

Contents

- 1 It's About Time** 1
 - 1.1 Bibliographic Remarks..... 6
 - References..... 7
- 2 Languages and Interpretations** 9
 - 2.1 Syntax and Semantics 9
 - 2.2 Language Features 11
 - 2.2.1 Formality 11
 - 2.2.2 Medium 13
 - 2.3 Languages for System Modeling 13
 - 2.4 Operational and Descriptive Languages..... 15
 - 2.4.1 Operational Formalisms 16
 - 2.4.2 Descriptive Formalisms: Mathematical Logic 17
 - 2.5 Bibliographic Remarks..... 25
 - References..... 26
- 3 Dimensions of the Time Modeling Problem** 27
 - 3.1 Discrete Versus Dense Time Domains 27
 - 3.1.1 Continuous Versus Non-continuous Time Models 28
 - 3.1.2 Bounded, Finite, and Periodic Time Models 29
 - 3.1.3 Hybrid Systems 30
 - 3.2 Ordering Versus Metric 32
 - 3.2.1 Total Versus Partial Ordering 34
 - 3.2.2 Time Granularity 35
 - 3.3 Linear Versus Branching Time Models 37
 - 3.4 Deterministic, Nondeterministic, and Probabilistic Models..... 39
 - 3.4.1 Deterministic Versus Nondeterministic Models..... 39
 - 3.4.2 Nondeterministic Versus Probabilistic Models..... 41
 - 3.4.3 Deterministic, Probabilistic, and
Nondeterministic Versus Linear- and
Branching-Time Models 44
 - 3.5 Implicit Versus Explicit Time Reference..... 44

3.6	The Time Advancement Problem.....	46
3.7	Concurrency and Composition	49
3.7.1	Synchronous Versus Asynchronous Composition	50
3.7.2	Message Passing Versus Resource Sharing	51
3.8	Analysis and Verification Issues	52
3.8.1	Expressiveness	53
3.8.2	Decidability and Complexity.....	53
3.8.3	Analysis and Verification Techniques	54
3.9	Bibliographic Remarks.....	55
	References.....	56

Part I Historical Approaches

4	Dynamical Systems	61
4.1	Discrete-Time Dynamical Systems.....	62
4.2	Continuous-Time Dynamical Systems	63
4.3	The State-Space Representation of Dynamical Systems	65
4.4	Dynamical Systems as Models of Computation	68
4.5	From Continuous to Discrete	69
4.6	Dynamical Systems and the Dimensions of Temporal Modeling.....	71
4.6.1	Discrete and Continuous (Time) Domains	72
4.6.2	Irregular and Zeno Behaviors	72
4.6.3	Determinism in Dynamical Systems.....	74
4.6.4	Other Dimensions of Temporal Modeling in Dynamical Systems.....	75
4.7	Notations and Tools for Dynamical System Analysis	77
4.8	Bibliographic Remarks.....	78
	References.....	78
5	Time in Hardware Modeling and Design	81
5.1	From Transistors to Sequential Logic Circuits.....	81
5.1.1	Logic Devices from Transistors.....	81
5.1.2	An Abstract View of Logic Gates.....	83
5.1.3	From Combinatorial to Sequential Logic Circuits	84
5.2	From Two to Many States: Raising the Level of Abstraction	86
5.2.1	Sequential Machines and Zero-Time Transitions	86
5.2.2	Finite-State Machines	88
5.2.3	Finite-State Machines with Output: Moore and Mealy Machines	89
5.3	From Asynchronous to Synchronous Logic Circuits	90
5.3.1	Logic Synchronized by a Clock: The Complete-Synchrony Abstraction	91
5.3.2	From Continuous to Discrete Time	93

5.4	Modular Abstractions in Hardware Design	95
5.4.1	The Behavioral Abstraction	95
5.4.2	Hardware Description Languages	96
5.5	Methods and Tools for Hardware Analysis	98
5.6	Bibliographic Remarks.....	100
	References.....	101
6	Time in the Analysis of Algorithms.....	103
6.1	Models of Algorithms and Computational Complexity	104
6.2	Computational Complexity and Automata Models	105
6.2.1	Measures of Computational Complexity	106
6.2.2	Finite-State Automata	106
6.2.3	Turing Machines.....	107
6.2.4	Universal Computation and the Church-Turing Thesis ...	110
6.2.5	Complexity of Algorithms and Problems	112
6.2.6	The Linear Speed-Up Theorem	113
6.2.7	Complexity Classes and Polynomial Correlation	115
6.2.8	Nondeterministic Models of Computation	119
6.2.9	Nondeterministic Turing Machines	122
6.2.10	NP-Completeness.....	123
6.3	Computational Complexity and Architecture Models	125
6.3.1	Random Access Machines	125
6.3.2	Algorithmic Complexity Analysis with Random Access Machines	127
6.3.3	Random Access Machines and Complexity Classes	131
6.4	Randomized Models of Computation	133
6.4.1	Probabilistic Finite-State Automata	133
6.4.2	Probabilistic Turing Machines and Complexity Classes.....	141
6.5	Bibliographic Remarks.....	144
	References.....	146

Part II Temporal Models in Modern Theory and Practice

7	Synchronous Abstract Machines.....	153
7.1	Transition Systems	153
7.1.1	Composition of Transition Systems	159
7.2	Automata Over Discrete Time	167
7.2.1	Extending Finite-State Machines with Variables.....	170
7.2.2	Finite-State Automata Features	173
7.3	Decoupling Passing of Time and Transitions	175
7.3.1	Timed Transition Models.....	175
7.3.2	Statecharts.....	178

