

# Contents of Volume 2

<b>Chapter 1. Complexity: A Language-Theoretic Point of View</b>	
<i>Cristian Calude and Juraj Hromkovič</i> .....	1
1. Introduction .....	1
2. Theory of computation .....	3
2.1 Computing fallibilities .....	3
2.2 Turing machines, Chaitin computers, and Chomsky grammars .	7
2.3 Universality .....	8
2.4 Silencing a universal computer .....	11
2.5 Digression: A simple grammatical model of brain behaviour ...	12
2.6 The halting problem .....	13
2.7 The Church–Turing Thesis .....	14
2.8 Digression: mind, brain, and computers .....	15
3. Computational complexity measures and complexity classes .....	16
3.1 Time and space complexities and their properties .....	16
3.2 Classification of problems according to computational difficulty and nondeterminism .....	25
3.3 Hard problems and probabilistic computations .....	31
4. Program-size complexity .....	36
4.1 Dynamic versus program-size complexities .....	36
4.2 The halting problem revisited .....	38
4.3 Random strings .....	39
4.4 From random to regular languages .....	41
4.5 Trade-offs .....	45
4.6 More about $P = ?NP$ .....	46
5. Parallelism .....	47
5.1 Parallel computation thesis and alternation .....	47
5.2 Limits to parallel computation and $P$ -completeness .....	51
5.3 Communication in parallel and distributive computing .....	52
References .....	54

## Chapter 2. Parsing of Context-Free Languages

<i>Klaas Sikkel and Anton Nijholt</i> .....	61
1. Introduction .....	61
1.1 Parsing algorithms .....	62
1.2 Parsing technology .....	63
1.3 About this chapter .....	64
2. An informal introduction .....	66

3.	Parsing schemata	70
3.1	Parsing systems	70
3.2	Parsing schemata	71
3.3	Correctness of parsing schemata	72
4.	Generalization	74
4.1	Some examples	74
4.2	Formalization	75
4.3	Properties of generalization	77
5.	Filtering	79
5.1	Static filtering	79
5.2	Dynamic filtering	80
5.3	Step contraction	82
5.4	Properties of filtering relations	83
6.	Some larger examples	83
6.1	Left-corner parsing	84
6.2	De Vreught and Honig's algorithm	86
6.3	Rytter's algorithm	90
6.4	Some general remarks	92
7.	From schemata to algorithms	93
8.	Beyond context-free grammars	96
9.	Conclusions	97
	References	97

**Chapter 3. Grammars with Controlled Derivations**

	<i>Jürgen Dassow, Gheorghe Păun, and Arto Salomaa</i>	101
1.	Introduction and notations	101
2.	Some types of controlled derivations and their power	103
2.1	Prescribed sequences	103
2.2	Control by context conditions	115
2.3	Grammars with partial parallelism	124
2.4	Indexed grammars	134
2.5	Hierarchies of families with controlled derivations	135
3.	Basic properties	139
3.1	Operations on language families	139
3.2	Decision problems	141
3.3	Descriptive complexity	145
4.	Further topics	148
	References	150

**Chapter 4. Grammar Systems**

	<i>Jürgen Dassow, Gheorghe Păun, and Grzegorz Rozenberg</i>	155
1.	Introduction	155
2.	Formal language prerequisites	157
3.	CD grammar systems	158
3.1	Definitions	158

3.2	Examples	160
3.3	On the generative capacity	162
3.4	Hybrid systems	164
3.5	Increasing the power by teams	167
3.6	Descriptional complexity	169
3.7	Other classes of CD grammar systems	172
4.	PC grammar systems	173
4.1	Definitions	173
4.2	Examples	177
4.3	On the generative capacity	180
4.4	The context-sensitive case	184
4.5	Non-synchronized PC grammar systems	185
4.6	Descriptional and communication complexity	186
4.7	PC grammar systems with communication by command	189
4.8	Further variants and results	194
5.	Related models	196
5.1	Eco-grammar systems	196
5.2	Test tube systems	201
	References	207

