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Automated Deduction – CADE-25

25th International Conference on Automated Deduction
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Preface

This volume contains the papers presented at the 25th Jubilee Edition of the International Conference on Automated Deduction (CADE-25), held August 1–7, 2015, in Berlin, Germany. CADE is the major forum for the presentation of research in all aspects of automated deduction, including foundations, applications, implementations, and practical experience.

The Program Committee (PC) accepted 36 papers (24 full papers and 12 system descriptions) out of a total of 85 submissions. Each submission was reviewed by at least three PC members or external reviewers appointed by the PC members in charge. The program also included invited lectures given by Ulrich Furbach (University of Koblenz, Germany) and Edward Zalta (Stanford University, USA). In addition, Michael Genesereth (Stanford University, USA) gave an invited lecture in conjunction with the co-located event RuleML (9th International Web Rule Symposium).

To celebrate the 25th jubilee edition of the conference, additional invited speakers were featured at several events. A Special Session on the Past, Present, and Future of Automated Deduction included talks by Ursula Martin (University of Oxford, UK), Frank Pfenning (Carnegie Mellon University, USA), David Plaisted (University of North Carolina at Chapel Hill, USA), and Andrei Voronkov (University of Manchester, UK). Also, the conference reception and the banquet dinner featured speakers Wolfgang Bibel and Jörg Siekmann. In addition, the program was enriched by several affiliated events that took place before the main conference. These events included eight workshops, seven tutorials, three competitions, and one poster event.

During the conference, the Herbrand Award for Distinguished Contributions to Automated Reasoning was presented to Andrei Voronkov in recognition of his numerous theoretical and practical contributions to automated deduction and the development of the award-winning Vampire theorem prover. The Selection Committee for the Herbrand Award consisted of the CADE-25 Program Committee members, the trustees of CADE Inc., and the Herbrand Award winners of the last ten years.

The Best Paper Award was conferred to Vijay D'Silva (Google, Inc., USA) and Caterina Urban (École Normale Supérieure, France) for their paper entitled "Abstract Interpretation as Automated Deduction." In addition, the first Thoralf Skolem Awards were conferred this year to reward CADE papers that have passed the test of time by being most influential papers in the field:

CADE-20 (2005) Nominal techniques in Isabelle/HOL by Christian Urban and Christine Tasson: The first paper showing how to use nominal techniques to deal with bound variables in higher-order theorem provers.

CADE-14 (1997) SATO: An Efficient Propositional Prover by Hantao Zhang: For its seminal contribution to the design and implementation of novel techniques, including lazy data structures and clever Boolean constraint propagation that caused a step change in the area and deeply influenced later systems.

CADE-8 (1986) Commutation, Transformation, and Termination by Leo Bachmair and Nachum Dershowitz: For laying the foundations of today's termination theorem-proving techniques.

CADE-0-1 (1968 and 1975) The mathematical language AUTOMATH, its usage, and some of its extensions by N.G. de Bruijn: For his landmark and remarkable contribution to the design and implementation of higher-order theorem provers.

Also, several students received Woody Bledsoe Travel Awards, thus named to remember the late Woody Bledsoe, funded by CADE Inc. to sponsor student participation.

Many people contributed to making CADE-25 a success. We are very grateful to the members of the Program Committee and the external reviewers for carefully reviewing and evaluating papers. CADE-25 would not have been possible without the dedicated work of the Organizing Committee, headed by Conference Chair Christoph Benzmüller. Many thanks also go to Workshop, Tutorial, and Competition Co-chairs Jasmin Blanchette and Andrew Reynolds, and to Publicity and Web Chair Julian Röder. On behalf of the Program Committee, we also thank all the invited speakers for their contribution to the success of this jubilee edition. We also acknowledge the important contributions of the workshop organizers, tutorial speakers, competition organizers, and poster event organizer. Thanks also go to Andrei Voronkov and the development team of the EasyChair system. Last, but not least, we thank all authors who submitted papers to CADE-25 and all participants of the conference.

CADE-25 received support from many organizations. On behalf of all organizers, we thank the German Research Foundation, DFG, for supporting the special session, and the European Coordinating Committee for Artificial Intelligence (ECCAI) for supporting the invited talk given by Ulrich Furbach. We also gratefully acknowledge support from Freie Universität Berlin, the *Artificial Intelligence Journal,* and Microsoft Research.

