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Reachability Problems

8th International Workshop, RP 2014
Oxford, UK, September 22-24, 2014
Proceedings



Springer

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ISSN 0302-9743

e-ISSN 1611-3349

ISBN 978-3-319-11438-5

e-ISBN 978-3-319-11439-2

DOI 10.1007/978-3-319-11439-2

Springer Cham Heidelberg New York Dordrecht London

Library of Congress Control Number: 2014948071

LNCS Sublibrary: SL 1 – Theoretical Computer Science and General Issues

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Typesetting: Camera-ready by author, data conversion by Scientific Publishing Services, Chennai, India

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Preface

This volume contains the papers presented at the 8th International Workshop on Reachability Problems (RP 2014) held during September 22–24, 2014, at the Department of Computer Science, University of Oxford, UK.

RP 2014 was the eighth in the series of workshops, following successful meetings at the Uppsala University, Sweden, in 2013, University of Bordeaux, France, in 2012, the University of Genoa, Italy, in 2011, Masaryk University of Brno, Czech Republic, in 2010, Ecole Polytechnique, France, in 2009, at the University of Liverpool, UK, in 2008, and at Turku University, Finland, in 2007.

The aim of the workshop is to bring together scholars from diverse fields with a shared interest in reachability problems. Reachability is a fundamental computational problem that appears in many different contexts: concurrent systems, computational models such as cellular automata and Petri nets, decision procedures for logical theories, program analysis, discrete and continuous systems, time-critical systems, hybrid systems, rewriting systems, algebraic structures (groups, semigroups and rings), deterministic or non-deterministic iterative maps, probabilistic and parametric systems, and open systems modelled as games.

Typically, for a fixed system description given in some form (rewriting rules, transformations by computable functions, systems of equations, logical formulas, etc.) a reachability problem consists in checking whether a given set of target states can be reached starting from a fixed set of initial states. The set of target states can be represented explicitly or via some implicit representation (e.g., a system of equations, a set of minimal elements with respect to some ordering on the states). Sophisticated quantitative and qualitative properties can often be reduced to basic reachability questions. Decidability and complexity boundaries, algorithmic solutions, and efficient heuristics are all important aspects to be considered in this context. Algorithmic solutions are often based on different combinations of exploration strategies, symbolic manipulations of sets of states, decomposition properties, reduction to optimisation problems and logical decision procedures. Such algorithms also benefit from approximations, abstractions, accelerations, and extrapolation heuristics. Ad hoc solutions as well as solutions based on general-purpose constraint solvers and deduction engines are often combined in order to balance efficiency and flexibility.

The purpose of the conference is to promote the exploration of new approaches for the modelling and analysis of computational processes by combining mathematical, algorithmic, and computational techniques. Topics of interest include (but are not limited to): reachability for infinite state systems; rewriting systems; reachability analysis in counter/timed/cellular/communicating automata; Petri-nets; computational aspects of semigroups, groups, and rings; reachability in dynamical and hybrid systems; frontiers between decidable and

undecidable reachability problems; complexity and decidability aspects; predictability in iterative maps and new computational paradigms. All these aspects were discussed in the presentations of the eighth edition of the RP workshop. The proceedings of the previous editions of the workshop appeared in the following volumes:

Mika Hirvensalo, Vesa Halava, Igor Potapov, Jarkko Kari (Eds.): Proceedings of the Satellite Workshops of DLT 2007. TUCS General Publication No 45, June 2007. ISBN: 978-952-12-1921-4.

Vesa Halava and Igor Potapov (Eds.): Proceedings of the Second Workshop on Reachability Problems in Computational Models (RP 2008). Electronic Notes in Theoretical Computer Science. Volume 223, Pages 1-264 (26 December 2008).

Olivier Bournez and Igor Potapov (Eds.): Reachability Problems, Third International Workshop, RP 2009, Palaiseau, France, September 23–25, 2009, Lecture Notes in Computer Science, 5797, Springer 2009.

Antonin Kucera and Igor Potapov (Eds.): Reachability Problems, 4th International Workshop, RP 2010, Brno, Czech Republic, August 28–29, 2010, Lecture Notes in Computer Science, 6227, Springer 2010.

Giorgio Delzanno, Igor Potapov (Eds.): Reachability Problems, 5th International Workshop, RP 2011, Genoa, Italy, September 28–30, 2011, Lecture Notes in Computer Science, 6945, Springer 2011.

