

Contents

Foreword	v
Preface	xvii
Chapter 1 Introduction	1
1.1 Basic Concepts and Examples	2
1.2 Overview by Chapter	8
1.2.1 Inference	9
1.2.2 Search	10
1.3 Mathematical Background	12
1.3.1 Sets, Domains, and Tuples	13
1.3.2 Relations	13
1.3.3 Graphs: General Concepts	17
1.3.4 Background in Complexity	19
1.4 Bibliographical Notes	21
1.5 Exercises	21
Part I Basics of Constraint Processing	23
Chapter 2 Constraint Networks	25
2.1 Constraint Networks and Constraint Satisfaction	25
2.1.1 The Basics of the Framework	25
2.1.2 Solutions of a Constraint Network	27
2.1.3 Constraint Graphs	29
2.2 Numeric and Boolean Constraints	34
2.2.1 Numeric Constraints	34
2.2.2 Boolean Constraints and Propositional CNF	35
2.2.3 Combinatorial Circuits Diagnosis	37

2.3	Properties of Binary Constraint Networks	38
2.3.1	Equivalence and Deduction with Constraints	38
2.3.2	The Minimal and the Projection Networks	40
2.3.3	Binary-Decomposable Networks	44
2.4	Summary	45
2.5	Bibliographical Notes	45
2.6	Exercises	45
Chapter 3	Consistency-Enforcing and Constraint Propagation	51
3.1	Why Propagate Constraints?	51
3.2	Arc-Consistency	54
3.3	Path-Consistency	61
3.4	Higher Levels of i-Consistency	67
3.4.1	A Note on 3-Consistency and Path-Consistency	69
3.5	Arc-Consistency for Nonbinary Constraints	70
3.5.1	Generalized Arc-Consistency	70
3.5.2	Global Constraints	71
3.5.3	Bounds-Consistency	73
3.6	Constraint Propagation for Numeric and Boolean Constraints	74
3.6.1	Algebraic Constraints	74
3.6.2	Boolean Constraint Propagation	75
3.7	Trees, Bivalued Networks, and Horn Theories	76
3.8	Summary	77
3.9	Bibliographical Notes	78
3.10	Exercises	80
Chapter 4	Directional Consistency	85
4.1	Graph Concepts: Induced Width	86
4.1.1	Greedy Algorithms for Finding Induced Widths	88
4.1.2	Chordal Graphs	90
4.1.3	k -Trees	91
4.2	Directional Local Consistency	91
4.2.1	Directional Arc-Consistency	92
4.2.2	Directional Path-Consistency	94
4.2.3	Directional i -Consistency	96
4.2.4	Graph Aspects of Directional Consistency	98
4.3	Width versus Local Consistency	100
4.3.1	Solving Trees: Case of Width 1	100

4.3.2	Solving Width-2 Problems	102	
4.3.3	Solving Width- i Problems	103	
4.4	Adaptive Consistency and Bucket Elimination		104
4.5	Summary		110
4.6	Bibliographical Notes		111
4.7	Exercises		112
Chapter 5	General Search Strategies: Look-Ahead		117
5.1	The State Space Search		118
5.1.1	Variable Ordering	119	
5.1.2	Consistency Level	119	
5.2	Backtracking		123
5.2.1	Complexity of Extending a Partial Solution	125	
5.2.2	Improvements to Backtracking	127	
5.3	Look-Ahead Strategies		130
5.3.1	Look-Ahead Algorithms for Value Selection	131	
5.3.2	Look-Ahead for Variable Ordering	137	
5.3.3	The Cycle-Cutset Effect	140	
5.3.4	An Implementation Issue	141	
5.3.5	Extensions to Stronger Look-Aheads	141	
5.4	Satisfiability: Look-Ahead in Backtracking		142
5.5	Summary		144
5.6	Bibliographical Notes		144
5.7	Exercises		146
Chapter 6	General Search Strategies: Look-Back		151
6.1	Conflict Sets		151
6.2	Backjumping Styles		153
6.2.1	Gaschnig's Backjumping	154	
6.2.2	Graph-Based Backjumping	155	
6.2.3	Conflict-Directed Backjumping	162	
6.2.4	i -Backjumping	166	
6.3	Complexity of Backjumping		166
6.4	Learning Algorithms		169
6.4.1	Graph-Based Learning	170	
6.4.2	Deep versus Shallow Learning	172	
6.4.3	Jumpback Learning	173	
6.4.4	Bounded and Relevance-Bounded Learning	174	

