

contents

preface xiii
acknowledgments xv
about this book xviii

1 A new paradigm for Big Data 1

- 1.1 How this book is structured 2
- 1.2 Scaling with a traditional database 3
 - Scaling with a queue* 3 ▪ *Scaling by sharding the database* 4
 - Fault-tolerance issues begin* 5 ▪ *Corruption issues* 5 ▪ *What went wrong?* 5 ▪ *How will Big Data techniques help?* 6
- 1.3 NoSQL is not a panacea 6
- 1.4 First principles 6
- 1.5 Desired properties of a Big Data system 7
 - Robustness and fault tolerance* 7 ▪ *Low latency reads and updates* 8 ▪ *Scalability* 8 ▪ *Generalization* 8 ▪ *Extensibility* 8
 - Ad hoc queries* 8 ▪ *Minimal maintenance* 9 ▪ *Debuggability* 9
- 1.6 The problems with fully incremental architectures 9
 - Operational complexity* 10 ▪ *Extreme complexity of achieving eventual consistency* 11 ▪ *Lack of human-fault tolerance* 12
 - Fully incremental solution vs. Lambda Architecture solution* 13

- 1.7 Lambda Architecture 14
 - Batch layer* 16 ▪ *Serving layer* 17 ▪ *Batch and serving layers satisfy almost all properties* 17 ▪ *Speed layer* 18
- 1.8 Recent trends in technology 20
 - CPUs aren't getting faster* 20 ▪ *Elastic clouds* 21 ▪ *Vibrant open source ecosystem for Big Data* 21
- 1.9 Example application: SuperWebAnalytics.com 22
- 1.10 Summary 23

PART 1 BATCH LAYER.....25

2 *Data model for Big Data* 27

- 2.1 The properties of data 29
 - Data is raw* 31 ▪ *Data is immutable* 34 ▪ *Data is eternally true* 36
- 2.2 The fact-based model for representing data 37
 - Example facts and their properties* 37 ▪ *Benefits of the fact-based model* 39
- 2.3 Graph schemas 43
 - Elements of a graph schema* 43 ▪ *The need for an enforceable schema* 44
- 2.4 A complete data model for SuperWebAnalytics.com 45
- 2.5 Summary 46

3 *Data model for Big Data: Illustration* 47

- 3.1 Why a serialization framework? 48
- 3.2 Apache Thrift 48
 - Nodes* 49 ▪ *Edges* 49 ▪ *Properties* 50 ▪ *Tying everything together into data objects* 51 ▪ *Evolving your schema* 51
- 3.3 Limitations of serialization frameworks 52
- 3.4 Summary 53

4 *Data storage on the batch layer* 54

- 4.1 Storage requirements for the master dataset 55
- 4.2 Choosing a storage solution for the batch layer 56
 - Using a key/value store for the master dataset* 56 ▪ *Distributed filesystems* 57

- 4.3 How distributed filesystems work 58
- 4.4 Storing a master dataset with a distributed filesystem 59
- 4.5 Vertical partitioning 61
- 4.6 Low-level nature of distributed filesystems 62
- 4.7 Storing the SuperWebAnalytics.com master dataset on a distributed filesystem 64
- 4.8 Summary 64

5 *Data storage on the batch layer: Illustration* 65

- 5.1 Using the Hadoop Distributed File System 66
 - The small-files problem* 67 ▪ *Towards a higher-level abstraction* 67
- 5.2 Data storage in the batch layer with Pail 68
 - Basic Pail operations* 69 ▪ *Serializing objects into pails* 70
 - Batch operations using Pail* 72 ▪ *Vertical partitioning with Pail* 73 ▪ *Pail file formats and compression* 74 ▪ *Summarizing the benefits of Pail* 75
- 5.3 Storing the master dataset for SuperWebAnalytics.com 76
 - A structured pail for Thrift objects* 77 ▪ *A basic pail for SuperWebAnalytics.com* 78 ▪ *A split pail to vertically partition the dataset* 78
- 5.4 Summary 82

