## Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foreword</td>
<td>xxiii</td>
</tr>
<tr>
<td>Introduction</td>
<td>xxv</td>
</tr>
<tr>
<td><strong>Part One</strong></td>
<td>1</td>
</tr>
<tr>
<td><strong>Chapter 1</strong></td>
<td>3</td>
</tr>
<tr>
<td>Preparing to Program a Semantic Web of Data</td>
<td></td>
</tr>
<tr>
<td>Defining the Semantic Web</td>
<td>4</td>
</tr>
<tr>
<td>Identifying the Major Programming Components</td>
<td>10</td>
</tr>
<tr>
<td>Determining Impacts on Programming</td>
<td>13</td>
</tr>
<tr>
<td>Establishing a Web Data–Centric Perspective</td>
<td>13</td>
</tr>
<tr>
<td>Expressing Semantic Data</td>
<td>14</td>
</tr>
<tr>
<td>Sharing Data</td>
<td>16</td>
</tr>
<tr>
<td>Making Data Dynamic and Flexible</td>
<td>18</td>
</tr>
<tr>
<td>Avoiding the Roadblocks, Myths, and Hype</td>
<td>19</td>
</tr>
<tr>
<td>Semantic Web Roadblocks</td>
<td>19</td>
</tr>
<tr>
<td>Semantic Web Myths</td>
<td>21</td>
</tr>
<tr>
<td>Semantic Web Hype</td>
<td>22</td>
</tr>
<tr>
<td>Understanding Semantic Web Origins</td>
<td>23</td>
</tr>
<tr>
<td>Exploring Semantic Web Examples</td>
<td>26</td>
</tr>
<tr>
<td>Semantic Wikis (<a href="http://semantic-mediawiki.org">semantic-mediawiki.org</a>)</td>
<td>26</td>
</tr>
<tr>
<td>Twine (<a href="http://www.twine.com">www.twine.com</a>)</td>
<td>27</td>
</tr>
<tr>
<td>The FOAF Project (<a href="http://www.foaf-project.org">www.foaf-project.org</a>)</td>
<td>28</td>
</tr>
<tr>
<td>RDFa and Microformats</td>
<td>30</td>
</tr>
<tr>
<td>Semantic Query Endpoint (<a href="http://dbpedia.org/sparql">dbpedia.org/sparql</a>)</td>
<td>32</td>
</tr>
<tr>
<td>Semantic Search (<a href="http://www.trueknowledge.com">www.trueknowledge.com</a>)</td>
<td>32</td>
</tr>
<tr>
<td>Summary and Onward</td>
<td>34</td>
</tr>
<tr>
<td>Notes</td>
<td>34</td>
</tr>
</tbody>
</table>
Chapter 2  Hello Semantic Web World  35
  Setting Up Your Semantic Web Development Environment  36
  Programming the Hello Semantic Web World Application  38
  Summary  58

Part Two  Foundations of Semantic Web Programming  61

Chapter 3  Modeling Information  63
  Modeling Information in Software  64
    Sharing Information: Syntax and Semantics  65
    Serialized Objects  66
    Relational Databases  66
    Extensible Markup Language (XML)  66
    Metadata and Data in Information Sharing  67
  The Semantic Web Information Model: The Resource Description Framework (RDF)  68
    Nodes: Resources and Literals  69
    Edges: Predicates  71
  Exchanging Information with RDF  72
    Statements as Points  73
    RDF Serializations  74
      RDF/XML  74
      Terse RDF Triple Language (Turtle)  78
      N-Triples  81
      Quick Hack  82
    More RDF  84
      Blank Nodes  84
      Reification  88
      RDF Organizational Constructs  88
  Summary  91

Chapter 4  Incorporating Semantics  93
  Semantics on the Web  94
    Motivating Factors  94
      Understanding the World Wide Web  95
      Knowledge Domain Integration  97
    Expressing Semantics in RDF  98
      Vocabularies, Taxonomies, and Ontologies  99
      A Vocabulary Language for RDF  100
      An Ontology Language for the Web  101
  Introduction to Ontologies  102
    Distributed Knowledge  102
    Open World Assumption  103
    No Unique Names Assumption  104
    Overview of Ontology Elements  104
Contents