Alain Finkel, Jerome Leroux, Igor Potapov (Eds.): Reachability Problems, 6th International Workshop, RP 2012, Bordeaux, France, September 17-19, 2012. Lecture Notes in Computer Science 7550, Springer 2012.

Parosh Aziz Abdulla, Igor Potapov (Eds.): Reachability Problems, 7th International Workshop, RP 2013, Uppsala, Sweden, September 24-26, 2013. Lecture Notes in Computer Science 8169, Springer 2013.

The four keynote speakers at the 2014 conference were:

- **Byron Cook**, UCL and Microsoft Research, UK.
- **Kousha Etessami**, University of Edinburgh, UK.
- **Anca Muscholl**, LaBRI, University of Bordeaux, France.
- **Sylvain Schmitz**, LSV and ENS-Cachan, France.

There were 25 submissions. Each submission was reviewed by at least three Program Committee members. The full list of the members of the Program Committee and the list of external reviewers can be found on the next two pages. The Program Committee is grateful for the highly appreciated and high-quality work produced by these external reviewers. Based on these reviews, the Program

Committee decided to accept 17 papers, in addition to the four invited talks. The workshop also provided the opportunity to researchers to give informal presentations that are prepared very shortly before the event and inform the participants about current research and work in progress.

We gratefully acknowledge the organization team for their help. In particular we wish to thank Andrea Pilot, Renate Henison, Jordan Summers-Young and Elizabeth Walsh.

It is also a great pleasure to acknowledge the team of the EasyChair system, and the fine cooperation with the Lecture Notes in Computer Science team of Springer, which made the production of this volume possible in time for the conference. Finally, we thank all the authors for their high-quality contributions, and the participants for making this edition of RP 2014 a success.

September 2014

Joël Ouaknine
Igor Potapov
James Worrell

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Abstracts of Invited Talks

Algorithms for Branching Markov Decision Processes

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Multi-type branching processes (BPs) are classic stochastic processes with applications in many areas, including biology and physics. A BP models the stochastic evolution of a population of entities of distinct types. In each generation, every entity of each type, t , produces a set of entities of various types in the next generation according to a given probability distribution on offsprings for the type t . In a *Branching Markov Decision Process* (BMDP), there is also a controller who can take actions that affect the probability distribution of the offsprings for each entity of each type. For both BPs and BMDPs, the state space consists of all possible populations, given by the number of entities of each type, so there are infinitely many states.

In recent years there has been a body of research aimed at studying the computational complexity of key analysis problems associated with MDP extensions (and, more generally *stochastic game* extensions) of important classes of finitely-presented but (countably) infinite-state stochastic processes, including BMDPs, and closely related models, such as stochastic context-free grammars extended with a controller. A central analysis problem for all of these models, which forms the key to a number of other analyses, is the problem of computing their optimal termination (extinction) probability. In the setting of BMDPs, these are the maximum (minimum) probabilities, over all control strategies (or policies), starting from a single entity of a given type, that the process will eventually reach extinction (i.e., the state where no entities have survived). From these quantities, one can compute the optimum probability for any initial population, as well as other quantities of interest.

One can write Bellman optimality equations for the optimal extinction probabilities of BMDPs, and for a number of related important infinite-state MDP models. These Bellman equations are multivariate systems of monotone probabilistic max (or min) *polynomial* equations, which we call max/minPPSs. They have the form $x_i = P_i(x_1, \dots, x_n)$, $i = 1, \dots, n$, where each $P_i(x) \equiv \max_j q_{i,j}(x)$ (respectively $P_i(x) \equiv \min_j q_{i,j}(x)$) is the max (min) over a finite number of probabilistic polynomials, $q_{i,j}(x)$. A *probabilistic polynomial*, $q(x)$, is a multi-variate polynomial where the monomial coefficients and constant term of $q(x)$ are all non-negative and sum to ≤ 1 . The *least fixed point* (LFP) solution of such Bellman equations, corresponding to a given BMDP, captures its vector of optimal extinction probabilities, starting with one object of each type.

This talk will survey algorithms for, and discuss the complexity of, some key analysis problems for BMDPs. In particular, I will discuss recent joint work with

Alistair Stewart and Mihalis Yannakakis ([2, 1]), which forms part of Alistair Stewart's Ph.D. thesis, in which we have obtained polynomial time algorithms for computing, to within arbitrary desired precision, the (optimal) extinction probability values for BPs and BMDPs, by computing the LFP solution of the corresponding max/min polynomial Bellman equations. Our algorithms combine generalizations of Newton's method with other techniques, including linear programming.

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Walking with Data - Where Does it Stop?

