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Theory and Applications of Satisfiability Testing – SAT 2014

17th International Conference

Held as Part of the Vienna Summer of Logic, VSL 2014

Vienna, Austria, July 14-17, 2014

Proceedings



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logic n. 1 the science of reasoning.

– ORIGIN from Greek *logikē teknē*
'art of reason'.



Foreword



In the summer of 2014, Vienna hosted the largest scientific conference in the history of logic. The Vienna Summer of Logic (VSL, <http://vsl2014.at>) consisted of twelve large conferences and 82 workshops, attracting more than 2000 researchers from all over the world. This unique event was organized by the Kurt Gödel Society and took place at Vienna University of Technology during July 9 to 24, 2014, under the auspices of the Federal President of the Republic of Austria, Dr. Heinz Fischer.

The conferences and workshops dealt with the main theme, logic, from three important angles: logic in computer science, mathematical logic, and logic in artificial intelligence. They naturally gave rise to respective streams gathering the following meetings:

Logic in Computer Science / Federated Logic Conference (FLoC)

- 26th International Conference on Computer Aided Verification (CAV)
- 27th IEEE Computer Security Foundations Symposium (CSF)
- 30th International Conference on Logic Programming (ICLP)
- 7th International Joint Conference on Automated Reasoning (IJCAR)
- 5th Conference on Interactive Theorem Proving (ITP)
- Joint meeting of the 23rd EACSL Annual Conference on Computer Science Logic (CSL) and the 29th ACM/IEEE Symposium on Logic in Computer Science (LICS)
- 25th International Conference on Rewriting Techniques and Applications (RTA) joint with the 12th International Conference on Typed Lambda Calculi and Applications (TLCA)
- 17th International Conference on Theory and Applications of Satisfiability Testing (SAT)
- 76 FLoC Workshops
- FLoC Olympic Games (System Competitions)

Mathematical Logic

- Logic Colloquium 2014 (LC)
- Logic, Algebra and Truth Degrees 2014 (LATD)
- Compositional Meaning in Logic (GeTFun 2.0)
- The Infinity Workshop (INFINITY)
- Workshop on Logic and Games (LG)
- Kurt Gödel Fellowship Competition

Logic in Artificial Intelligence

- 14th International Conference on Principles of Knowledge Representation and Reasoning (KR)
- 27th International Workshop on Description Logics (DL)
- 15th International Workshop on Non-Monotonic Reasoning (NMR)
- 6th International Workshop on Knowledge Representation for Health Care 2014 (KR4HC)

The VSL keynote talks which were directed to all participants were given by Franz Baader (Technische Universität Dresden), Edmund Clarke (Carnegie Mellon University), Christos Papadimitriou (University of California, Berkeley) and Alex Wilkie (University of Manchester); Dana Scott (Carnegie Mellon University) spoke in the opening session. Since the Vienna Summer of Logic contained more than a hundred invited talks, it would not be feasible to list them here.

The program of the Vienna Summer of Logic was very rich, including not only scientific talks, poster sessions and panels, but also two distinctive events. One was the award ceremony of the Kurt Gödel Research Prize Fellowship Competition, in which the Kurt Gödel Society awarded three research fellowship prizes endowed with 100.000 Euro each to the winners. This was the third edition of the competition, themed Logical Mind: Connecting Foundations and Technology this year.

The 1st FLoC Olympic Games formed the other distinctive event and were hosted by the Federated Logic Conference (FLoC) 2014. Intended as a new FLoC element, the Games brought together 12 established logic solver competitions by different research communities. In addition to the competitions, the Olympic Games facilitated the exchange of expertise between communities, and increased the visibility and impact of state-of-the-art solver technology. The winners in the competition categories were honored with Kurt Gödel medals at the FLoC Olympic Games award ceremonies.

Organizing an event like the Vienna Summer of Logic was a challenge. We are indebted to numerous people whose enormous efforts were essential in making this vision become reality. With so many colleagues and friends working with us, we are unable to list them individually here. Nevertheless, as representatives of the three streams of VSL, we would like to particularly express our gratitude to all people who helped to make this event a success: the sponsors and the Honorary Committee; the Organization Committee and

the local organizers; the conference and workshop chairs and Program Committee members; the reviewers and authors; and of course all speakers and participants of the many conferences, workshops and competitions.

The Vienna Summer of Logic continues a great legacy of scientific thought that started in Ancient Greece and flourished in the city of Gödel, Wittgenstein and the Vienna Circle. The heroes of our intellectual past shaped the scientific world-view and changed our understanding of science. Owing to their achievements, logic has permeated a wide range of disciplines, including computer science, mathematics, artificial intelligence, philosophy, linguistics, and many more. Logic is everywhere – or in the language of Aristotle, πάντα πλήρη λογικῆς τέχνης.