Ontology Header 105
Classes and Individuals 105
Properties 106
Annotations 106
Data types 106
Elements of an Ontology 107
OWL 2 Typing 107
Ontology Header 108
Annotations 109
Basic Classification 110
   Classes and Individuals 110
   rdfs:SubClassOf 111
   Instance versus Subclass 112
   owl:Thing and owl:Nothing 113
Defining and Using Properties 113
Property Domain and Range 114
Describing Properties 115
   rdfs:subPropertyOf 115
   Top and Bottom Properties 116
Inverse Properties 116
Disjoint Properties 117
Property Chains 118
Symmetric, Reflexive, and Transitive Properties 119
Functional and Inverse Functional Properties 120
Keys 121
Datatypes 122
   Data type Restrictions 122
   Defining Datatypes in Terms of Other Datatypes 124
Negative Property Assertions 126
Property Restrictions 127
   Value Restrictions 127
Cardinality Restrictions 130
   Qualified Cardinality Restrictions 132
Advanced Class Description 134
   Enumerating Class Membership 134
   Set Operators 134
Disjoint Classes 136
Equivalence in OWL 137
   Equivalence among Individuals 138
   Equivalence among Classes and Properties 139
Summary 139

Chapter 5  Modeling Knowledge in the Real World 141
Exploring the Components of the Semantic Web 141
Semantic Web Frameworks 143
**Contents**

Storing and Retrieving RDF  
RDF Store Implementations  144  
Retrieving Information in a Knowledgebase  146  
Realizing the Semantics of OWL  
Understanding Forward Chaining Inference  148  
Understanding Backward Chaining Inference  152  
Choosing the Right Inference Method  153  
Common Frameworks and Components  153  
RDF Store Implementations  154  
Retrieval Components  156  
Reasoning Engines  156  
Knowledgebase Performance  157  
Exploring the Profiles of OWL  158  
OWL Full and OWL DL  159  
The Profiles of OWL  
OWL EL  160  
OWL QL  161  
OWL RL  162  
Demonstrating OWL Inference  163  
The Ontology  163  
The Example Application  165  
The Results  169  
Performing No Inference  169  
Performing RDFS Inference  170  
Performing OWL Inference  171  
Working with Ontologies  172  
Decoupling the Knowledge Model from the Application  173  
Sharing across Domain and Application Boundaries  174  
What Is a Foundational Ontology?  175  
Common Foundational Ontologies  177  
BFO  177  
Cyc and OpenCyc  178  
DOLCE  179  
SUMO  179  
Dublin Core Metadata Initiative  179  
FOAF  180  
GeoRSS and OWL-Time  180  
Finding Ontologies to Reuse or Extend  181  
Choosing the Right Foundational Ontologies  183  
Summary  184  

**Chapter 6**  **Discovering Information**  185  
Navigating the Semantic Web  186  
Searching the Semantic Web  190
Querying the Semantic Web 192
   Quickstart with SPARQL 192
   Four Foundational Query Forms 196
   SELECT Essentials 197
   RDF Datasets, FROM and FROM NAMED 202
   Query Modifiers 208
      DISTINCT 209
      REDUCED 210
      ORDER BY 210
   Data Streaming with OFFSET and LIMIT 211
   Flexible Querying with FILTER and OPTIONAL 213
      FILTER 213
      OPTIONAL 215
      UNION 219
   CONSTRUCT Essentials 222
   DESCRIBE Essentials 224
   ASK Essentials 225
   SPARQL Entailment 226
   Unsupported Functionality 228
      Data Modification 228
      Subqueries 228
      Aggregation 228
   Summary 229

Chapter 7 Adding Rules 231
   What Are Rules? 232
   Reasons for Rules 232
      No Support for Property Composition 232
      Use of Built-ins 232
      Ontological Mediation 233
      Limiting Assumptions 233
   Rule Languages 233
   SWRL Essentials 234
      The Abstract Syntax 235
      The XML Concrete Syntax 237
         var 238
         imp 239
         _rlab 239
         _body 239
         _head 240
         classAtom 240
         datarangeAtom 241
         individualPropertyAtom 241
         datavaluedPropertyAtom 242
         sameIndividualAtom 242
Contents

differentIndividualsAtom 243
builtinAtom 243
The RDF Concrete Syntax 243
Built-ins 244
Examples 244
DL-Safe Rules 245
Ontological Mediation 252
Mapping Friends without Upsetting Any of Them 253
The Power of Rules 256
Jena Rules 257
Rule Interchange Format 259
Delving into the Details 260
The Future of RIF 260
Summary 261