**Chapter 5. Contextual Grammars and Natural Languages**

<i>Solomon Marcus</i>	215
The year 1957: two complementary strategies	215
The origin of contextual grammars	216
Motivation of simple contextual grammars and of contextual grammars with choice	216
The duality between strings and contexts and the Sestier closure	218
Steps in modelling morphological categories	219
The contextual approach in a generative perspective	221
Contextual grammars can generate both strings and contexts	223
Interplay of strings, contexts and contextual grammars with choice	225
Going deeper in the interplay strings-contexts	227
A higher level of abstraction: parts of speech	228
Generative power of contextual grammars	229
Further suggestions: restricted contextual grammars, grammar systems and splicing contextual schemes	230
References	232

**Chapter 6. Contextual Grammars and Formal Languages**

<i>Andrzej Ehrenfeucht, Gheorghe Păun, and Grzegorz Rozenberg</i>	237
1. Introduction	237
2. Contextual grammars with unrestricted choice	238
2.1 Preliminaries	238
2.2 Definitions	238

2.3	Examples	241
2.4	Necessary conditions and counterexamples	243
2.5	Generative capacity	247
2.6	Closure properties	249
2.7	Decidability properties	253
3.	Contextual grammars with restricted choice	256
3.1	Definitions and basic results	256
3.2	Internal contextual grammars with finite choice	261
3.3	External contextual grammars with regular choice	264
4.	Variants of contextual grammars	275
4.1	Deterministic grammars	275
4.2	One-sided contexts	277
4.3	Leftmost derivation	281
4.4	Parallel derivation	282
4.5	Maximal/minimal use of selectors	284
5.	Bibliographical notes	285
	References	290

**Chapter 7. Language Theory and Molecular Genetics**

	<i>Thomas Head, Gheorghe Păun, and Dennis Pixton</i>	295
1.	Introduction	295
2.	Formal language theory prerequisites	298
3.	The splicing operation	298
3.1	The uniterated case	298
3.2	The iterated case	306
3.3	The case of multisets	319
4.	Generative mechanisms based on splicing	325
4.1	Simple H systems	326
4.2	Extended H systems	333
5.	Splicing circular words	335
5.1	Circular words	335
5.2	Circular splicing	336
5.3	Mixed splicing	342
6.	Computing by splicing	344
7.	Bibliographical notes	348
	Appendix	351
	References	358

**Chapter 8. String Editing and Longest Common Subsequences**

	<i>Alberto Apostolico</i>	361
1.	Introduction	361
1.1	Approximate string searching	363
1.2	Local similarity searches in DNA and protein sequences	363
1.3	Longest common subsequences	364

2. Two basic paradigms for the LCS problem . . . . . 366  
 2.1 Hirschberg’s paradigm: finding antichains one at a time . . . . . 368  
 2.2 Incremental antichain decompositions and the Hunt-Szymanski  
 paradigm . . . . . 371  
 3. A speed-up for HS . . . . . 372  
 4. Finger trees . . . . . 375  
 5. Linear space . . . . . 379  
 5.1 Computing the length of a solution . . . . . 380  
 5.2 Computing an LCS in  $O(n(m - l))$  time and linear space . . . . . 382  
 6. Combining few and diverse tools: Hirschberg’s paradigm in linear  
 space . . . . . 386  
 7. Parallel algorithms . . . . . 389  
 References . . . . . 395