July 2014

Matthias Baaz
Thomas Eiter
Helmut Veith

Preface

This volume contains the papers presented at the 17th International Conference on Theory and Applications of Satisfiability Testing (SAT 2014) held during July 14–17, 2014, in Vienna, Austria. SAT 2014 was part of the Federated Logic Conference (FLoC) 2014 and the Vienna Summer of Logic (VSL) and was hosted by the Vienna University of Technology.

The International Conference on Theory and Applications of Satisfiability Testing (SAT) is the primary annual meeting for researchers focusing on the theory and applications of the propositional satisfiability problem, broadly construed: Besides plain propositional satisfiability, it includes Boolean optimization (including MaxSAT and Pseudo-Boolean, PB, constraints), Quantified Boolean Formulas (QBF), Satisfiability Modulo Theories (SMT), and Constraint Programming (CP) for problems with clear connections to propositional reasoning. Many hard combinatorial problems can be tackled using SAT-based techniques, including problems that arise in formal verification, artificial intelligence, operations research, biology, cryptology, data mining, machine learning, mathematics, etc. Indeed, the theoretical and practical advances in SAT research over the past 20 years have contributed to making SAT technology an indispensable tool in various domains.

SAT 2014 welcomed scientific contributions addressing different aspects of SAT, including (but not restricted to) theoretical advances (including exact algorithms, proof complexity, and other complexity issues), practical search algorithms, knowledge compilation, implementation-level details of SAT solvers and SAT-based systems, problem encodings and reformulations, applications, as well as case studies and reports on insightful findings based on rigorous experimentation.

A total of 78 papers were submitted to SAT 2014, distributed into 51 regular papers, 15 short papers, and 12 tool papers. Three regular paper submissions were found by the Program Committee to be out of scope for the conference (based on guidelines in the Call for Papers), and were returned without review. The 75 remaining paper submissions were assigned for review to at least four Program Committee members and their selected external reviewers. Continuing the procedure initiated in SAT 2012, the review process included an author-response period, during which the authors of submitted papers were given the opportunity to respond to the initial reviews for their submissions. For reaching final decisions, a Program Committee discussion period followed the author-response period. This year, external reviewers supporting the Program Committee were also invited to participate directly in the discussions for the papers they reviewed. In the end, the Program Committee decided to accept 21 regular papers, seven short papers, and four tool papers.

In addition to presentations of the accepted papers, the scientific program of SAT 2014 included two invited talks:

- Leonardo de Moura (Microsoft Research, USA):
“A Model-Constructing Satisfiability Calculus”
- Jakob Nordström (KTH Royal Institute of Technology, Sweden):
“A (Biased) Proof Complexity Survey for SAT Practitioners”

Two additional keynote talks were held jointly with other conferences of the Vienna Summer of Logic:

- Christos Papadimitriou (University of California, Berkeley, USA):
“Computational Ideas and the Theory of Evolution”
- Alex Wilkie (University of Manchester, UK):
“The Theory and Applications of o-Minimal Structures”

Moreover, there was a VSL opening speech given by Dana Scott from Carnegie Mellon University, USA.

SAT 2014, together with the other conferences of the Vienna Summer of Logic, hosted various associated events: 14 workshops, held on July 12/13 and 18/19 were (co-)affiliated with SAT 2014:

- FLoC Workshop on Proof Complexity (PC 2014)
Organizers: Olaf Beyersdorff, Jan Johannsen
- 5th Pragmatics of SAT Workshop (POS 2014)
Organizers: Daniel Le Berre, Allen Van Gelder
- Second International Workshop on Quantified Boolean Formulas (QBF 2014)
Organizers: Charles Jordan, Florian Lonsing, Martina Seidl
- All About Proofs, Proofs for All (APPA 2014)
Organizers: David Delahaye, Bruno Woltzenlogel Paleo
- International Joint Workshop on Implementation of Constraint and Logic Programming Systems and Logic-Based Methods in Programming Environments (CICLOPS-WLPE 2014)
Organizers: Thomas Ströder, Terrance Swift
- 4th International Workshop on the Cross-Fertilization Between CSP and SAT (CSPSAT 2014)
Organizers: Yael Ben-Haim, Valentin Mayer-Eichberger, Yehuda Naveh
- Higher Order Program Analysis (HOPA 2014)
Organizer: Matthew Hague
- Interpolation: From Proofs to Applications (iPRA 2014)
Organizers: Laura Kovacs, Georg Weissenbacher
- 4th International Workshop on Logic and Search (LaSh 2014)
Organizers: Marc Denecker, David Mitchell, Emilia Oikarinen
- Parallel Methods for Search Optimization (ParSearchOpt 2014)
Organizers: Philippe Codognet, Meinolf Sellmann, Guido Tack
- Second Workshop on the Parameterized Complexity of Computational Reasoning (PCCR 2014)
Organizers: Michael R. Fellows, Serge Gaspers, Toby Walsh

