

Contents

Introduction	5
1 Elements of Formal Languages	7
1.1 Basic Terms	8
1.2 Formal Systems	10
1.3 Generative Grammars	12
1.4 Chomsky Hierarchy	15
2 Regular Languages and Finite Automata	23
2.1 Regular Grammars	24
2.2 Regular Expressions	29
2.3 Finite Automata as Language Recognizers	34
2.3.1 Synthesis and Analysis of Finite Automata	43
2.3.2 The Word Problem	50
2.4 Properties of Regular Languages	52
2.4.1 Closure Properties	52
2.4.2 Myhill–Nerode theorem	54
2.5 Finite Transducers	55
2.5.1 Mealy Automata	55
2.5.2 Moore Automata	60
2.5.3 Automata Mappings	64
3 Linear Languages	65
3.1 Linear Grammars	66
3.2 One-Turn Pushdown Automata	72
3.3 Closure Properties	72
4 Context-free Languages	75
4.1 Notation Techniques for Programming Languages	76
4.1.1 Backus–Naur Form	76
4.1.2 Syntax Diagram	77
4.2 Chomsky Normal Form	77
4.3 Pumping Lemma for Context-free Languages	83

4.4	Closure Properties	84
4.5	Parsing	87
4.5.1	The CYK Algorithm	87
4.5.2	The Earley Algorithm	89
4.6	Pushdown Automata	92
4.6.1	Acceptance by Empty Stack	95
4.6.2	Equivalence of PDAs and Context-free Grammars	98
4.6.3	Deterministic Pushdown Automata	99
4.6.4	One-turn Pushdown Automata	100
5	Context-Sensitive Languages	103
5.1	Context-Sensitive and Monotone Grammars	104
5.1.1	Normal Forms	105
5.2	Linear Bounded automata	112
5.3	Properties of Context-Sensitive Languages	112
5.3.1	Closure Properties	112
5.3.2	About the Word Problem	116
6	Recursively Enumerable Languages and Turing Machines	119
6.1	Recursive and Recursively Enumerable Languages	120
6.1.1	Closure Properties	122
6.1.2	Normal Forms	123
6.2	Turing Machine, the Universal Language Acceptor	125
6.2.1	Equivalent Definitions	128
6.3	Turing Machine, the Universal Computing Device	129
6.4	Linear Bounded Automata	132
	Literature	137