May 2015

Amy P. Felty
Aart Middeldorp

Affiliated Events

Workshops

- Bridging: Bridging the Gap Between Human and Automated Reasoning, organized by Ulrich Furbach, Natarajan Shankar, Marco Ragni, and Steffen Hölldobler
- DT: 29. Jahrestreffen der GI-Fachgruppe Deduktionssysteme, organized by Christoph Benzmüller, Matthias Horbach, Alexander Steen, and Max Wisniewski
- HOL4: HOL4 Workshop, organized by Ramana Kumar
- IWC: Fourth International Workshop on Confluence, organized by Takahito Aoto and Ashish Tiwari
- LFMTP: International Workshop on Logical Frameworks and Meta-Languages: Theory and Practice, organized by Kaustuv Chaudhuri and Iliano Cervesato
- PxTP: Workshop on Proof eXchange for Theorem Proving, organized by Cezary Kaliszyk and Andrei Paskevich
- QUANTIFY: Second International Workshop on Quantification, organized by Hubie Chen, Florian Lonsing, and Martina Seidl
- Vampire: The Vampire Workshop, organized by Laura Kovacs and Andrei Voronkov

Tutorials

- Abella: Reasoning About Computational Systems Using Abella, given by Kaustuv Chaudhuri and Gopalan Nadathur
- Beluga: Programming Proofs About Formal Systems, given by Brigitte Pientka
- CPROVER: From Programs to Logic: The CPROVER Verification Tools, given by Daniel Kroening, Martin Brain, and Peter Schrammel
- Isabelle: Isabelle Tutorial, given by Makarius Wenzel
- KeY: The Sequent Calculus of the KeY Tool, given by Reiner Hähnle and Peter Schmitt
- Lean: Lean Theorem Prover: A Tutorial, given by Leonardo de Moura, Soonho Kong, Jeremy Avigad, and Floris van Doorn
- Superposition: 25th Anniversary of Superposition: Status and Future, given by Stephan Schulz and Christoph Weidenbach

Competitions

- CoCo: The Fourth Confluence Competition, organized by Takahito Aoto, Nao Hirokawa, Julian Nagele, Naoki Nishida, and Harald Zankl
- CASC: The CADE ATP System Competition, organized by Geoff Sutcliffe
- termCOMP: Termination Competition, organized by Johannes Waldmann and Stefan von der Krone

Poster Events

- EPS: The CADE-25 Taskforce Towards an Encyclopedia of Proof Systems, organized by Bruno Woltzenlogel Paleo

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The CADE conference series is sponsored by CADE Inc., a sub-corporation of the Association for Automated Reasoning. In addition, CADE-25 gratefully acknowledges support from Freie Universität Berlin, the *Artificial Intelligence Journal,* Microsoft Research, the German Research Foundation, DFG, and the European Coordinating Committee for Artificial Intelligence.

Abstracts of Invited Talks

The first three abstracts are for invited talks given in the Special Session on the Past, Present, and Future of Automated Deduction. The next three are for those given during the main conference. These are followed by three abstracts describing the competitions held at CADE-25.

History and Prospects for First-Order Automated Deduction

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On the fiftieth anniversary of the appearance of Robinson's resolution paper [1], it is appropriate to consider the history and status of theorem proving, as well as its possible future directions. Here we discuss the history of first-order theorem proving both before and after 1965, with some personal reflections. We then generalize model-based reasoning to first-order provers, and discuss what it means for a prover to be goal sensitive. We also present a way to analyze asymptotically the size of the search space of a first-order prover in terms of the size of a minimal unsatisfiable set of ground instances of a set of first-order clauses.

Reference

1. Robinson, J.: A machine-oriented logic based on the resolution principle. J. ACM **12**(1), 23–41 (1965)

On the Role of Proof Theory in Automated Deduction

Frank Pfenning

Carnegie Mellon University, USA

Since the seminal work by Gentzen, who developed both natural deduction and the sequent calculus, there has been a line of research concerned with discovering deep structural properties of proofs in order to control the search space in theorem proving. This is particularly important in non-classical logics where traditional model-theoretic techniques may be more difficult to apply. We will walk through some of the key developments, starting with cut elimination and identity expansion, followed by focusing, polarization, and the separation of judgments and propositions. These concepts have been surprisingly robust, applicable to many non-classical logics, to the extent that one may consider them a litmus test on whether a set of rules or axioms form a coherent logic. We illustrate how each of these ideas affect proof search. In some cases, proofs are sufficiently restricted so that proof search can be seen as a fundamental computational mechanism, giving rise to logic programming.