7.4	Automata Over Continuous Time	183
7.4.1	Timed Automata	183
7.4.2	Hybrid Automata	187
7.4.3	From Dense Back to Discrete Time: Digitization	191
7.5	Probabilistic and Stochastic Automata	192
7.5.1	Stochastic Transition Systems	193
7.5.2	Probabilistic Timed Automata	196
7.5.3	Stochastic Automata	198
7.6	Methods and Tools Based on Synchronous Abstract Machines	202
7.7	Bibliographic Remarks	203
	References	205
8	Asynchronous Abstract Machines: Petri Nets	209
8.1	Basic Petri Nets	209
8.2	Variations and Extensions of Basic Petri Nets	219
8.3	Timed Petri Nets	222
8.3.1	Issues in the Semantics of Timed Petri Nets	223
8.3.2	Formalizing the Semantics of Timed Petri Nets	227
8.3.3	Timed Petri Nets: Complexity and Expressiveness	232
8.4	Timed Petri Nets with Inhibitor Arcs	233
8.5	Stochastic Petri Nets	236
8.6	Languages, Methods, and Tools Based on Petri Nets	240
8.6.1	CO-OPN2 and the Railroad Crossing Problem	241
8.6.2	Tools for Petri Nets	242
8.7	Bibliographic Remarks	244
	References	245
9	Logic-Based Formalisms	249
9.1	Linear- and Branching-Time Temporal Logics	250
9.1.1	Linear Temporal Logic	250
9.1.2	Branching-Time Temporal Logic	257
9.2	Future and Past Temporal Logics	265
9.3	Temporal Logics with Metric on Time	270
9.3.1	Metric Temporal Logic	271
9.3.2	TRIO	273
9.3.3	Specifying Properties in First-Order Metric Temporal Logics	274
9.4	Discrete and Dense Time Domains	279
9.4.1	Dense-Time Modeling	280
9.4.2	Sampling as a Means to Reconcile Discrete- and Dense-Time Semantics	289
9.5	Interval-Based Temporal Logics	291
9.5.1	Interval-Based and Point-Based Predicates	297
9.6	Dealing with Heterogeneous Time Granularities	298

9.7	Explicit-Time Logics.....	301
9.7.1	Real-Time Logic.....	302
9.7.2	Temporal Logic of Actions.....	303
9.7.3	Timed Propositional Temporal Logic.....	304
9.8	Probabilistic Temporal Logics.....	304
9.8.1	Probabilistic Computation Tree Logic.....	305
9.8.2	Continuous Stochastic Logic.....	308
9.9	Methods and Tools Based on Temporal Logics.....	309
9.9.1	A Deductive Approach to the Analysis of TRIO Specifications.....	310
9.9.2	An Approach to Discrete-Time MTL Verification Based on Satisfiability Solvers.....	312
9.9.3	Runtime Verification Based on Temporal Logic.....	315
9.10	Bibliographic Remarks.....	316
	References.....	319
10	Algebraic Formalisms.....	325
10.1	Communicating Sequential Processes.....	326
10.1.1	Processes and Events.....	326
10.1.2	Internal and External Choice.....	327
10.1.3	Hiding of Events.....	329
10.1.4	Concurrent Process Composition.....	330
10.1.5	Inter-process Communication.....	332
10.2	Formal Semantics of Process Algebras.....	334
10.2.1	Trace Semantics.....	334
10.2.2	Transition System Semantics.....	337
10.2.3	Failure Semantics.....	339
10.2.4	Algebraic Laws.....	342
10.3	Process Algebras with Metric Time.....	344
10.3.1	Time Advancement as an Explicit Event.....	344
10.3.2	Timed Process Algebras.....	346
10.4	Probabilistic Process Algebras.....	353
10.4.1	Probabilistic CSP.....	354
10.4.2	External Choice and Concurrency in Probabilistic CSP.....	355
10.4.3	Nondeterminism and Hiding in Probabilistic CSP.....	357
10.5	Methods and Tools Based on Process Algebras.....	358
10.6	Bibliographic Remarks.....	360
	References.....	361
11	Dual-Language Approaches.....	365
11.1	Model Checking Frameworks.....	366
11.1.1	Automata-Theoretic Model Checking.....	367
11.1.2	Satisfiability-Based Model Checking.....	372
11.1.3	CTL Model Checking by Tableau.....	374

11.1.4	Model Checking Timed Automata.....	377
11.1.5	Concluding Remarks on Model Checking.....	383
11.2	The TTM/RTTL Framework.....	384
11.3	The TRIO-Petri Nets Approach	387
11.3.1	Axiomatization of a Subclass of Timed Petri Nets.....	388
11.3.2	Axiomatization of General Timed Petri Nets	393
11.4	Verification Tools for Dual-Language Approaches	404
11.4.1	Model Checkers	404
11.4.2	Tools Supporting the TTL/RTTL Approach.....	405
11.4.3	Tools Supporting the TRIO/Petri Nets Approach	405
11.5	Bibliographic Remarks.....	405
	References.....	406
12	Time Is Up	409
12.1	Modeling Time: Past, Present... ..	409
12.2	... and Future	412
	References.....	414
	Index	415

Modeling Time in Computing

Furia, C.A.; Mandrioli, D.; Morzenti, A.; Rossi, M.

2012, XVI, 424 p., Hardcover

ISBN: 978-3-642-32331-7