
Contents

1	Introduction	1
1.1	Formal Methods	1
1.2	Partial Orders and Graphs	3
1.3	High-Level Specifications	5
1.4	Towards an Implementation	6
1.5	An Overview of the Book	7
2	Preliminaries	11
2.1	Words and Partial Orders	11
2.2	Monoids and Languages	12
2.3	Turing Machines and the Halting Problem	14
2.4	Bibliographic Notes	15
3	Graphs, Logics, and Graph Acceptors	17
3.1	Graphs	17
3.2	Monadic Second-Order Logic over Graphs	18
3.3	Hanf's Theorem	23
3.4	Graph Acceptors	27
3.5	Directed Acyclic Graphs	30
3.6	Pictures and Grids	31
3.7	Bibliographic Notes	34
4	Words and Finite Automata	35
4.1	Words	35
4.2	Finite Automata	36
4.3	Summary	40
4.4	Bibliographic Notes	41
5	Dags and Asynchronous Cellular Automata	43
5.1	$(\tilde{\Sigma}, C)$ -Dags	43
5.2	The Operational Behavior of $(\tilde{\Sigma}, C)$ -Dags	50

5.3	Asynchronous Cellular Automata with Types	52
5.4	ACATs vs. ACAs	56
5.5	The Expressive Equivalence of ACATs and EMSO Logic	60
5.6	Summary	74
5.7	Bibliographic Notes	75
6	Mazurkiewicz Traces and Asynchronous Automata	77
6.1	Mazurkiewicz Traces	77
6.2	Trace Languages	78
6.3	Asynchronous Automata	80
6.4	Asynchronous Automata vs. ACAs and EMSO Logic	84
6.5	Product Automata	87
6.6	Summary	89
6.7	Bibliographic Notes	90
7	Message Sequence Charts	91
7.1	Message Sequence Charts	91
7.2	Universal and Existential Bounds	95
7.3	High-Level Message Sequence Charts	96
7.4	Message Contents and Non-Fifo Behavior	103
7.5	Live Sequence Charts	105
7.6	Regular MSC Languages	107
7.7	(E)MSO-Definable MSC Languages	107
7.8	Product MSC Languages	109
7.9	Relationships to Mazurkiewicz Traces	110
7.10	Bibliographic Notes	114
8	Communicating Finite-State Machines	117
8.1	Communicating (Finite-State) Machines	117
8.2	Channel-Bounded and Deadlock-Free CMs	122
8.3	Undecidability Results	124
8.4	Lossy Channel Systems	128
8.5	Non-Fifo Channel Systems	130
8.6	CMs vs. Product MSC Languages	131
8.7	CFMs vs. Regular MSC Languages	132
8.8	CFMs vs. ACAs and EMSO Logic	133
8.9	CFMs vs. Graph Acceptors	138
8.10	CFMs vs. EMSO-Definable Product Languages	144
8.11	The Complete Hierarchy	145
8.12	Bibliographic Notes	149
9	Beyond Implementability	151
9.1	EMSO vs. MSO in the Bounded Setting	151
9.2	EMSO vs. MSO in the Unbounded Setting	153
9.3	Determinism vs. Nondeterminism	158

9.4	CFMs vs. Recognizability	159
9.5	CFMs vs. Rational MSC Languages	160
9.6	Summary	163
9.7	Bibliographic Notes	164
References		165
Symbols and Notation		173
Index		179