Stumbling Around in the Dark: Lessons from Everyday Mathematics

Ursula Martin

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The growing use of the internet for collaboration, and of numeric and symbolic software to perform calculations it is impossible to do by hand, not only augment the capabilities of mathematicians, but also afford new ways of observing what they do. In this essay we look at four case studies to see what we can learn about the everyday practice of mathematics: the *polymath* experiments for the collaborative production of mathematics, which tell us about mathematicians attitudes to working together in public; the *minipolymath* experiments in the same vein, from which we can examine in finer grained detail the kinds of activities that go on in developing a proof; the mathematical questions and answers in *math overflow,* which tell us about mathematical-research-in-the-small; and finally the role of computer algebra, in particular the GAP system, in the production of mathematics. We conclude with perspectives on the role of computational logic.

Automated Reasoning in the Wild

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This paper discusses the use of first order automated reasoning in question answering and cognitive computing. For this the natural language question answering project LogAnswer is briefly depicted and the challenges faced therein are addressed. This includes a treatment of query relaxation, web-services, large knowledge bases and co-operative answering. In a second part a bridge to human reasoning as it is investigated in cognitive psychology is constructed by using standard deontic logic.

Work supported by DFG FU 263/15-1 'Ratiolog'.

The Herbrand Manifesto

Thinking Inside the Box

Michael Genesereth and Eric J.Y. Kao

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The traditional semantics for (first-order) relational logic (sometimes called *Tarskian* semantics) is based on the notion of interpretations of constants in terms of objects external to the logic. *Herbrand* semantics is an alternative that is based on truth assignments for ground sentences without reference to external objects. Herbrand semantics is simpler and more intuitive than Tarskian semantics; and, consequently, it is easier to teach and learn.

Moreover, it is more expressive than Tarskian semantics. For example, while it is not possible to finitely axiomatize natural number arithmetic completely with Tarskian semantics, this can be done easily with Herbrand semantics. Herbrand semantics even enables us to define the least fixed-point model of a stratified logic program without any special constructs.

The downside is a loss of some familiar logical properties, such as compactness and proof-theoretic completeness. However, there is no loss of inferential power—anything that can be deduced according to Tarskian semantics can also be deduced according to Herbrand semantics.

Based on these results, we argue that there is value in using Herbrand semantics for relational logic in place of Tarskian semantics. It alleviates many of the current problems with relational logic and ultimately may foster a wider use of relational logic in human reasoning and computer applications. To this end, we have already taught several sessions of the computational logic course at Stanford and a popular MOOC using Herbrand semantics, with encouraging results in both cases.

Automating Leibniz's Theory of Concepts

Jesse Alama[1], Paul E. Oppenheimer[2], and Edward N. Zalta[2]

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Our computational metaphysics group describes its use of automated reasoning tools to study Leibniz's theory of concepts. We start with a reconstruction of Leibniz's theory within the theory of abstract objects (henceforth 'object theory'). Leibniz's theory of concepts, under this reconstruction, has a nonmodal algebra of concepts, a concept-containment theory of truth, and a modal metaphysics of complete individual concepts. We show how the object-theoretic reconstruction of these components of Leibniz's theory can be represented for investigation by means of automated theorem provers and finite model builders. The fundamental theorem of Leibniz's theory is derived using these tools.

Confluence Competition 2015

Takahito Aoto[1], Nao Hirokawa[2], Julian Nagele[3],
Naoki Nishida[4], and Harald Zankl[3]

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[2] JAIST, Japan
[3] University of Innsbruck, Austria
[4] Nagoya University, Japan

Confluence is one of the central properties of rewriting. Our competition aims to foster the development of techniques for proving/disproving confluence of various formalisms of rewriting automatically. We explain the background and setup of the 4th Confluence Competition.

The CADE-25 ATP System Competition CASC-25

Geoff Sutcliffe

University of Miami, USA

The CADE ATP System Competition (CASC) is an annual evaluation of fully automatic Automated Theorem Proving (ATP) systems for classical logic the world championship for such systems. One purpose of CASC is to provide a public evaluation of the relative capabilities of ATP systems. Additionally, CASC aims to stimulate ATP research, motivate development and implementation of robust ATP systems that are useful and easily deployed in applications, provide an inspiring environment for personal interaction between ATP researchers, and expose ATP systems within and beyond the ATP community. Fulfillment of these objectives provides insight and stimulus for the development of more powerful ATP systems, leading to increased and more effective use.

CASC-25 was held on 4th August 2015 as part of the 25th International Conference on Automated Deduction (CADE-25), run on computers supplied by the StarExec project. The CASC-25 web site provides access to all systems and competition resources: http://www.tptp.org/CASC/25.