**Chapter 9. Automata for Matching Patterns**

*Maxime Crochemore and Christophe Hancart* . . . . . 399  
 1. Pattern matching and automata . . . . . 399  
 2. Notations . . . . . 400  
 2.1 Alphabet and words . . . . . 401  
 2.2 Languages . . . . . 401  
 2.3 Regular expressions . . . . . 401  
 2.4 Finite automata . . . . . 402  
 2.5 Algorithms for matching patterns . . . . . 403  
 3. Representations of deterministic automata . . . . . 405  
 3.1 Transition matrix . . . . . 405  
 3.2 Adjacency lists . . . . . 406  
 3.3 Transition list . . . . . 407  
 3.4 Failure function . . . . . 407  
 3.5 Table-compression . . . . . 408  
 4. Matching regular expressions . . . . . 408  
 4.1 Outline . . . . . 408  
 4.2 Regular-expression-matching automata . . . . . 409  
 4.3 Searching with regular-expression-matching automata . . . . . 411  
 4.4 Time-space trade-off . . . . . 414  
 5. Matching finite sets of words . . . . . 414  
 5.1 Outline . . . . . 414  
 5.2 Dictionary-matching automata . . . . . 415  
 5.3 Linear dictionary-matching automata . . . . . 416  
 5.4 Searching with linear dictionary-matching automata . . . . . 420  
 6. Matching words . . . . . 422  
 6.1 Outline . . . . . 422  
 6.2 String-matching automata . . . . . 423  
 6.3 Linear string-matching automata . . . . . 426  
 6.4 Properties of string-matching automata . . . . . 428  
 6.5 Searching with linear string-matching automata . . . . . 431

7. Suffix automata .....	434
7.1 Outline .....	434
7.2 Sizes and properties .....	435
7.2.1 End-positions .....	435
7.2.2 Suffix function .....	436
7.2.3 State splitting .....	437
7.2.4 Sizes of suffix automata .....	439
7.3 Construction .....	441
7.3.1 Suffix links and suffix paths .....	441
7.3.2 On-line construction .....	442
7.3.3 Complexity .....	446
7.4 As indexes .....	447
7.4.1 Membership .....	448
7.4.2 First position .....	448
7.4.3 Occurrence number .....	449
7.4.4 List of positions .....	450
7.4.5 Longest repeated factor .....	450
7.5 As string-matching automata .....	451
7.5.1 Ending factors .....	451
7.5.2 Optimization of suffix links .....	452
7.5.3 Searching for rotations .....	453
7.6 Factor automata .....	454
7.6.1 Relation to suffix automata .....	454
7.6.2 Size of factor automata .....	455
7.6.3 On-line construction .....	456
Bibliographic notes .....	459
References .....	461

**Chapter 10. Symbolic Dynamics and Finite Automata**

<i>Marie-Pierre Béal and Dominique Perrin</i> .....	463
1. Introduction .....	463
2. Symbolic dynamical systems .....	464
3. Recurrence and minimality .....	470
4. Sofic systems and shifts of finite type .....	472
5. Minimal automaton of a subshift .....	477
6. Codes and finite-to-one maps .....	480
7. State splitting and merging .....	484
8. Shift equivalence .....	487
9. Entropy .....	490
10. The road coloring problem .....	496
11. The zeta function of a subshift .....	498
12. Circular codes, shifts of finite type and Krieger embedding theorem .....	500
References .....	503

**Chapter 11. Cryptology: Language-Theoretic Aspects**

<i>Valtteri Niemi</i> .....	507
1. Introduction .....	507
2. Basic notions in cryptology .....	507
3. Connections between cryptology and language theory .....	510
4. Public-key systems based on language theory .....	511
4.1 Wagner-Magyarik system .....	511
4.2 Salomaa–Welzl system .....	512
4.3 Subramanian et al. system .....	513
4.4 Siromoney–Mathew system .....	514
4.5 Niemi system .....	514
4.6 Oleshchuk system .....	515
5. Cryptosystems based on automata theory .....	516
5.1 Wolfram system .....	516
5.2 Guan public-key system .....	516
5.3 Tao-Chen public-key system .....	517
6. Theoretical cryptologic research based on language theory .....	518
7. Cryptanalysis based on language theory .....	519
8. Language-theoretic research inspired by cryptology .....	520
9. Research associated with language theory and cryptology .....	521
References .....	521
<b>Index</b> .....	<b>525</b>