Contents

1	Intro	duction		1			
	1.1	What i	s Competitive Programming?	1			
		1.1.1	Programming Contests	2			
		1.1.2	Tips for Practicing	3			
	1.2	About	This Book	3			
	1.3	CSES	Problem Set	5			
	1.4	Other 1	Resources	7			
2	Programming Techniques						
	2.1	Langua	age Features	9			
		2.1.1	Input and Output	10			
		2.1.2	Working with Numbers	12			
		2.1.3	Shortening Code	14			
	2.2	Recurs	ive Algorithms	15			
		2.2.1	Generating Subsets	15			
		2.2.2	Generating Permutations	16			
		2.2.3	Backtracking	18			
	2.3	Bit Ma	nnipulation	20			
		2.3.1	Bit Operations	21			
		2.3.2	Representing Sets	23			
3	Effic	iency		27			
	3.1	-	Complexity	27			
		3.1.1	Calculation Rules	27			
		3.1.2	Common Time Complexities	30			
		3.1.3	Estimating Efficiency	31			
		3.1.4	Formal Definitions	32			
	3.2	Examp	oles	32			
		3.2.1	Maximum Subarray Sum	32			
		3.2.2	Two Queens Problem	35			
4	Sorti	ing and	Searching	37			
	4.1	Sorting	g Algorithms	37			
		111	Rubble Sort	38			

viii Contents

		4.1.2	Merge Sort	39
		4.1.3	Sorting Lower Bound	40
		4.1.4	Counting Sort	41
		4.1.5	Sorting in Practice	41
	4.2	Solving	g Problems by Sorting	43
		4.2.1	Sweep Line Algorithms	44
		4.2.2	Scheduling Events	45
		4.2.3	Tasks and Deadlines	45
	4.3	Binary	Search	46
		4.3.1	Implementing the Search	47
		4.3.2	Finding Optimal Solutions	48
5	Data	Structu	res	51
•	5.1		nic Arrays	51
	0.11	5.1.1	Vectors	52
		5.1.2	Iterators and Ranges	53
		5.1.3	Other Structures	54
	5.2	Set Str	uctures	55
		5.2.1	Sets and Multisets	55
		5.2.2	Maps	57
		5.2.3	Priority Queues	58
		5.2.4	Policy-Based Sets	59
	5.3		ments	60
		5.3.1	Set Versus Sorting.	60
		5.3.2	Map Versus Array	61
		5.3.3	Priority Queue Versus Multiset	62
6	Dvn	amic Pro	ogramming	63
•	6.1		Concepts	63
	0.1	6.1.1	When Greedy Fails	63
		6.1.2	Finding an Optimal Solution	64
		6.1.3	Counting Solutions	67
	6.2		Examples	68
		6.2.1	Longest Increasing Subsequence	69
		6.2.2	Paths in a Grid	70
		6.2.3	Knapsack Problems	71
		6.2.4	From Permutations to Subsets	72
		6.2.5	Counting Tilings	74
7	Grai	nh Algar	ithms	77
•	7.1		of Graphs.	78
	,	7.1.1	Graph Terminology	78
		7.1.2	Graph Representation	80
	7.2		Traversal	83
	=	7.2.1	Depth-First Search.	83
			1	

Contents ix

86 87 88 89 92 94 94 96 97 98 99 100 101 103 106 107 107 110 111
88 89 92 94 94 96 97 98 99 100 101 103 106 107 107 108 110 111
89 92 94 94 96 97 98 99 100 101 103 106 107 107 108 110 111
92 94 94 96 97 98 99 100 101 103 106 107 107 108 110 111
94 94 96 97 98 99 100 101 103 106 107 107 108 110 111
94 96 97 98 99 100 101 103 106 107 107 108 110 111
96 97 98 99 100 101 103 106 107 107 108 110 111
97 98 99 100 101 103 106 107 107 108 110 111
98 99 100 101 103 106 107 107 108 110 111
99 100 101 103 106 107 107 107 108 110
100 101 103 106 107 107 108 110
101 103 106 107 107 107 108 110
103 106 107 107 107 108 110 111
106 107 107 107 108 110 111
107 107 107 108 110 111
107 107 108 110 111
 107 108 110 111
 108 110 111
 110 111
 111
111
 111
 113
 114
 115
 115
 116
 117
 119
 119
120
 121
122
122
125
128
 131
131
132
 134
135

