

Contents

1. Introduction	1
1.1 Real-Time Systems	1
1.1.1 Two Examples	1
1.1.2 Real Time	3
1.1.3 State Models	4
1.1.4 State Durations	6
1.2 Interval Logic	9
1.2.1 Interval Variables	9
1.2.2 Interval Modalities	10
1.3 Duration Calculus	14
1.3.1 Models	14
1.3.2 Applications	18
1.3.3 Tools	20
1.4 Book Structure	21
2. Interval Logic	23
2.1 Syntax	23
2.2 Semantics	24
2.3 Proof System	27
2.3.1 Deduction	31
2.4 Theorems	34
3. Duration Calculus	41
3.1 Syntax	41
3.2 Semantics	41
3.3 Proof System	45
3.3.1 Soundness	46
3.3.2 Deduction	48
3.4 Theorems	51
3.5 Example: Gas Burner	60
3.5.1 Informal Argument	60
3.5.2 Proof	62

4. Deadline-Driven Scheduler	67
4.1 Formalization of the Deadline-Driven Scheduler	67
4.1.1 Shared Processor	68
4.1.2 Periodic Requests and Deadlines	69
4.1.3 Requirement	72
4.1.4 Scheduler	74
4.2 Liu and Layland's Theorem	76
5. Relative Completeness	89
5.1 Ideas Behind the Proof	89
5.2 Proof of Relative Completeness	90
6. Decidability	99
6.1 Discrete-Time Duration Calculus	99
6.1.1 Discrete Time Versus Continuous Time	100
6.1.2 Expressiveness of Discrete-Time <i>RDC</i>	101
6.2 Decidability for Discrete Time	102
6.3 Decidability for Continuous Time	106
6.4 Complexity, Tools and Other Decidable Subclasses	109
7. Undecidability	111
7.1 Extensions of <i>RDC</i>	111
7.1.1 $RDC_1(r)$	111
7.1.2 RDC_2	112
7.1.3 RDC_3	112
7.1.4 Two-Counter Machines	113
7.2 Undecidability of $RDC_1(r)$	114
7.3 Undecidability of RDC_2	118
7.4 Undecidability of RDC_3	122
8. Model Checking: Linear Duration Invariants	125
8.1 Example	126
8.2 Real-Time Automata	131
8.3 Linear Duration Invariants	133
8.4 Reduction	135
8.4.1 Congruent Equivalence	136
8.4.2 Closure Properties of Normal Forms	141
8.4.3 An Algorithm Deriving Normal Forms	142
8.4.4 Infinite Term	143
8.5 Generalization	143
9. State Transitions and Events	145
9.1 Introduction	145
9.2 Transition Formulas	148
9.2.1 Formulas $\blacktriangleleft S$, $\blacktriangleright S$, $\blacktriangleleft S$ and $\blacktriangleright S$	148

9.2.2	Formulas $\downarrow S$, $\uparrow S$, $\perp S$ and $\top S$	150
9.2.3	Example: NOR Circuit	152
9.3	Calculus for State Transitions	153
9.3.1	Proof System: Part I	154
9.3.2	Proof System: Part II	157
9.3.3	Soundness and Relative Completeness	159
9.4	Example: Automaton	160
9.4.1	Specification	161
9.4.2	Verification	162
10.	Superdense State Transitions	165
10.1	Introduction	165
10.1.1	Superdense Computation	166
10.1.2	Superdense Chop	169
10.2	Calculus for Superdense State Transitions	170
10.2.1	Syntax	170
10.2.2	Semantics	170
10.2.3	Proof System	171
10.2.4	Theorems	173
10.3	Real-Time Semantics	175
10.3.1	Program Notation	175
10.3.2	Program States	176
10.3.3	Program Semantics	180
10.3.4	Program Specification	185
11.	Neighborhood Logic	189
11.1	Introduction	189
11.2	Syntax and Semantics	191
11.3	Adequacy of Neighborhood Modalities	193
11.4	Proof System	194
11.4.1	Axioms and Rules	195
11.4.2	Theorems	197
11.5	Completeness for an Abstract Domain	201
11.6	NL-Based Duration Calculus	204
11.6.1	State Transitions, Liveness and Fairness	204
11.6.2	Example: Delay-Insensitive Circuits	206
12.	Probabilistic Duration Calculus	209
12.1	Introduction	209
12.2	Probabilistic Automata	211
12.2.1	State Sequence	212
12.2.2	Satisfaction Probability	213
12.3	Probabilistic Duration Calculus: Axioms and Rules	215
12.3.1	Syntax	215
12.3.2	Proof System: Part I	216

12.3.3 Proof System: Part II	218
12.4 Example: Gas Burner	219
12.4.1 Calculation of $\mu(\neg Des_1)$	220
12.4.2 Calculation of $\mu(\neg Des_2)$	223
References	227
Abbreviations	239
Symbol Index	241
Index	243