these cases appear to much rarer than what one would expect in the empirical evaluations. The key concept is that of green contexts and green terms: superposition only occurs at green subterms, and the term orderings have to be compatible with green contexts (not all contexts) on ground terms. The completeness proofs also have to be adapted to this new, more permissive setting. This is especially challenging in the presence of redundancy criteria.

In an ironic twist, A. Bentkamp then shows an alternative route to a complete superposition calculus for lambda-free higher-logic, by designing a ground-total simplification ordering for untyped lambda-tree terms.

Next, A. Bentkamp explores a more expressive fragment of higher-order logic, the clausal fragment. Here the terms may involve lambda-abstractions as well, which incurs additional difficulties. Crucially, A. Bentkamp shows that one can retain completeness by restricting superposition inferences to unapplied subterms occurring in the first-order outer skeleton of clauses. Surprisingly, he decides to use full higher-order unification, even in the case of so-called flex-flex pairs. It had been widely believed since Huet that one should never try to solve flex-flex pairs, which incur a form of blind search; but solving them appears to be more efficient in the end. This requires a form of unification that regularly pauses and gives back control to the proof search engine.

Finally, A. Bentkamp goes to full higher-order logic, complete with polymorphism, extensionality and the axiom of choice in the form of Hilbert's epsilon symbol. Here, one cannot convert to clausal form statically. Instead, clausification is also performed during proof search. On top of that, new rules implement Boolean rewriting, and a clever, so-called $Q_{\approx}$-normalization procedure is introduced to deal with quantifiers so as to preserve completeness while retaining efficiency. The completeness proof proceeds by a generalization of the techniques used in previous chapters, which involve several intermediate logics and calculi.

It seems clear that the thesis will have a lasting impact in the field. Beyond the level of mastery and of novelty that the thesis displays, and also the number of bold and sometimes surprising decisions that were made, and proved successful in the end, one should stress that this thesis, despite a high degree of technical sophistication, is a pleasure to read.

Biographical sketch

Alexander Bentkamp carried out his PhD at the Vrije Universiteit Amsterdam under the supervision of Jasmin Blanchette, Uwe Waldmann, and Wan Fokkink. He won a best junior researcher paper award at FSCD 2020, a best student paper award at CADE 2021, and the 1st place in the higher-order category of the CADE ATP System Competition (CASC) in 2020, 2021 and 2022. Furthermore, he won the Bill McCune PhD Award for distinguished PhD theses in Automated Reasoning, and the E.W. Beth Outstanding Dissertation Prize for outstanding PhD dissertations in Logic, Language, and Information. He is currently a postdoctoral researcher at the mathematical institute of the Heinrich-Heine-Universität Düsseldorf.

Jury

The jury for the **Ackermann Award 2022** consisted of ten members, two of them *ex officio*, namely, the president and the vice-president of EACSL. In addition, the jury also included a representative of SIGLOG (the ACM Special Interest Group on Logic and Computation).

The members of the jury were:

- Christel Baier (TU Dresden);
- Maribel Fernandez (King's College London);
- Delia Kesner (IRIF, U Paris Cité);
- Slawomir Lasota (U Warsaw);
- Jean Goubault-Larrecq (ENS Paris-Saclay);
- Prakash Panangaden (McGill University);
- Simona Ronchi Della Rocca (University of Torino), the vice-president of EACSL;
- Thomas Schwentick (TU Dortmund), the president of EACSL;
- Alexandra Silva (Cornell University), ACM SigLog representative;
- James Worrell (U Oxford).

Previous winners

Previous winners of the Ackermann Award were

2005, Oxford:
Mikołaj Bojańczyk from Poland,
Konstantin Korovin from Russia, and
Nathan Segerlind from the USA.

2006, Szeged:
Balder ten Cate from the Netherlands, and
Stefan Milius from Germany.

2007, Lausanne:
Dietmar Berwanger from Germany and Romania,
Stéphane Lengrand from France, and
Ting Zhang from the People's Republic of China.

2008, Bertinoro:
Krishnendu Chatterjee from India.

2009, Coimbra:
Jakob Nordström from Sweden.

2010, Brno:
no award given.

2011, Bergen:
Benjamin Rossman from USA.

2012, Fontainebleau:
Andrew Polonsky from Ukraine, and
Szymon Toruńczyk from Poland.

2013, Turin:
Matteo Mio from Italy.

2014, Vienna:
Michael Elberfeld from Germany.

2015, Berlin:
Hugo Férée from France, and
Mickael Randour from Belgium.

2016, Marseille:
Nicolai Kraus from Germany

2017, Stockholm:
Amaury Pouly from France.

2018, Birmingham:
Amina Doumane from France.

2019, Barcelona (conference in 2020):
Antoine Mottet from France.

2020, Ljubljana (conference online in 2021)
Benjamin Kaminski from Germany.

2021, Göttingen (conference online in 2022)
Marie Fortin from France, and
Sandra Kiefer from Germany.

Detailed reports on their work appeared in the CSL proceedings and are also available on the EACSL homepage.