

Table of contents

Preface	VII
---------------	-----

Part I. An introduction to Network Algebra

Brief overview of the key results	3
Regular expressions	3
Iteration theories	4
Flownomials	5
Basic results	11
Mixed calculi	12
Structure of the book	12
Acknowledgments	14
 1. Network Algebra and its applications	 17
1.1 Algebra of finite relations	18
1.2 Basic Network Algebra, BNA	22
1.3 Flownomial expressions	27
1.4 Concrete vs. abstract networks	32
1.5 Network algebra, NA	34
1.6 Control, space, time: 3 faces of NA models	36
1.7 Feedback, iteration, and repetition	41
1.8 Network behaviours as xy -flows	48
1.9 Mixed Network Algebra, MixNA	51
* Comments, problems, bibliographic remarks	51

Part II. Relations, flownomials, and abstract networks

 2. Networks modulo graph isomorphism	 57
2.1 Symocats	58
2.2 Bijections in symocats	59
2.3 Bijections in BNAs	65
2.4 Semantic models: I. BNA structure	66
2.5 Other presentations of BNAs	71

2.6	Network representation; model $[X, T]_{a\alpha}$	73
2.7	Working with flownomials	79
2.8	BNA soundness	80
2.9	BNA completeness	82
2.10	Networks as $a\alpha$ -flownomials	86
* Comments, problems, bibliographic remarks		88
3.	Algebraic models for branching constants	91
3.1	xy -symocats (xy -weak rules)	92
3.2	Angelic vs. demonic operators	95
3.3	Semantic models: II. NA structure	99
3.4	Normal form for relations	99
3.5	Axioms for relations	104
3.6	Simplification	109
3.7	Relations in xy -symocats	114
3.8	Relations in xy -symocats with feedback	116
3.9	Networks with branching constants	120
* Comments, problems, bibliographic remarks		120
4.	Network behaviour	123
4.1	Strong xy -symocats (xy -strong rules)	124
4.2	Algebraic theories	125
4.3	Matrix theories	126
4.4	Enzymatic rule (xy -enzymatic rules)	129
4.5	Strong axioms: from cells to networks	133
4.6	xy -flows	134
4.7	Semantic models: III. xy -flow structure	135
4.8	Simulation	135
4.9	Enzymatic rule: from connections to networks	140
4.10	Duality: I. Reversing arrows	142
* Comments, problems, bibliographic remarks		143
5.	Elgot theories	147
5.1	Input behaviour; regular trees	148
5.2	Elgot theories ($a\delta$ -flows)	151
5.3	Structural Theorem, case $a\delta$	152
5.4	Soundness for $a\delta$ -flow	160
5.5	Completeness for $a\delta$ -flow	162
5.6	Working with $a\delta$ -flownomials	163
5.7	Output behaviour	163
5.8	Bisimulation: two-way simulation	164
5.9	Milner theories	167
* Comments, problems, bibliographic remarks		168
6.	Kleene theories	169
6.1	IO behaviour, deterministic case	170

6.2	Park theories ($b\delta$ -flow)	170
6.3	Structural Theorem, case $b\delta$	170
6.4	Soundness for $b\delta$ -flow	179
6.5	Completeness for $b\delta$ -flow	180
6.6	Working with $b\delta$ -flownomials	181
6.7	IO behaviour, nondeterministic case	181
6.8	Kleene theories ($d\delta$ -flow)	182
6.9	Structural Theorem, case $d\delta$	183
6.10	Soundness for $d\delta$ -flow	188
6.11	Completeness for $d\delta$ -flow	189
6.12	Working with $d\delta$ -flownomials	192
*	Comments, problems, bibliographic remarks	192

Part III. Algebraic theory of special networks

7.	Flowchart schemes	197
7.1	Structural programs	197
7.2	Flowchart representation	200
7.3	Floyd-Hoare logic	202
7.4	Soundness of Floyd-Hoare logic	206
7.5	Completeness of Floyd-Hoare logic	210
7.6	Duality: II. Control-Space	212
7.7	Iteration and feedback in (co)algebraic theories	218
*	Comments, problems, bibliographic remarks	222
8.	Automata	223
8.1	Finite automata	224
8.2	Simulation	227
8.3	From nondeterministic to deterministic automata	228
8.4	Minimization: I. Accessibility	231
8.5	Minimization: II. Reduction	233
8.6	Minimization: III. Deterministic automata	235
8.7	Regular expressions and Kleene algebras	237
8.8	Kleene Theorem: I. From automata to regular expressions	240
8.9	Kleene Theorem: II. From regular expressions to automata	242
8.10	Axiomatization, regular expressions	244
8.11	Repetition, iteration, and feedback in matrix theories	246
*	Comments, problems, bibliographic remarks	248
9.	Process algebra	249
9.1	An overview on parallel processes	249
9.2	Transition systems	253
9.3	Nondeterministic sequential processes; BPA plus recursion	255
9.4	Coloured traces	259
9.5	Communicating processes; ACP	261

9.6 Soundness and completeness of ACP	263
9.7 Abstraction	269
9.8 A case study: Alternating Bit Protocol	270
* Comments, problems, bibliographic remarks	273
10. Data-flow networks	275
10.1 Data-flow networks; general presentation	276
10.2 Synchronous networks	280
10.3 Asynchronous networks	282
10.4 Axiomatization: asynchronous, deterministic case	285
10.5 Time anomaly for nondeterministic networks	289
10.6 Axiomatization: asynchronous, nondeterministic case	292
10.7 Fully abstract models	294
10.8 Network algebra on top of process algebra	296
* Comments, problems, bibliographic remarks	301
11. Petri nets	305
11.1 Introducing the model	305
11.2 Concurrent regular expressions (CRegExp)	309
11.3 Decomposed Petri nets	312
11.4 From Petri net languages to CRegExp	314
11.5 From CRegExp to Petri net languages	316
11.6 Equivalence of CRegExp and Petri net languages	318
* Comments, problems, bibliographic remarks	318
<hr/>	
Part IV. Towards an algebraic theory for software components	
12. Mixed Network Algebra	323
12.1 Why mixed network algebra models?	323
12.2 Mixing control, space, and time	324
12.3 Acyclic models	326
12.3.1 Syscats	326
12.3.2 Mixed relations	327
12.3.3 Distributive categories (discats)	328
12.3.4 Mixalgebras	329
12.3.5 Plans	333
12.4 Compilers, code generation	338
12.5 Duality: III. Space-time	342
12.6 Object-oriented programs/software components	348
* Comments, problems, bibliographic remarks	349
Related calculi, closing remarks	351
Appendices	353
Appendix A: Equivalent BNA presentation (LR-flows)	353

Appendix B: Lifting BNA from connections to networks	359
Appendix C: Demonic relation operators	362
Appendix D. Generating congruences	368
Appendix E: Automata, complements	369
Appendix F: Data-flow networks; checking NA axioms	371
Appendix G: Axiomatizing mixed relations	373
Appendix H: Discats as syscats	375
Appendix I: Decomposing morphisms in discats	377
Appendix J: Plans as free discats	379
Bibliography	381
List of tables	391
List of figures	393
Index	395