

Contents

<i>Figures and tables</i>	<i>page</i> viii
<i>Preface</i>	x
I A Classic Theory of Reactive Systems	1
1 Introduction	1
Aims of this book	1
1.1 What are reactive systems?	2
1.2 Process algebras	5
2 The language CCS	7
2.1 Some CCS process constructions	7
2.2 CCS, formally	16
3 Behavioural equivalences	31
3.1 Criteria for good behavioural equivalence	31
3.2 Trace equivalence: a first attempt	34
3.3 Strong bisimilarity	36
3.4 Weak bisimilarity	53
3.5 Game characterization of bisimilarity	65
3.6 Further results on equivalence checking	72
4 Theory of fixed points and bisimulation equivalence	75
4.1 Posets and complete lattices	75
4.2 Tarski's fixed point theorem	78
4.3 Bisimulation as a fixed point	85
5 Hennessy–Milner logic	89
5.1 Introduction to Hennessy–Milner logic	89
5.2 Hennessy–Milner theorem	98

6 HML with recursion	102
Introduction	102
6.1 Examples of recursive properties	107
6.2 Syntax and semantics of HML with recursion	109
6.3 Largest fixed points and invariant properties	113
6.4 A game characterization for HML with recursion	115
6.5 Mutually recursive equational systems	120
6.6 Characteristic properties	125
6.7 Mixing largest and least fixed points	134
6.8 Further results on model checking	139
7 Modelling mutual exclusion algorithms	142
Introduction	142
7.1 Specifying mutual exclusion in HML	147
7.2 Specifying mutual exclusion using CCS itself	149
7.3 Testing mutual exclusion	152
II A Theory of Real-time Systems	159
8 Introduction	159
8.1 Real-time reactive systems	159
9 CCS with time delays	161
9.1 Intuition	161
9.2 Timed labelled transition systems	163
9.3 Syntax and SOS rules of timed CCS	165
9.4 Parallel composition	169
9.5 Other timed process algebras and discussion	173
10 Timed automata	175
10.1 Motivation	175
10.2 Syntax of timed automata	176
10.3 Semantics of timed automata	180
10.4 Networks of timed automata	185
10.5 More on timed-automata formalisms	190
11 Timed behavioural equivalences	193
11.1 Timed and untimed trace equivalence	193
11.2 Timed and untimed bisimilarity	195
11.3 Weak timed bisimilarity	200
11.4 Region graphs	203
11.5 Zones and reachability graphs	214
11.6 Further results on timed equivalences	218

12 Hennessy–Milner logic with time	220
Introduction	220
12.1 Basic logic	221
12.2 Hennessy–Milner logic with time and regions	229
12.3 Timed bisimilarity versus HML with time	232
12.4 Recursion in HML with time	237
12.5 More on timed logics	246
13 Modelling and analysis of Fischer’s algorithm	248
Introduction	248
13.1 Mutual exclusion using timing	250
13.2 Modelling Fischer’s algorithm	251
13.3 Further exercises on timing-based mutual exclusion algorithms	258
Appendix A Suggestions for student projects	261
A.1 Alternating-bit protocol	261
A.2 Gossiping girls	262
A.3 Implementation of regions	263
<i>References</i>	267
<i>Index</i>	281