# Contents

Acknowledgments  xi  
Setting the Stage  xiii  

1   Our Vision of Linguistics for the Age of AI  1  
1.1 What Is Linguistics for the Age of AI?  1  
1.2 What Is So Hard about Language?  2  
1.3 Relevant Aspects of the History of Natural Language Processing  4  
1.4 The Four Pillars of Linguistics for the Age of AI  8  
1.4.1 Pillar 1: Language Processing Capabilities Are Developed within an Integrated, Comprehensive Agent Architecture  9  
1.4.2 Pillar 2: Modeling Is Human-Inspired in Service of Explanatory AI and Actionability  13  
1.4.3 Pillar 3: Insights Are Gleaned from Linguistic Scholarship and, in Turn, Contribute to That Scholarship  15  
1.4.3.1 Theoretical syntax  16  
1.4.3.2 Psycholinguistics  17  
1.4.3.3 Semantics  17  
1.4.3.4 Pragmatics  20  
1.4.3.5 Cognitive linguistics  22  
1.4.3.6 Language evolution  23  
1.4.4 Pillar 4: All Available Heuristic Evidence Is Incorporated When Extracting and Representing the Meaning of Language Inputs  25  
1.4.4.1 Handcrafted knowledge bases for NLP  25  
1.4.4.2 Using results from empirical NLP  27  
1.5 The Goals of This Book  29  
1.6 Deep Dives  31  
1.6.1 The Phenomenological Stance  31  
1.6.2 Learning  33  
1.6.3 NLP and NLU: It’s Not Either-Or  33  
1.6.4 Cognitive Systems: A Bird’s-Eye View  36  
1.6.5 Explanation in AI  38  
1.6.6 Incrementality in the History of NLP  40  
1.6.7 Why Machine-Readable, Human-Oriented Resources Are Not Enough  42  
1.6.8 Coreference in the Knowledge-Lean Paradigm  44
1.6.9 Dialog Act Detection  46  
1.6.10 Grounding  48  
1.6.11 More on Empirical NLP  50  
1.6.12 Manual Corpus Annotation: Its Contributions, Complexities, and Limitations  52  
1.7 Further Exploration  55  

2 A Brief Overview of Natural Language Understanding by LEIAs  59  
2.1 Theory, Methodology, and Strategy  59  
2.2 A Warm-Up Example  64  
2.3 Knowledge Bases  68  
2.3.1 The Ontology  69  
2.3.2 The Lexicon  73  
2.3.3 Episodic Memory  77  
2.4 Incrementality  77  
2.5 The Stages of NLU and Associated Decision-Making  79  
2.5.1 Decision-Making after Pre-Semantic Analysis  84  
2.5.2 Decision-Making after Pre-Semantic Integration  85  
2.5.3 Decision-Making after Basic Semantic Analysis  85  
2.5.4 Decision-Making after Basic Coreference Resolution  86  
2.5.5 Decision-Making after Extended Semantic Analysis  87  
2.5.6 Decision-Making after Situational Reasoning  87  
2.6 Microtheories  88  
2.7 “Golden” Text Meaning Representations  93  
2.8 Deep Dives  94  
2.8.1 The LEIA Knowledge Representation Language versus Other Options  94  
2.8.2 Issues of Ontology  97  
2.8.3 Issues of Lexicon  102  
2.8.4 Paraphrase in Natural Language and the Ontological Metalanguage  111  
2.9 Further Exploration  115  

3 Pre-Semantic Analysis and Integration  117  
3.1 Pre-Semantic Analysis  117  
3.2 Pre-Semantic Integration  118  
3.2.1 Syntactic Mapping: Basic Strategy  118  
3.2.2 Recovering from Production Errors  124  
3.2.3 Learning New Words and Word Senses  124  
3.2.4 Optimizing Imperfect Syn-Maps  126  
3.2.5 Reambiguating Certain Syntactic Decisions  128  
3.2.6 Handling Known Types of Parsing Errors  129  
3.2.7 From Recovery Algorithm to Engineering Strategy  131  
3.3 Managing Combinatorial Complexity  134  
3.4 Taking Stock  138  
3.5 Further Exploration  139
## 4 Basic Semantic Analysis