Part Three Building Semantic Web Applications 263

Chapter 8 Applying a Programming Framework 265
Framing the Semantic Web 266
The Jena Semantic Web Framework 269
Defining Jena Programming Concepts 269
Programming with Jena 273
Establishing the Jena Development Environment 276
Establishing the Knowledgebase: Setting Up the Model 276
Populating the Model with Semantic Web Data 279
Combining Semantic Web Data 282
Interrogating Semantic Web Data 283
Reasoning across Semantic Web Data 285
Exporting Semantic Web Data 290
Deallocating Semantic Web Data Resources 290
Managing Semantic Web Data 291
Getting Information Regarding Your Semantic Web Data 291
Generating Events Based on Semantic Web Data 292
Dealing with Concurrency and Your Semantic Web Data 293
Customizing the Jena Framework 295
Serializing Semantic Web Data 297
Common App Overview: FriendTracker 298
Summary 299

Chapter 9 Combining Information 301
Combining Information 303
Representing Information 303
Translating between Representations 304
Addressing the Challenges of Translation 305
## Contents

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maintaining Fidelity</td>
<td>305</td>
</tr>
<tr>
<td></td>
<td>Tracking Provenance Information</td>
<td>305</td>
</tr>
<tr>
<td></td>
<td>Reversing the Process</td>
<td>306</td>
</tr>
<tr>
<td></td>
<td>Handling Varying Data</td>
<td>306</td>
</tr>
<tr>
<td></td>
<td>Managing Data Volume</td>
<td>306</td>
</tr>
<tr>
<td></td>
<td>Introducing the FriendTracker Data Sources</td>
<td>307</td>
</tr>
<tr>
<td></td>
<td>Facebook XML Web Service</td>
<td>307</td>
</tr>
<tr>
<td></td>
<td>Jabber Java Client</td>
<td>308</td>
</tr>
<tr>
<td></td>
<td>Upcoming.org XML Web Service</td>
<td>308</td>
</tr>
<tr>
<td></td>
<td>WordPress Relational Database</td>
<td>308</td>
</tr>
<tr>
<td></td>
<td>Exposing XML-Based Web Services as RDF</td>
<td>309</td>
</tr>
<tr>
<td></td>
<td>Introducing the Weather.gov XML Feed</td>
<td>310</td>
</tr>
<tr>
<td></td>
<td>Exposing XML Using XSL Transformations</td>
<td>311</td>
</tr>
<tr>
<td></td>
<td>Traversing XML Documents with XPath</td>
<td>313</td>
</tr>
<tr>
<td></td>
<td>Applying XSLT to a Simple Example</td>
<td>315</td>
</tr>
<tr>
<td></td>
<td>Processing XML and XSLT Programmatically</td>
<td>319</td>
</tr>
<tr>
<td></td>
<td>Applying XSLT to the Facebook Data Source</td>
<td>322</td>
</tr>
<tr>
<td></td>
<td>Weighing the Benefits and the Costs of XSLT</td>
<td>326</td>
</tr>
<tr>
<td></td>
<td>Exposing XML Using XML Bindings and Velocity</td>
<td>328</td>
</tr>
<tr>
<td></td>
<td>Generating Java Bindings for XML Data</td>
<td>329</td>
</tr>
<tr>
<td></td>
<td>Unmarshalling XML Data into Java</td>
<td>331</td>
</tr>
<tr>
<td></td>
<td>Introducing the Velocity Template Engine</td>
<td>333</td>
</tr>
<tr>
<td></td>
<td>Generating RDF with Velocity</td>
<td>336</td>
</tr>
<tr>
<td></td>
<td>Weighing the Benefits and the Costs</td>
<td>336</td>
</tr>
<tr>
<td></td>
<td>Exposing Relational Databases as RDF</td>
<td>337</td>
</tr>
<tr>
<td></td>
<td>Exposing a WordPress Blog Using D2RQ</td>
<td>338</td>
</tr>
<tr>
<td></td>
<td>Creating D2RQ Mappings for the WordPress Database</td>
<td>339</td>
</tr>
<tr>
<td></td>
<td>Wrapping the D2RQ Instance in a Jena Model</td>
<td>341</td>
</tr>
<tr>
<td></td>
<td>Querying the D2RQ Exposed WordPress Database</td>
<td>342</td>
</tr>
<tr>
<td></td>
<td>Weighing the Benefits and the Costs of D2RQ</td>
<td>345</td>
</tr>
<tr>
<td></td>
<td>Exposing Other Sources of Data</td>
<td>346</td>
</tr>
<tr>
<td></td>
<td>Exposing Jabber with a Custom Streaming RDF Writer</td>
<td>346</td>
</tr>
<tr>
<td></td>
<td>Exposing Java Objects Using Reflection</td>
<td>352</td>
</tr>
<tr>
<td></td>
<td>Applying the RDF Generator to the Weather.gov XML Feed</td>
<td>356</td>
</tr>
<tr>
<td></td>
<td>Applying the RDF Generator to the Upcoming.org XML Feed</td>
<td>358</td>
</tr>
<tr>
<td></td>
<td>Summary</td>
<td>359</td>
</tr>
</tbody>
</table>

