

Cambridge Tracts in Theoretical Computer Science 58

Temporal Logics in Computer Science

This comprehensive text provides a modern and technically precise exposition of the fundamental theory and applications of temporal logics in computer science. Part I presents the basics of discrete transition systems, including constructions and behavioural equivalences. Part II examines the most important temporal logics for transition systems and Part III looks at their expressiveness and complexity. Finally, Part IV describes the main computational methods and decision procedures for model checking and model building – based on tableaux, automata and games – and discusses their relationships.

The book contains a wealth of examples and exercises, as well as an extensive annotated bibliography. Thus, the book is not only a solid professional reference for researchers in the field but also a comprehensive graduate textbook that can be used for self-study as well as for teaching courses.

STÉPHANE DEMRI is a CNRS directeur de recherche at Laboratoire Spécification et Vérification (LSV), ENS de Cachan, and he is currently the head of LSV. His current research interests include verification of infinite-state systems, temporal logics and analysis of systems with data. He has participated in numerous international and national projects and has been co-responsible for bilateral projects with Poland, South Africa and Australia. He is regularly involved in teaching, in program committees, in steering committees and in editorial boards. He has co-authored more than 125 publications in the field of formal/logical methods for analysing computer systems, including a monograph, 4 edited proceedings, 6 book chapters and 50 articles in international journals.

VALENTIN GORANKO is currently a professor of logic and theoretical philosophy at Stockholm University. He has more than 30 years of university teaching and research experience in mathematics, computer science and philosophy in universities in Bulgaria, South Africa, Denmark and Sweden. His main expertise and research interests are in theory and applications of modal and temporal logics to computer science, artificial intelligence, multiagent systems and philosophy. He has authored and co-authored more than 100 publications, including two recent textbooks on logic and discrete mathematics. He is a member of several editorial boards and steering bodies of professional organisations and is currently the vice-president of the Association for Logic, Language and Information (FoLLI).

MARTIN LANGE is currently a professor in theoretical computer science at the University of Kassel, Germany. His research interests include model checking and general decision procedures for logics in computer science with a focus on temporal logics. He has published more than 80 papers in international journals and conference proceedings. He received an ERC Starting Grant in 2010 and a Heisenberg professorship from the German Research Council in 2013.

Cambridge University Press
 978-1-107-02836-4 — Temporal Logics in Computer Science
 Stéphane Demri, Valentin Goranko, Martin Lange
 Frontmatter
[More Information](#)

CAMBRIDGE TRACTS IN THEORETICAL COMPUTER SCIENCE 58

Editorial Board

S. Abramsky, *Department of Computer Science, University of Oxford*
 P. H. Aczel, *School of Computer Science, University of Manchester*
 Y. Gurevich, *Microsoft Research*
 J. V. Tucker, *Department of Computer Science, Swansea University*

Titles in the series

A complete list of books in the series can be found at
www.cambridge.org/computerscience.
 Recent titles include the following:

29. P. Gärdenfors (ed) *Belief Revision*
30. M. Anthony & N. Biggs *Computational Learning Theory*
31. T. F. Melham *Higher Order Logic and Hardware Verification*
32. R. Carpenter *The Logic of Typed Feature Structures*
33. E. G. Manes *Predicate Transformer Semantics*
34. F. Nielson & H. R. Nielson *Two-Level Functional Languages*
35. L. M. G. Feijs & H. B. M. Jonkers *Formal Specification and Design*
36. S. Mauw & G. J. Veltink (eds) *Algebraic Specification of Communication Protocols*
37. V. Stavridou *Formal Methods in Circuit Design*
38. N. Shankar *Metamathematics, Machines and Gödel's Proof*
39. J. B. Paris *The Uncertain Reasoner's Companion*
40. J. Desel & J. Esparza *Free Choice Petri Nets*
41. J.-J. Ch. Meyer & W. van der Hoek *Epistemic Logic for AI and Computer Science*
42. J. R. Hindley *Basic Simple Type Theory*
43. A. S. Troelstra & H. Schwichtenberg *Basic Proof Theory*
44. J. Barwise & J. Seligman *Information Flow*
45. A. Asperti & S. Guerrini *The Optimal Implementation of Functional Programming Languages*
46. R. M. Amadio & P.-L. Curien *Domains and Lambda-Calculi*
47. W.-P. de Roever & K. Engelhardt *Data Refinement*
48. H. Kleine Büning & T. Lettmann *Propositional Logic*
49. L. Novak & A. Gibbons *Hybrid Graph Theory and Network Analysis*
50. J. C. M. Baeten, T. Basten & M. A. Reniers *Process Algebra: Equational Theories of Communicating Processes*
51. H. Simmons *Derivation and Computation*
52. D. Sangiorgi & J. Rutten (eds) *Advanced Topics in Bisimulation and Coinduction*
53. P. Blackburn, M. de Rijke & Y. Venema *Modal Logic*
54. W.-P. de Roever et al. *Concurrency Verification*
55. Terese *Term Rewriting Systems*
56. A. Bundy et al. *Rippling: Meta-Level Guidance for Mathematical Reasoning*
57. A. M. Pitts *Nominal Sets*
58. S. Demri, V. Goranko & M. Lange *Temporal Logics in Computer Science*

Temporal Logics in Computer Science

Finite-State Systems

STÉPHANE DEMRI

Centre National de la Recherche Scientifique (CNRS), France

VALENTIN GORANKO

Stockholms Universitet

MARTIN LANGE

Universität Kassel, Germany



CAMBRIDGE
UNIVERSITY PRESS

Cambridge University Press
978-1-107-02836-4 — Temporal Logics in Computer Science
Stéphane Demri , Valentin Goranko , Martin Lange
Frontmatter
[More Information](#)

CAMBRIDGE UNIVERSITY PRESS

University Printing House, Cambridge CB2 8BS, United Kingdom

Cambridge University Press is part of the University of Cambridge.