Anca Muscholl

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Data formalisms apply to numerous settings where the reasoning involves explicit comparisons of object identities. Such formalisms are usually based on automata or logics that have the ability to compare data from an unbounded domain. In the realm of databases, data may take the meaning of attribute values. In program verification, data may represent identities of processes, communication channels, pointers or any other resource that can be of interest in the analysis of programs with dynamic objects.

This talk will survey several models of logics and automata with data and analyse their limits in decidability regarding fundamental questions such as non-emptiness (satisfiability) and inclusion (containment). We will focus on recently considered data formalisms such as data-walking automata and Datalog, that are promising models regarding the above problems.

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Complexity Bounds for Ordinal-Based Termination^{*}

Sylvain Schmitz

LSV, ENS Cachan & CNRS & INRIA, France

Abstract. ‘What more than its truth do we know if we have a proof of a theorem in a given formal system?’ We examine Kreisel’s question in the particular context of program termination proofs, with an eye to deriving complexity bounds on program running times.

Our main tool for this are *length function theorems*, which provide complexity bounds on the use of well quasi orders. We illustrate how to prove such theorems in the simple yet until now untreated case of ordinals. We show how to apply this new theorem to derive complexity bounds on programs when they are proven to terminate thanks to a ranking function into some ordinal.

^{*} Work funded in part by the ANR grant 11-BS02-001-01 REACHARD.

On the Subtle Interaction Between Reachability and Liveness

Byron Cook

Microsoft Research, Cambridge, UK

Abstract. One of the key difficulties of proving program termination and liveness of systems is managing the subtle interplay between the finding of a termination argument and the finding of the arguments supporting invariant. In this talk I will discuss some mechanisms that we have used to facilitate better cooperation between these two types of reasoning in tools, both for software as well as biological models.

Table of Contents

Complexity Bounds for Ordinal-Based Termination (Invited Talk)	1
<i>Sylvain Schmitz</i>	
On The Complexity of Bounded Time Reachability for Piecewise Affine Systems	20
<i>Hugo Bazille, Olivier Bournez, Walid Gomaa, and Amaury Pouly</i>	
Reachability and Mortality Problems for Restricted Hierarchical Piecewise Constant Derivatives	32
<i>Paul C. Bell, Shang Chen, and Lisa Jackson</i>	
Parameterized Verification of Communicating Automata under Context Bounds	45
<i>Benedikt Bollig, Paul Gastin, and Jana Schubert</i>	
Regular Strategies in Pushdown Reachability Games	58
<i>Arnaud Carayol and Matthew Hague</i>	
Parameterized Verification of Graph Transformation Systems with Whole Neighbourhood Operations	72
<i>Giorgio Delzanno and Jan Stückrath</i>	
Equivalence Between Model-Checking Flat Counter Systems and Presburger Arithmetic	85
<i>Stéphane Demri, Amit Kumar Dhar, and Arnaud Sangnier</i>	
Synthesising Succinct Strategies in Safety and Reachability Games	98
<i>Gilles Geeraerts, Joël Goossens, and Amélie Stainer</i>	
Integer Vector Addition Systems with States	112
<i>Christoph Haase and Simon Halfon</i>	
Reachability in MDPs: Refining Convergence of Value Iteration	125
<i>Serge Haddad and Benjamin Monmege</i>	
On the Expressiveness of Metric Temporal Logic over Bounded Timed Words	138
<i>Hsi-Ming Ho</i>	
Trace Inclusion for One-Counter Nets Revisited	151
<i>Piotr Hofman and Patrick Totzke</i>	

Mean-Payoff Games with Partial-Observation (Extended Abstract)	163
<i>Paul Hunter, Guillermo A. Pérez, and Jean-François Raskin</i>	
Parameter Synthesis for Probabilistic Timed Automata Using Stochastic Game Abstractions	176
<i>Aleksandra Jovanović and Marta Kwiatkowska</i>	
On Functions Weakly Computable by Petri Nets and Vector Addition Systems	190
<i>Jerome Leroux and Philippe Schnoebelen</i>	
Generalized Craig Interpolation for Stochastic Satisfiability Modulo Theory Problems	203
<i>Ahmed Mahdi and Martin Fränzle</i>	
Transformations for Compositional Verification of Assumption-Commitment Properties	216
<i>Ahmed Mahdi, Bernd Westphal, and Martin Fränzle</i>	
Compositional Reachability in Petri Nets	230
<i>Julian Rathke, Paweł Sobociński, and Owen Stephens</i>	
Author Index	245