### Chapter 10 Aligning Information

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Data Source, Domain, and Application Ontologies</td>
<td>361</td>
</tr>
<tr>
<td></td>
<td>Aligning Ontologies</td>
<td>362</td>
</tr>
<tr>
<td></td>
<td>Ontology Constructs</td>
<td>363</td>
</tr>
<tr>
<td></td>
<td>Translation via Rules</td>
<td>365</td>
</tr>
</tbody>
</table>
xx Contents

Explicit Translation 365
Ad Hoc Approaches to Translation 366
FriendTracker 366
Aligning Ontologies with OWL and SWRL 372
Aligning Ontologies with XSLT 376
Aligning Ontologies with Code 381
Aligning Simple Ontologies with RDFS 382
Record Linkage 385
Summary 388

Chapter 11 Sharing Information 389

Microformats 390
eRDF 392
RDFa 395
Supported Attributes 396
xmlns 396
rel 396
rev 398
content 398
href 399
src 399
about 399
property 399
resource 400
datatype 401
typeof 401
Blank Nodes 402
Language Support 403
Tools and Frameworks 404
RDF Transformational Tools 404
SPARQL Endpoints 404
Joseki Installation and Operation 405
xOperator 408
Installation and Operation 409
Example Query 410
FriendTracker in RDFa 411
Summary 417

Part Four Expanding Semantic Web Programming 419

Chapter 12 Developing and Using Semantic Services 421

Background 422
Discovery 424
Invocation 424
Negotiation 425
Contents

Error Handling 425
Monitoring 425
Composition 425
Implementing Semantic Services 426
Semantic Markup for Web Services 427
  ServiceProfile 428
  ServiceModel 428
  ServiceGrounding 428
Web Service Modeling Ontology 429
Semantic Annotations for WSDL 432
  SAWSDL Example 433
  SAWSDL Tools 434
Summary 435

Chapter 13 Managing Space and Time 437
  Space and Time in Software 437
    Spatial Information 438
    Temporal Information 440
  Representing Spatiotemporal Data on the Semantic Web 441
  Spatial and Temporal Software with Jena 450
    Working with Spatial Data 452
    Example: Spatial Queries 453
      Framing the Problem 453
      Approach and Rationale 454
      Components 454
    Example: Transaction Time–Bounded Queries 461
      Framing the Problem 461
      Approach and Rationale 462
      Components 462
  Summary 465
  Notes 465

Chapter 14 Semantic Web Patterns and Best Practices 467
  Aggregating Disparate Data Sources 468
    Exposing Data Sources as RDF 469
    Bringing Data into the Domain Knowledge Model 470
    Storing Information in the Knowledgebase 472
    Initiating the Flow of Data 472
  Annotating Unstructured Data 472
    Annotation Management 474
    Ontology Management 475
    Unstructured Data Sources and the Client Application 476
  Coordinating Semantic Services 478
  Applying Semantic Web Best Practices 480