6.4.5	Nonsystematic Randomized Backtrack Learning	174
6.4.6	Complexity of Backtracking with Learning	175
6.5	Look-Back Techniques for Satisfiability	175
6.6	Integration and Comparison of Algorithms	178
6.6.1	Integrating Backjumping and Look-Ahead	178
6.6.2	Comparison of Algorithms	180
6.7	Summary	186
6.8	Bibliographical Notes	186
6.9	Exercises	188
Chapter 7 Stochastic Greedy Local Search		191
7.1	Greedy Local Search	192
7.1.1	The Algorithm	192
7.1.2	Heuristics for Improving Local Search	194
7.2	Random Walk Strategies	195
7.2.1	WalkSAT	195
7.2.2	Properties of Local Search	197
7.2.3	Examples of Empirical Evaluation	198
7.3	Hybrids of Local Search and Inference	198
7.3.1	The Effect of Constraint Propagation on SLS	198
7.3.2	Local Search on Cycle-Cutset	200
7.4	Summary	205
7.5	Bibliographical Notes	206
7.6	Exercises	207
Part II Advanced Methods		209
Chapter 8 Advanced Consistency Methods		211
8.1	Relational Consistency	212
8.1.1	Relational m -Consistency	212
8.1.2	Space Bound versus Time Bound	215
8.2	Directional Consistency Revisited	218
8.2.1	Directional Relational Consistency	218
8.2.2	Complexity	221
8.3	Domain and Constraint Tightness	223
8.3.1	Domain Tightness	223
8.3.2	Constraint Tightness	224

8.4	Inference for Boolean Theories	225
8.4.1	Consistency for Propositional CNF Theories	225
8.4.2	Directional Resolution	227
8.4.3	Tractable Boolean Theories	230
8.5	Row-Convex Constraints	231
8.5.1	Identifying Row-Convex Relations	234
8.5.2	Nonbinary Row-Convex Constraints	235
8.6	Linear Inequalities	237
8.6.1	Linear Elimination	237
8.6.2	Fourier Bucket Elimination	239
8.7	Summary	241
8.8	Bibliographical Notes	241
8.9	Exercises	242
	Chapter 9 Tree Decomposition Methods	245
9.1	Acyclic Networks	245
9.1.1	Solving Acyclic Problems	245
9.1.2	Recognizing Acyclic Networks	249
9.2	Tree-Based Clustering	253
9.2.1	Join-Tree Clustering	253
9.2.2	Unifying Tree Decomposition Schemes	257
9.3	ADAPTIVE-CONSISTENCY as Tree Decomposition	263
9.4	Summary	267
9.5	Bibliographical Notes	267
9.6	Exercises	268
	Chapter 10 Hybrids of Search and Inference: Time-Space Trade-Offs	271
10.1	Specialized Cutset Schemes	273
10.1.1	The Cycle-Cutset Scheme	273
10.1.2	Structure-Based Recursive Search	276
10.2	Hybrids: Conditioning First	277
10.2.1	The Idea	277
10.2.2	Hybrid Algorithm for Propositional Theories	280
10.3	Hybrids: Inference First	283
10.3.1	The SUPER-CLUSTER-TREE-ELIMINATION Algorithm	284
10.3.2	Decomposition into Nonseparable Components	286
10.3.3	Hybrids of Hybrids	289