x Contents

	10.2	_	ries	137
		10.2.1 F	Finding Ancestors	137
		10.2.2 S	Subtrees and Paths	138
			Lowest Common Ancestors	140
		10.2.4 N	Merging Data Structures	142
	10.3		d Techniques	144
		10.3.1 C	Centroid Decomposition	144
		10.3.2 H	Heavy-Light Decomposition	145
11	Math	ematics		147
	11.1	Number 7	Γheory	147
		11.1.1 F	Primes and Factors	148
		11.1.2 S	Sieve of Eratosthenes	150
		11.1.3 E	Euclid's Algorithm	151
		11.1.4 N	Modular Exponentiation	153
			Euler's Theorem	153
			Solving Equations	155
	11.2		torics	156
		11.2.1 E	Binomial Coefficients	157
		11.2.2	Catalan Numbers	159
			nclusion-Exclusion	161
			Burnside's Lemma	163
			Cayley's Formula	164
	11.3			164
			Matrix Operations	165
			Linear Recurrences	167
		11.3.3	Graphs and Matrices	169
			Gaussian Elimination	170
	11.4		ty	173
			Working with Events	174
			Random Variables	175
		11.4.3 N	Markov Chains	178
			Randomized Algorithms	179
	11.5		eory	181
			Game States	181
			Nim Game	182
			Sprague-Grundy Theorem	184
12	Adva	nced Gran	ph Algorithms	189
	12.1	_	onnectivity	189
			Kosaraju's Algorithm	190
			2SAT Problem	192
	12.2		Paths	193
			Eulerian Paths	194

Contents xi

	12.3	12.2.2 12.2.3 Maximu 12.3.1	Hamiltonian Paths	195 196 198 199
	12.4	12.3.2 12.3.3 12.3.4 Depth-I 12.4.1 12.4.2	Disjoint Paths	202 203 205 207 207 209
13	Geon	net r v		211
13	13.1	·	tric Techniques	211
	1011	13.1.1	Complex Numbers	211
		13.1.2	Points and Lines	213
		13.1.3	Polygon Area	216
		13.1.4	Distance Functions	218
	13.2	Sweep	Line Algorithms	220
		13.2.1	Intersection Points	220
		13.2.2	Closest Pair Problem	221
		13.2.3	Convex Hull Problem	224
14	String	g Algori	thms	225
	14.1	Basic T	Topics	225
		14.1.1	Trie Structure	226
		14.1.2	Dynamic Programming	227
	14.2	_	Hashing	228
		14.2.1	Polynomial Hashing	228
		14.2.2	Applications	229
	142	14.2.3	Collisions and Parameters	230
	14.3	2-Aigo:	rithm	231 232
		14.5.1	Constructing the Z-Array	232
			· · · · · · · · · · · · · · · · · · ·	233
	14 4	14.3.2	Applications	233 234
	14.4	14.3.2 Suffix A	Applications	234
	14.4	14.3.2	Applications	
	14.4	14.3.2 Suffix A 14.4.1	Applications	234 235
15		14.3.2 Suffix A 14.4.1 14.4.2 14.4.3	Applications Arrays Prefix Doubling Method Finding Patterns LCP Arrays	234 235 236 236
15		14.3.2 Suffix A 14.4.1 14.4.2 14.4.3 tional To	Applications Arrays Prefix Doubling Method Finding Patterns LCP Arrays	234 235 236 236 239
15	Addi	14.3.2 Suffix A 14.4.1 14.4.2 14.4.3 tional To	Applications Arrays Prefix Doubling Method Finding Patterns LCP Arrays	234 235 236 236
15	Addi	14.3.2 Suffix A 14.4.1 14.4.2 14.4.3 tional To Square	Applications Arrays Prefix Doubling Method Finding Patterns LCP Arrays opics Root Techniques	234 235 236 236 239 239
15	Addi	14.3.2 Suffix A 14.4.1 14.4.2 14.4.3 tional To Square 15.1.1	Applications Arrays Prefix Doubling Method Finding Patterns LCP Arrays opics Root Techniques Data Structures	234 235 236 236 239 239 240

xii Contents

15.2	Segmen	nt Trees Revisited	245
	15.2.1	Lazy Propagation	246
	15.2.2	Dynamic Trees	249
	15.2.3	Data Structures in Nodes	251
	15.2.4	Two-Dimensional Trees	253
15.3	Treaps.		253
	15.3.1	Splitting and Merging	253
	15.3.2	Implementation	255
	15.3.3	Additional Techniques	257
15.4	Dynam	ic Programming Optimization	258
	15.4.1	Convex Hull Trick	258
	15.4.2	Divide and Conquer Optimization	260
	15.4.3	Knuth's Optimization	261
15.5	Miscell	aneous	262
	15.5.1	Meet in the Middle	263
	15.5.2	Counting Subsets	263
	15.5.3	Parallel Binary Search	265
	15.5.4	Dynamic Connectivity	266
Appendix	A: Mat	hematical Background	269
Reference	s		277
Indev			279



http://www.springer.com/978-3-319-72546-8

Guide to Competitive Programming Learning and Improving Algorithms Through Contests Laaksonen, A.

2017, XII, 283 p. 266 illus., 96 illus. in color., Softcover

ISBN: 978-3-319-72546-8