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1 Modification</td>
<td>143</td>
</tr>
<tr>
<td>4.1.1 Recorded Property Values</td>
<td>143</td>
</tr>
<tr>
<td>4.1.2 Dynamically Computed Values for Scalar Attributes</td>
<td>145</td>
</tr>
<tr>
<td>4.1.3 Modifiers Explained Using Combinations of Concepts</td>
<td>149</td>
</tr>
<tr>
<td>4.1.4 Dynamically Computed Values for Relative Text Components</td>
<td>150</td>
</tr>
<tr>
<td>4.1.5 Quantification and Sets</td>
<td>152</td>
</tr>
<tr>
<td>4.1.6 Indirect Modification</td>
<td>158</td>
</tr>
<tr>
<td>4.1.7 Recap of Modification</td>
<td>159</td>
</tr>
<tr>
<td>4.2 Proposition-Level Semantic Enhancements</td>
<td>160</td>
</tr>
<tr>
<td>4.2.1 Modality</td>
<td>160</td>
</tr>
<tr>
<td>4.2.2 Aspect</td>
<td>162</td>
</tr>
<tr>
<td>4.2.3 Non-Modal, Non-Aspectual Matrix Verbs</td>
<td>163</td>
</tr>
<tr>
<td>4.2.4 Questions</td>
<td>163</td>
</tr>
<tr>
<td>4.2.5 Commands</td>
<td>164</td>
</tr>
<tr>
<td>4.2.6 Recap of Proposition-Level Semantic Enhancements</td>
<td>165</td>
</tr>
<tr>
<td>4.3 Multicomponent Entities Recorded as Lexical Constructions</td>
<td>165</td>
</tr>
<tr>
<td>4.3.1 Semantically Null Components of Constructions</td>
<td>169</td>
</tr>
<tr>
<td>4.3.2 Typical Uses of Null-Semming</td>
<td>169</td>
</tr>
<tr>
<td>4.3.3 Modification of Null-Semmed Constituents</td>
<td>170</td>
</tr>
<tr>
<td>4.3.4 Utterance-Level Constructions</td>
<td>172</td>
</tr>
<tr>
<td>4.3.5 Additional Knowledge Representation Requirements</td>
<td>173</td>
</tr>
<tr>
<td>4.3.6 Recap of Constructions</td>
<td>175</td>
</tr>
<tr>
<td>4.4 Indirect Speech Acts, Lexicalized</td>
<td>175</td>
</tr>
<tr>
<td>4.5 Nominal Compounds, Lexicalized</td>
<td>176</td>
</tr>
<tr>
<td>4.6 Metaphors, Lexicalized</td>
<td>180</td>
</tr>
<tr>
<td>4.6.1 Past Work on Metaphor</td>
<td>180</td>
</tr>
<tr>
<td>4.6.2 Conventional Metaphors</td>
<td>182</td>
</tr>
<tr>
<td>4.6.3 Copular Metaphors</td>
<td>184</td>
</tr>
<tr>
<td>4.6.4 Recap of Metaphors</td>
<td>185</td>
</tr>
<tr>
<td>4.7 Metonymies, Lexicalized</td>
<td>185</td>
</tr>
<tr>
<td>4.8 Ellipsis</td>
<td>186</td>
</tr>
<tr>
<td>4.8.1 Verb Phrase Ellipsis</td>
<td>186</td>
</tr>
<tr>
<td>4.8.2 Verb Phrase Ellipsis Constructions</td>
<td>187</td>
</tr>
<tr>
<td>4.8.3 Event Ellipsis: Aspectual+NPOBJECT</td>
<td>189</td>
</tr>
<tr>
<td>4.8.4 Event Ellipsis: Lexically Idiosyncratic</td>
<td>189</td>
</tr>
<tr>
<td>4.8.5 Event Ellipsis: Conditions of Change</td>
<td>190</td>
</tr>
<tr>
<td>4.8.6 Gapping</td>
<td>192</td>
</tr>
<tr>
<td>4.8.7 Head Noun Ellipsis</td>
<td>192</td>
</tr>
<tr>
<td>4.8.8 Recap of Ellipsis</td>
<td>192</td>
</tr>
<tr>
<td>4.9 Fragmentary Utterances</td>
<td>193</td>
</tr>
<tr>
<td>4.10 Nonselection of Optional Direct Objects</td>
<td>193</td>
</tr>
<tr>
<td>4.11 Unknown Words</td>
<td>193</td>
</tr>
<tr>
<td>4.11.1 Completely Unknown Words</td>
<td>194</td>
</tr>
<tr>
<td>4.11.2 Known Words in a Different Part of Speech</td>
<td>196</td>
</tr>
<tr>
<td>4.12 Wrapping Up Basic Semantic Analysis</td>
<td>198</td>
</tr>
<tr>
<td>4.13 Further Exploration</td>
<td>199</td>
</tr>
</tbody>
</table>
5 Basic Coreference Resolution 201