10.4	A Case Study of Combinatorial Circuits	290
10.4.1	Parameters of Primary Join-Trees	291
10.4.2	Parameters Controlling Hybrids	292
10.5	Summary	296
10.6	Bibliographical Notes	297
10.7	Exercises	297
Chapter 11	Tractable Constraint Languages	299
	David Cohen and Peter Jeavons	
11.1	The CSP Search Problem	300
11.1.1	Restricting the General CSP	300
11.2	Constraint Languages	301
11.2.1	Tractable Constraint Languages	303
11.3	Expressiveness of Constraint Languages	308
11.3.1	Gadgets for Expressing Relations	308
11.3.2	A Universal Gadget for Finite Domains	310
11.4	Complexity of Constraint Languages	313
11.4.1	Why Develop a Theory of Tractability?	313
11.4.2	Tractable Constraint Languages over a Domain with Two Elements	314
11.4.3	Tractability and Reduced Languages	316
11.4.4	Maximal Tractable Languages	317
11.4.5	A Necessary Condition for Tractability over a Finite Domain	317
11.4.6	Sufficient Conditions for Tractability	321
11.4.7	Necessary and Sufficient Conditions for Tractability	324
11.5	Hybrid Tractability	324
11.6	Summary	326
11.7	Bibliographical Notes	326
11.8	Exercises	328
Chapter 12	Temporal Constraint Networks	333
12.1	Qualitative Networks	334
12.1.1	The Interval Algebra	334
12.1.2	Path-Consistency in Interval Algebra	339
12.1.3	The Point Algebra	341
12.2	Quantitative Temporal Networks	344
12.2.1	The Simple Temporal Problem	348
12.2.2	Solving the General TCSP	351

12.2.3	Path-Consistency in Quantitative Networks	353
12.2.4	Network-Based Algorithms	357
12.3	Translations between Representations	357
12.4	Summary	359
12.5	Bibliographical Notes	360
12.6	Exercises	361
Chapter 13	Constraint Optimization	363
13.1	Constraint Optimization and Cost Networks	364
13.1.1	Solving COP as a Series of CSPs	366
13.2	Branch-and-Bound Search	366
13.2.1	A "First-Choice" Bounding Function	367
13.2.2	The Russian Doll Search	369
13.3	Bucket Elimination for Optimization	370
13.3.1	Deriving ELIM-OPT	371
13.3.2	Complexity	374
13.3.3	Counting the Number of Solutions	378
13.4	Mini-bucket Elimination	379
13.5	Search with Mini-bucket Heuristics	384
13.5.1	Generating a Bounding Function for Search	384
13.5.2	Algorithm BBMB(<i>i</i>)	388
13.6	Empirical Demonstration	390
13.7	Summary	392
13.8	Bibliographical Notes	395
13.9	Exercises	396
Chapter 14	Probabilistic Networks	399
14.1	Bucket Elimination for Belief Assessment	402
14.1.1	Deriving ELIM-BEL	402
14.2	An Elimination Algorithm for mpe	405
14.3	Complexity	407
14.4	Hybrids of Elimination and Conditioning	408
14.4.1	Search for Probabilistic Reasoning	409
14.4.2	Cycle-Cutset and Other Hybrids	409
14.5	Summary	411
14.6	Bibliographical Notes	411

Chapter 15 Constraint Logic Programming	413
Francesca Rossi	
15.1 Logic Programming	414
15.1.1 Syntax	414
15.1.2 Operational Semantics	416
15.1.3 Logic Programming versus Prolog	419
15.1.4 Data Structures in LP: Records and Lists	420
15.2 Logic Programming as a Constraint Programming Language	421
15.3 Syntax and Semantics of Constraint Logic Programming	424
15.3.1 Syntax	425
15.3.2 Operational Semantics	425
15.4 CLP over Finite Domain Constraints	428
15.5 Issues and Notions Coming from CLP Use	433
15.5.1 Variables, Constraints, Domains	434
15.5.2 Bounds-Consistency	435
15.5.3 Global Constraints	436
15.6 Summary	438
15.7 Bibliographical Notes	438
15.8 Exercises	439
Bibliography	441
Index	459