CASC is run in divisions according to problem and system characteristics. For CASC-25 the divisions were:

- THF: **T**yped **H**igher-order **F**orm theorems (axioms with a provable conjecture).
- THN: **T**yped **H**igher-order form **N**on-theorems (axioms with a countersatisfiable conjecture, and satisfiable axiom sets). This division was new for CASC-25.
- TFA: **T**yped **F**irst-order with **A**rithmetic theorems (axioms with a provable conjecture).
- TFN: **T**yped **F**irst-order with arithmetic **N**on-theorems (axioms with a countersatisfiable conjecture, and satisfiable axiom sets). This division was new for CASC-25.
- FOF: **F**irst-**O**rder **F**orm theorems (axioms with a provable conjecture).
- FNT: **F**irst-order form syntactically non-propositional **N**on-**T**heorems (axioms with a countersatisfiable conjecture, and satisfiable axiom sets).
- EPR: **E**ffectively **PR**opositional clause normal form (non-)theorems.
- LTB: First-order form theorems (axioms with a provable conjecture) from **L**arge **T**heories, presented in **B**atches with a shared time limit.

Problems for CASC are taken from the TPTP Problem Library. The TPTP version used for CASC is released after the competition, so that new problems have not been seen by the entrants. The THF, TFA, FOF, FNT, and LTB divisions were ranked according to the number of problems solved with an acceptable proof/model output. The THN, TFN, and EPR divisions were ranked according to the number of problems solved, but not necessarily accompanied by a proof or model. Ties are broken according to the average time over problems solved. Division winners are announced and prizes are awarded.

The design and organization of CASC has evolved over the years to a sophisticated state. Decisions made for CASC (alongside the TPTP, and the ES* series of workshops) have influenced the direction of development in ATP for classical logic. CASC-25 was the 20th edition of CASC, and it is interesting to look back on some of the key decisions that have helped bring ATP to its current state.

– CASC-13, 1996: The first CASC stimulated research towards robust, fully automatic systems that take only logical formulae as input. It increased the visibility of systems and developers, and rewarded implementation efforts.
– CASC-14, 1997: Introduced the SAT division, stimulating the development of model finding systems for CNF.
– CASC-15, 1998: Introduced the FOF division, starting the slow demise of CNF to becoming just the “assembly language” of ATP.
– CASC-16, 1999: Changes to the problem selection motivated the development of techniques for automatic tuning of ATP systems’ search parameters.
– CASC-JC, 2001: Introduced ranking based on proof output, starting the the trend towards ATP systems that efficiently output proofs and models. Introduced the EPR division, stimulating the development of specialized techniques for this important subclass of problems.
– CASC-20, 2005: Required systems to develop builtin equality reasoning, by removing the equality axioms from the TPTP problems.
– CASC-J3, 2006: The FOF division was promoted as the most important, stimulating development of ATP systems for full first-order logic.
– CASC-21, 2007: Introduced the FNT division, further stimulating the development of model finding systems.
– CASC-J4, 2008: Introduced the LTB division, leading to the development of techniques for automatically dealing with very large axiom sets.
– CASC-J5, 2010: Introduced the THF division, stimulating development of ATP systems for higher-order logic.
– CASC-23, 2011: Introduced the TFA division, stimulating development of ATP systems for full first-order logic with arithmetic.
– CASC-J6, 2012: Otter replaced by Prover9 as the “fixed-point” in the FOF division, demonstrating the progress in ATP.
– CASC-24, 2013: Removed the CNF division, confirming the demise of CNF.
– CASC-J7, 2014: Required use of the SZS ontology, so the ATP systems unambiguously report what they have established about the input.
– CASC-25, 2015: Introduced the THN and TFN divisions, stimulating development of model finding for the TFA and THF logics.

The ongoing success and utility of CASC depends on ongoing contributions of problems to the TPTP. The automated reasoning community is encouraged to continue making contributions of all types of problems.

Termination Competition (termCOMP 2015)

Jürgen Giesl[1], Frédéric Mesnard[2], Albert Rubio[3],
René Thiemann[4], and Johannes Waldmann[5]

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[2] Université de la Réunion, France
[3] Universitat Politècnica de Catalunya - BarcelonaTech, Spain
[4] Universität Innsbruck, Austria
[5] HTWK Leipzig, Germany

The termination competition focuses on automated termination analysis for all kinds of programming paradigms, including categories for term rewriting, imperative programming, logic programming, and functional programming. Moreover, the competition also features categories for automated complexity analysis. In all categories, the competition also welcomes the participation of tools providing certified proofs. The goal of the termination competition is to demonstrate the power of the leading tools in each of these areas.

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R. Thiemann—This author is supported by the Austrian Science Fund (FWF) project Y757.

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