- 21st RCRA International Workshop on Experimental Evaluation of Algorithms for Solving Problems with Combinatorial Explosion (RCRA 2014)
Organizers: Toni Mancini, Marco Maratea, Francesco Ricca
- 12th International Workshop on Satisfiability Modulo Theories (SMT 2014)
Organizers: Philipp Ruemmer, Christoph M. Wintersteiger
- Working Conference on Verified Software: Theories, Tools, and Experiments (VSTTE 2014)
Organizers: Dimitra Giannakopoulou, Daniel Kroening, Natarajan Shankar

SAT 2014 also encompassed five competitions and system evaluations:

- SAT Competition 2014
Organizers: Anton Belov, Daniel Diepold, Matti Järvisalo, Marijn Heule
- Configurable SAT Solver Challenge Organizers: Frank Hutter, Marius Lindauer, Sam Bayless, Holger Hoos, Kevin Leyton-Brown
- MaxSAT Evaluation
Organizers: Josep Argelich, Chu Min Li, Felip Manyà, Jordi Planes
- QBF Gallery
Organizers: Charles Jordan, Martina Seidl
- SMT-COMP 2014 (also affiliated with CAV 2014) Organizers: David Cok, David Deharbe, Tjark Weber

Moreover, an *SAT/SMT Summer School* was organized by Clark Barrett, Pascal Fontaine, Dejan Jovanović, and Georg Weissenbacher. It took place a few days before SAT 2014, during July 10–12 at Semmering, close to Vienna.

We would like to thank everyone who contributed to making SAT 2014 a success. First and foremost we would like to thank the members of the Program Committee and the additional external reviewers for their careful and thorough work, without which it would not have been possible for us to put together such an outstanding conference program. We also wish to thank all the authors who submitted their work for our consideration. We thank the SAT Association chair Armin Biere, vice chair John Franco, and treasurer Hans Kleine Büning for their help and advice in organizational matters. We wish to thank the workshop chair Inês Lynce and the competition chair Laurent Simon for their excellent work, and all the organizers of the SAT affiliated workshops and competitions. Special thanks go to the organizers of FLoC and VSL, in particular to Matthias Baaz, Helmut Veith, and Moshe Vardi, for their great help and for coordinating the various conferences. The EasyChair conference system provided invaluable assistance in coordinating the submission and review process, as well as in the assembly of these proceedings. Thanks also to Matti Järvisalo and Allen Van Gelder, the co-chairs of SAT 2013, for their advice on running the conference. We also thank the local organization team for their efforts with practical aspects of local organization.

Finally, we gratefully thank the Vienna University of Technology, the SAT Association, and Intel for financial and organizational support for SAT 2014.

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**Invited Talks
(Abstracts)**

A Model-Constructing Satisfiability Calculus

Leonardo de Moura¹ and Dejan Jovanović²

¹ Microsoft Research

² SRI International

Abstract. Considering the theoretical hardness of SAT, the astonishing adeptness of SAT solvers when attacking practical problems has changed the way we perceive the limits of algorithmic reasoning. Modern SAT solvers are based on the idea of *conflict driven clause learning* (CDCL). The CDCL algorithm is a combination of an explicit backtracking search for a satisfying assignment complemented with a deduction system based on Boolean resolution. In this combination, the worst-case complexity of both components is circumvented by the components guiding and focusing each other. The generalization of the SAT problem into the first-order domain is called satisfiability modulo theories (SMT). The common way to solve an SMT problem is to employ a SAT solver to enumerate the assignment of the Boolean abstraction of the formula. The candidate Boolean assignment is then either confirmed or refuted by a *decision procedure* dedicated to reasoning about conjunctions of theory-specific constraints. This framework is commonly called DPLL(T) and is employed by most of the SMT solvers today. Although DPLL(T) at its core relies on a CDCL SAT solver, this SAT solver is only used as a black-box. This can be seen as an advantage since the advances in SAT easily transfer to performance improvements in SMT. On the other hand, in the last few years the idea of direct model construction complemented with conflict resolution has been successfully generalized to fragments of SMT dealing with theories such as linear real arithmetic, linear integer arithmetic, nonlinear arithmetic, and floating-point. All these procedures, although quite effective in their corresponding first-order domains, have not seen a more widespread acceptance due to their limitations in purely Boolean reasoning and incompatibility with DPLL(T). In this talk we describe a *model-constructing satisfiability calculus* (MCSAT) that encompasses all the decision procedures above, including the decision procedures aimed at DPLL(T), while resolving the limitations mentioned above. The MCSAT framework extends DPLL(T) by allowing assignments of variables to concrete values, while relaxing the restriction that decisions, propagations, and explanations of conflicts must be in term of existing atoms.

A (Biased) Proof Complexity Survey for SAT Practitioners

Jakob Nordström

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Abstract. This talk is intended as a selective survey of proof complexity, focusing on some comparatively weak proof systems that are of particular interest in connection with SAT solving. We will review resolution, polynomial calculus, and cutting planes (related to conflict-driven clause learning, Gröbner basis computations, and pseudo-Boolean solvers, respectively) and some proof complexity measures that have been studied for these proof systems. We will also briefly discuss if and how these proof complexity measures could provide insights into SAT solver performance.

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