5.1 A Nontechnical Introduction to Reference Resolution 201
5.1.1 Definitions 202
5.1.2 An Example-Based Introduction 203
5.1.3 A Dozen Challenges 205
5.1.4 Special Considerations about Ellipsis 210
5.1.5 Wrapping Up the Introduction 211

5.2 Personal Pronouns 212
5.2.1 Resolving Personal Pronouns Using an Externally Developed Engine 213
5.2.2 Resolving Personal Pronouns Using Lexico-Syntactic Constructions 213
5.2.3 Semantically Vetting Hypothesized Pronominal Coreferences 215
5.2.4 Recap of Resolving Personal Pronouns during Basic Coreference Resolution 217

5.3 Pronominal Broad Referring Expressions 217
5.3.1 Resolving Pronominal Broad RefExes Using Constructions 218
5.3.2 Resolving Pronominal Broad RefExes in Syntactically Simple Contexts 219
5.3.3 Resolving Pronominal Broad RefExes Indicating Things That Must Stop 221
5.3.4 Resolving Pronominal Broad RefExes Using the Meaning of Predicate Nominals 223
5.3.5 Resolving Pronominal Broad RefExes Using Selectional Constraints 224
5.3.6 Recap of Resolving Pronominal Broad RefExes 226

5.4 Definite Descriptions 227
5.4.1 Definite Description Processing So Far: A Refresher 227
5.4.2 Definite Description Processing at This Stage 228
5.4.2.1 Rejecting coreference links with property value conflicts 228
5.4.2.2 Running reference-resolution meaning procedures listed in lexical senses 228
5.4.2.3 Establishing that a sponsor is not needed 229
5.4.2.4 Identifying bridging references 229
5.4.2.5 Creating sets as sponsors for plural definite descriptions 231
5.4.2.6 Identifying sponsors that are hypernyms or hyponyms of definite descriptions 232
5.4.3 Definite Description Processing Awaiting Situational Reasoning 233
5.4.4 Recap of Definite Description Processing at This Stage 233

5.5 Anaphoric Event Coreference 234
5.5.1 What is the Verbal/EVENT Head of the Sponsor? 235
5.5.2 Is There Instance or Type Coreference between the Events? 237
5.5.3 Is There Instance or Type Coreference between Objects in the VPs? 238
5.5.4 Should Adjuncts in the Sponsor Clause Be Included in, or Excluded from, the Resolution? 239
5.5.5 Should Modal and Other Scopers Be Included in, or Excluded from, the Resolution? 239
5.5.6 Recap of Anaphoric Event Coreference 240

5.6 Other Elided and Underspecified Events 241
5.7 Coreferential Events Expressed by Verbs 242
5.8 Further Exploration 244
6 Extended Semantic Analysis 247

