## **Contents**

	Preface ix				
	Notation xiii				
	Notation Am				
1	Introduction 1				
1					
	1.1 Natural Language Processing and Its Neighbors 1				
	1.2 Three Themes in Natural Language Processing 5				
	LEARNING 11				
2	Linear Text Classification 13				
	2.1 The Bag of Words 13				
	2.2 Naïve Bayes 17				
	2.3 Discriminative Learning 24				
	2.4 Loss Functions and Large-Margin Classification 28				
	2.5 Logistic Regression 34				
	2.6 Optimization 37				
	2.7 *Additional Topics in Classification 40				
	2.8 Summary of Learning Algorithms 42				
	7				
3	Nonlinear Classification 47				
	3.1 Feedforward Neural Networks 48				
	3.2 Designing Neural Networks 50				
	3.3 Learning Neural Networks 53				
	3.4 Convolutional Neural Networks 61				
	or convenient resident records				
4	Linguistic Applications of Classification 67				
	4.1 Sentiment and Opinion Analysis 67				
	4.2 Word Sense Disambiguation 71				
	4.3 Design Decisions for Text Classification 74				
	4.4 Evaluating Classifiers 78				
	4.5 Building Datasets 85				
	T.5 Dunding Datasets 05				

Contents

	Learn	ning without Supervision 91
	5.1	Unsupervised Learning 91
	5.2	Applications of Expectation-Maximization 99
	5.3	Semi-Supervised Learning 102
		Domain Adaptation 105
	5.5	*Other Approaches to Learning with Latent Variables 10
	SEQ	JENCES AND TREES 117
	Lang	uage Models 119
		N-Gram Language Models 120
	6.2	Smoothing and Discounting 122
	6.3	Recurrent Neural Network Language Models 127
		Evaluating Language Models 132
		Out-of-Vocabulary Words 134
	0.5	Out-01-vocabulary violas 131
	Comm	ence Labeling 137
	7.1	Sequence Labeling as Classification 137
		Sequence Labeling as Structure Prediction 139
	7.2	The Viterbi Algorithm 140
	7.3	Hidden Markov Models 145
	7.4	Discriminative Sequence Labeling with Features 149
	7.5	
	7.6	Neural Sequence Labeling 158 *Unsupervised Sequence Labeling 161
	7.7	*Unsupervised Sequence Labeling 101
	App	lications of Sequence Labeling 167
	8.1	Part-of-Speech Tagging 167
	8.2	Morphosyntactic Attributes 173
	8.3	Named Entity Recognition 175
	8.4	Tokenization 176
	8.5	Code Switching 177
	8.6	Dialogue Acts 178
	Forn	nal Language Theory 183
	9.1	Regular Languages 184
	9.2	Context-Free Languages 198
	9.3	*Mildly Context-Sensitive Languages 209
	7.5	Whiting Context-Sensitive Languages 209
0	Con	text-Free Parsing 215
-		Deterministic Bottom-Up Parsing 216
		Ambiguity 219
		Weighted Context-Free Grammars 222
		Learning Weighted Context-Free Grammars 227
		Grammar Refinement 231
		Beyond Context-Free Parsing 238
	10.0	Deyond Context-Free Faising 230

i

11	Dependency Parsing 243	
	11.1 Dependency Grammar 243	
	11.2 Graph-Based Dependency Parsing 248	
	11.3 Transition-Based Dependency Parsing 253	
	11.4 Applications 261	mil entit
Ш	MEANING 267	
12	Logical Semantics 269	
	12.1 Meaning and Denotation 270	
	12.2 Logical Representations of Meaning 270	
	12.3 Semantic Parsing and the Lambda Calculus 274	
	12.4 Learning Semantic Parsers 280	
13	Predicate-Argument Semantics 289	
	13.1 Semantic Roles 291	
	13.2 Semantic Role Labeling 295	
	13.3 Abstract Meaning Representation 302	
14	Distributional and Distributed Semantics 309	
	14.1 The Distributional Hypothesis 309	
	14.2 Design Decisions for Word Representations 311	
	14.3 Latent Semantic Analysis 313	
	14.4 Brown Clusters 315	
	14.5 Neural Word Embeddings 317	
	14.6 Evaluating Word Embeddings 322	
	- · · · - · · · · · · · · · · · · · · ·	324
	14.8 Distributed Representations of Multiword Units 327	
15	Reference Resolution 333	
	15.1 Forms of Referring Expressions 334	
	15.2 Algorithms for Coreference Resolution 339	
	15.3 Representations for Coreference Resolution 348	
	15.4 Evaluating Coreference Resolution 353	
16		
10	16.1 Segments 357	
	16.2 P-1-ti 262	
IV	APPLICATIONS 377	
mod	leing and estimation, see the esset at (2013); for a more advan-	
17	Information Extraction 379	

17.1 Entities 381 17.2 Relations 387

	<ul><li>17.3 Events 395</li><li>17.4 Hedges, Denials, and Hypotheticals 397</li><li>17.5 Question Answering and Machine Reading</li></ul>	399	y Parçe deserv Russe i for-its	
18	Machine Translation 405			
	18.1 Machine Translation as a Task 405			5.8
	18.2 Statistical Machine Translation 410			
	18.3 Neural Machine Translation 415			
	18.4 Decoding 423			

424

## 19 Text Generation 431

19.1 Data-to-Text Generation 43119.2 Text-to-Text Generation 437

18.5 Training toward the Evaluation Metric

19.3 Dialogue 440

## Appendix A: Probability 447

A.1 Probabilities of Event Combinations 447

A.2 Conditional Probability and Bayes' Rule 449

A.3 Independence 451

A.4 Random Variables 451

A.5 Expectations 452

A.6 Modeling and Estimation 453

## Appendix B: Numerical Optimization 455

B.1 Gradient Descent 456

B.2 Constrained Optimization 456

B.3 Example: Passive-Aggressive Online Learning 457

Bibliography 459 Index 509