

# Contents

## Part I Procedural Semantics

<b>1</b>	<b>Algorithmic Theory of Meaning</b> . . . . .	3
	References . . . . .	7
<b>2</b>	<b>Complexity in Linguistics</b> . . . . .	9
2.1	Computational Complexity . . . . .	10
2.2	Syntax . . . . .	11
2.3	Descriptive Syntax . . . . .	13
2.4	Semantics . . . . .	13
2.5	Finite Universes . . . . .	17
	References . . . . .	18

## Part II Simple Quantifiers

<b>3</b>	<b>Basic Generalized Quantifier Theory</b> . . . . .	23
3.1	Two Equivalent Concepts of Generalized Quantifiers . . . . .	25
3.2	Logic Enriched by Generalized Quantifiers . . . . .	27
3.3	Definability of Generalized Quantifiers . . . . .	27
3.4	Semantic Universals . . . . .	30
3.4.1	Boolean Combinations of Quantifiers . . . . .	30
3.4.2	Relativization of Quantifiers . . . . .	31
3.4.3	Domain Independence . . . . .	31
3.4.4	Conservativity . . . . .	32
3.4.5	CE-Quantifiers . . . . .	33
3.5	Monotonicity . . . . .	36
	References . . . . .	39
<b>4</b>	<b>Computing Simple Quantifiers</b> . . . . .	41
4.1	Representation of Finite Models . . . . .	42
4.2	Quantifier Automata . . . . .	44
4.3	Characterization Results . . . . .	46
	References . . . . .	49

<b>5</b>	<b>Cognitive Processing of Quantifiers</b> . . . . .	51
5.1	Processing Time. . . . .	54
5.1.1	Experiment 1 . . . . .	54
5.1.2	Experiment 2 . . . . .	56
5.2	Accuracy. . . . .	57
5.2.1	Probabilistic Semantic Automata . . . . .	57
5.2.2	Modeling the Data . . . . .	59
5.3	Working Memory. . . . .	61
5.3.1	Neurocognitive Evidence. . . . .	61
5.3.2	Concurrent Tasks . . . . .	62
5.3.3	Schizophrenic Patients . . . . .	63
5.3.4	Intelligence . . . . .	65
5.3.5	Executive Resources . . . . .	65
5.4	Corpora Distributions . . . . .	67
5.4.1	Power Laws. . . . .	68
5.5	Monotonicity . . . . .	69
5.5.1	Comparison with Literature . . . . .	74
5.6	Approximate Number System . . . . .	76
5.7	Discussion. . . . .	78
	References . . . . .	80
<b>Part III Complex Quantifiers</b>		
<b>6</b>	<b>Standard Polyadic Lifts</b> . . . . .	87
6.1	Iteration . . . . .	88
6.2	Cumulation . . . . .	90
6.3	Resumption . . . . .	90
6.4	Semantic Automata for Polyadic Quantifiers . . . . .	91
6.4.1	Experimental Direction . . . . .	94
6.5	The Frege Boundary. . . . .	95
6.5.1	Classic Characterization Results . . . . .	96
6.5.2	The Frege Boundary and the Chomsky Hierarchy? . . . . .	99
6.6	Summary . . . . .	100
	References . . . . .	100
<b>7</b>	<b>Complexity of Polyadic Quantifiers</b> . . . . .	101
7.1	Computational Complexity of Quantifiers . . . . .	102
7.2	PTIME Generalized Quantifiers Are Closed Under It, Cum, and Res . . . . .	106
7.3	Branching Quantifiers . . . . .	108
7.3.1	Henkin's Quantifiers . . . . .	109
7.3.2	Proportional Branching Quantifiers . . . . .	109
7.4	Ramsey Quantifiers . . . . .	111
7.4.1	The Branching Reading of Hintikka's Sentence . . . . .	111
7.4.2	Clique Quantifiers . . . . .	112

7.4.3	Proportional Ramsey Quantifiers . . . . .	113
7.4.4	Tractable Ramsey Quantifiers. . . . .	115
7.4.5	Intermediate Ramsey Quantifiers . . . . .	117
7.4.6	Dichotomy Result. . . . .	118
7.5	Summary . . . . .	119
	References . . . . .	120
<b>8</b>	<b>Complexity of Quantified Reciprocals . . . . .</b>	<b>123</b>
8.1	Reciprocal Expressions . . . . .	124
8.1.1	Strong Meaning Hypothesis. . . . .	127
8.2	Reciprocals as Polyadic Quantifiers . . . . .	128
8.2.1	Strong Reciprocal Lift. . . . .	128
8.2.2	Intermediate Reciprocal Lift. . . . .	129
8.2.3	Weak Reciprocal Lift . . . . .	129
8.2.4	The Reciprocal Lifts in Action. . . . .	129
8.3	Complexity of Strong Reciprocity . . . . .	130
8.3.1	Counting Quantifiers in the Antecedent. . . . .	131
8.3.2	Proportional Quantifiers in the Antecedent. . . . .	132
8.3.3	Tractable Strong Reciprocity . . . . .	133
8.4	Intermediate and Weak Lifts . . . . .	134
8.5	A Complexity Perspective on the SMH. . . . .	136
8.6	Empirical Evidence . . . . .	137
8.6.1	Cognitive Difficulty . . . . .	137
8.6.2	Distribution in English . . . . .	139
8.7	Summary . . . . .	140
	References . . . . .	141
<b>9</b>	<b>Branching Quantifiers . . . . .</b>	<b>143</b>
9.1	Hintikka's Thesis . . . . .	144
9.2	Other Hintikka-Like Sentences. . . . .	146
9.3	Theoretical Discussion . . . . .	147
9.3.1	A Remark on Possible Readings . . . . .	147
9.3.2	Hintikka-Like Sentences Are Symmetric . . . . .	148
9.3.3	Inferential Arguments . . . . .	149
9.3.4	Negation Normality . . . . .	150
9.3.5	Complexity Arguments . . . . .	152
9.3.6	Theoretical Conclusions . . . . .	152
9.4	Empirical Evidence . . . . .	153
9.4.1	Experimental Hypotheses . . . . .	153
9.4.2	Experiments. . . . .	154
9.5	Summary . . . . .	159
	References . . . . .	160

**Part IV Collective Quantifiers**

<b>10 Complexity of Collective Quantification</b> . . . . .	165
10.1 Collective Quantifiers . . . . .	166
10.1.1 Collective Readings in Natural Language . . . . .	166
10.1.2 Modeling Collectivity . . . . .	168
10.2 Lifting First-Order Determiners . . . . .	169
10.2.1 The Existential Modifier . . . . .	169
10.2.2 The Neutral Modifier . . . . .	171
10.2.3 The Determiner Fitting Operator . . . . .	171
10.2.4 A Note on Collective Invariance Properties . . . . .	172
10.3 Second-Order Generalized Quantifiers . . . . .	174
10.4 Defining Collective Determiners by SOGQs . . . . .	175
10.5 Definability Theory for SOGQs . . . . .	177
10.5.1 Basic Facts . . . . .	177
10.5.2 Characterization Result . . . . .	179
10.6 Collective Majority . . . . .	180
10.6.1 An Undefinability Result for the SOGQ 'MOST' . . . . .	180
10.6.2 Consequences of Undefinability . . . . .	181
10.7 Summary . . . . .	183
References . . . . .	184

**Part V Perspectives and Conclusions**

<b>11 Conclusions</b> . . . . .	187
References . . . . .	189
<b>Appendix A: Mathematical Machinery</b> . . . . .	191
<b>Index</b> . . . . .	209