6.1 Addressing Residual Ambiguities 248
   6.1.1 The Objects Are Linked by a Primitive Property 248
   6.1.2 The Objects Are Case Role Fillers of the Same Event 249
   6.1.3 The Objects Are Linked by an Ontologically Decomposable Property 249
   6.1.4 The Objects Are Clustered Using a Vague Property 251
   6.1.5 The Objects Are Linked by a Short Ontological Path That Is Computed Dynamically 252
   6.1.6 Reasoning by Analogy Using the TMR Repository 252
   6.1.7 Recap of Methods to Address Residual Ambiguity 254

6.2 Addressing Incongruities 254
   6.2.1 Metonymy 254
   6.2.2 Preposition Swapping 256
   6.2.3 Idiomatic Creativity 257
     6.2.3.1 Detecting creative idiom use 258
     6.2.3.2 Semantically analyzing creative idiom use 261
   6.2.4 Indirect Modification Computed Dynamically 262
   6.2.5 Recap of Treatable Types of Incongruities 264

6.3 Addressing Underspecification 264
   6.3.1 Nominal Compounds Not Covered by Lexical Senses 264
   6.3.2 Missing Values in Events of Change 270
   6.3.3 Ungrounded and Underspecified Comparisons 270
   6.3.4 Recap of Treatable Types of Underspecification 279

6.4 Incorporating Fragments into the Discourse Meaning 279
6.5 Further Exploration 284

7 Situational Reasoning 285

7.1 The OntoAgent Cognitive Architecture 286
7.2 Fractured Syntax 287
7.3 Residual Lexical Ambiguity: Domain-Based Preferences 290
7.4 Residual Speech Act Ambiguity 290
7.5 Underspecified Known Expressions 291
7.6 Underspecified Unknown Word Analysis 291
7.7 Situational Reference 292
   7.7.1 Vetting Previously Identified Linguistic Sponsors for RefExes 293
   7.7.2 Identifying Sponsors for Remaining RefExes 296
   7.7.3 Anchoring the TMRs Associated with All RefExes in Memory 297
7.8 Residual Hidden Meanings 297
7.9 Learning by Reading 299

8 Agent Applications: The Rationale for Deep, Integrated NLU 301

8.1 The Maryland Virtual Patient System 301
   8.1.1 Modeling Physiology 304
   8.1.2 An Example: The Disease Model for GERD 306
   8.1.3 Modeling Cognition 311
     8.1.3.1 Learning new words and concepts through language interaction 312
     8.1.3.2 Making decisions about action 313
8.1.4 An Example System Run  317
8.1.5 Visualizing Disease Models  320
  8.1.5.1 Authoring instances of virtual patients  320
  8.1.5.2 The knowledge about tests and interventions  321
  8.1.5.3 Traces of system functioning  324
8.1.6 To What Extent Can MVP-Style Models Be Learned from Texts?  324
8.1.7 To What Extent Can Cognitive Models Be Automatically Elicited from People?  328
8.2 A Clinician’s Assistant for Flagging Cognitive Biases  331
  8.2.1 Memory Support for Bias Avoidance  333
  8.2.2 Detecting and Flagging Clinician Biases  335
  8.2.3 Detecting and Flagging Patient Biases  339
8.3 LEIAs in Robotics  343
8.4 The Take-Home Message about Agent Applications  347

9 Measuring Progress  349
  9.1 Evaluation Options—and Why the Standard Ones Don’t Fit  350
  9.2 Five Component-Level Evaluation Experiments  354
    9.2.1 Nominal Compounding  355
    9.2.2 Multiword Expressions  358
    9.2.3 Lexical Disambiguation and the Establishment of the Semantic Dependency Structure  362
    9.2.4 Difficult Referring Expressions  365
    9.2.5 Verb Phrase Ellipsis  366
  9.3 Holistic Evaluations  369
  9.4 Final Thoughts  381

Epilogue  383
Notes  385
References  397
Index  415