It furthers the University's mission by disseminating knowledge in the pursuit of education, learning and research at the highest international levels of excellence.

www.cambridge.org

Information on this title: www.cambridge.org/9781107028364

© Stéphane Demri, Valentin Goranko and Martin Lange 2016

This publication is in copyright. Subject to statutory exception and to the provisions of relevant collective licensing agreements, no reproduction of any part may take place without the written permission of Cambridge University Press.

First published 2016

Printed in the United Kingdom by Clays, St Ives plc

A catalogue record for this publication is available from the British Library

ISBN 978-1-107-02836-4 Hardback

Cambridge University Press has no responsibility for the persistence or accuracy of URLs for external or third-party internet websites referred to in this publication, and does not guarantee that any content on such websites is, or will remain, accurate or appropriate.

Contents

1	Introduction	<i>page</i> 1
1.1	Temporal Logics and Computer Science: A Brief Overview	1
1.2	Structure and Summary of the Book Content	6
1.3	Using the Book for Teaching or Self-Study	12
PART I MODELS		
2	Preliminaries and Background I	17
2.1	Sets and Relations	18
2.2	Some Fundamental Preliminaries	25
3	Transition Systems	35
3.1	Basic Concepts	37
3.2	Reachability	49
3.3	Bisimulation Relations	55
3.4	Bisimilarity	62
3.5	Trace Equivalence	71
3.6	Exercises	75
3.7	Bibliographical Notes	79
PART II LOGICS		
4	Preliminaries and Background II	85
4.1	Preliminaries on Modal Logic	85
4.2	Logical Decision Problems	91
4.3	Expressive Power	93
4.4	Deductive Systems	93
5	Basic Modal Logics	100
5.1	The Basic Modal Logic BML	102
5.2	Renaming and Normal Forms	107
5.3	Modal and Bisimulation Equivalence	110
5.4	Model Checking	116
5.5	Satisfiability and the Tree Model Property	123

vi	<i>Contents</i>	
	5.6 The Basic Tense Logic BTL	131
	5.7 Axiomatic Systems	135
	5.8 Exercises	141
	5.9 Bibliographical Notes	146
6	Linear-Time Temporal Logics	150
	6.1 Syntax and Semantics on Linear Models	152
	6.2 Logical Decision Problems	159
	6.3 The Small Model Property	164
	6.4 Decision Procedures	169
	6.5 Adding Past-Time Operators	176
	6.6 Invariance Properties	182
	6.7 Extensions of LTL	185
	6.8 An Axiomatic System for LTL	191
	6.9 Exercises	196
	6.10 Bibliographical Notes	206
7	Branching-Time Temporal Logics	209
	7.1 A Hierarchy of Branching-Time Logics	211
	7.2 Bisimulation Invariance	228
	7.3 Model Checking	233
	7.4 Some Fragments and Extensions of CTL*	241
	7.5 Axiomatic Systems	252
	7.6 Exercises	259
	7.7 Bibliographical Notes	265
8	The Modal Mu-Calculus	271
	8.1 Fixpoint Quantifiers	272
	8.2 Fixpoint Iteration	282
	8.3 The Structural Complexity of Formulae	289
	8.4 Model-Checking Games	303
	8.5 Bisimulation Invariance	309
	8.6 The Second-Order Nature of Temporal Logics	313
	8.7 Variants	315
	8.8 Exercises	320
	8.9 Bibliographical Notes	324
9	Alternating-Time Temporal Logics	329
	9.1 Concurrent Multiagent Transition Systems	330
	9.2 Temporal Logics for Concurrent Game Models	337
	9.3 Logical Decision Problems	346
	9.4 Exercises	352
	9.5 Bibliographical Notes	355

PART III PROPERTIES

10 Expressiveness	361
10.1 Embeddings among Linear-Time Logics	363
10.2 Embeddings among Branching-Time Logics	376
10.3 Separation Results	385
10.4 Exercises	409
10.5 Bibliographical Notes	414
11 Computational Complexity	419
11.1 Proving Lower Bounds	421
11.2 Linear-Time Temporal Logics	435
11.3 Branching-Time Temporal Logics	445
11.4 An Overview of Completeness Results	453
11.5 Exercises	457
11.6 Bibliographical Notes	460

PART IV METHODS

12 Frameworks for Decision Procedures	467
12.1 A Brief Introduction to Three Methodologies	468
12.2 The Frameworks Compared	472
13 Tableaux-Based Decision Methods	476
13.1 A Generic Incremental Tableau Construction	479
13.2 Tableaux for LTL	498
13.3 Tableaux for TLR and CTL	514
13.4 Exercises	536
13.5 Bibliographical Notes	540
14 The Automata-Based Approach	543
14.1 Introduction to Nondeterministic Büchi Automata	546
14.2 From LTL Formulae to Automata	552
14.3 Introduction to Alternating Automata on Words	570
14.4 From LTL Formulae to Alternating Büchi Automata	581
14.5 Extensions of LTL	591
14.6 Tree Automata for Branching-Time Logics	598
14.7 Alternating Tree Automata and CTL	606
14.8 Exercises	615
14.9 Bibliographical Notes	621
15 The Game-Theoretic Framework	625
15.1 Parity Games	627
15.2 Constructions for Automata on Infinite Words	647
15.3 Model Checking	659

viii	<i>Contents</i>	
15.4	Satisfiability Checking	682
15.5	Exercises	705
15.6	Bibliographical Notes	711
	<i>References</i>	716
	<i>Index</i>	737