6 *Batch layer* 83

- 6.1 Motivating examples 84
 - Number of pageviews over time* 84 ▪ *Gender inference* 85
 - Influence score* 85
- 6.2 Computing on the batch layer 86
- 6.3 Recomputation algorithms vs. incremental algorithms 88
 - Performance* 89 ▪ *Human-fault tolerance* 90 ▪ *Generality of the algorithms* 91 ▪ *Choosing a style of algorithm* 91
- 6.4 Scalability in the batch layer 92
- 6.5 MapReduce: a paradigm for Big Data computing 93
 - Scalability* 94 ▪ *Fault-tolerance* 96 ▪ *Generality of MapReduce* 97
- 6.6 Low-level nature of MapReduce 99
 - Multistep computations are unnatural* 99 ▪ *Joins are very complicated to implement manually* 99 ▪ *Logical and physical execution tightly coupled* 101

6.7 Pipe diagrams: a higher-level way of thinking about batch computation 102

Concepts of pipe diagrams 102 ▪ Executing pipe diagrams via MapReduce 106 ▪ Combiner aggregators 107 ▪ Pipe diagram examples 108

6.8 Summary 109

7 **Batch layer: Illustration 111**

7.1 An illustrative example 112

7.2 Common pitfalls of data-processing tools 114

Custom languages 114 ▪ Poorly composable abstractions 115

7.3 An introduction to JCascalog 115

The JCascalog data model 116 ▪ The structure of a JCascalog query 117 ▪ Querying multiple datasets 119 ▪ Grouping and aggregators 121 ▪ Stepping through an example query 122 ▪ Custom predicate operations 125

7.4 Composition 130

Combining subqueries 130 ▪ Dynamically created subqueries 131 ▪ Predicate macros 134 ▪ Dynamically created predicate macros 136

7.5 Summary 138

8 **An example batch layer: Architecture and algorithms 139**

8.1 Design of the SuperWebAnalytics.com batch layer 140

Supported queries 140 ▪ Batch views 141

8.2 Workflow overview 144

8.3 Ingesting new data 145

8.4 URL normalization 146

8.5 User-identifier normalization 146

8.6 Deduplicate pageviews 151

8.7 Computing batch views 151

Pageviews over time 151 ▪ Unique visitors over time 152 ▪ Bounce-rate analysis 152

8.8 Summary 154

9 *An example batch layer: Implementation* 156

- 9.1 Starting point 157
- 9.2 Preparing the workflow 158
- 9.3 Ingesting new data 158
- 9.4 URL normalization 162
- 9.5 User-identifier normalization 163
- 9.6 Deduplicate pageviews 168
- 9.7 Computing batch views 169
 - Pageviews over time* 169 ▪ *Uniques over time* 171 ▪ *Bounce-rate analysis* 172
- 9.8 Summary 175

PART 2 SERVING LAYER.....177

10 *Serving layer* 179

- 10.1 Performance metrics for the serving layer 181
- 10.2 The serving layer solution to the normalization/denormalization problem 183
- 10.3 Requirements for a serving layer database 185
- 10.4 Designing a serving layer for SuperWebAnalytics.com 186
 - Pageviews over time* 186 ▪ *Uniques over time* 187 ▪ *Bounce-rate analysis* 188
- 10.5 Contrasting with a fully incremental solution 188
 - Fully incremental solution to uniques over time* 188 ▪ *Comparing to the Lambda Architecture solution* 194
- 10.6 Summary 195

11 *Serving layer: Illustration* 196

- 11.1 Basics of ElephantDB 197
 - View creation in ElephantDB* 197 ▪ *View serving in ElephantDB* 197 ▪ *Using ElephantDB* 198
- 11.2 Building the serving layer for SuperWebAnalytics.com 200
 - Pageviews over time* 200 ▪ *Uniques over time* 202 ▪ *Bounce-rate analysis* 203
- 11.3 Summary 204

PART 3 SPEED LAYER205

12 *Realtime views* 207

- 12.1 Computing realtime views 209
- 12.2 Storing realtime views 210
 - Eventual accuracy* 211 ▪ *Amount of state stored in the speed layer* 211
- 12.3 Challenges of incremental computation 212
 - Validity of the CAP theorem* 213 ▪ *The complex interaction between the CAP theorem and incremental algorithms* 214
- 12.4 Asynchronous versus synchronous updates 216
- 12.5 Expiring realtime views 217
- 12.6 Summary 219

13 *Realtime views: Illustration* 220

- 13.1 Cassandra's data model 220
- 13.2 Using Cassandra 222
 - Advanced Cassandra* 224
- 13.3 Summary 224

14 *Queuing and stream processing* 225

- 14.1 Queuing 226
 - Single-consumer queue servers* 226 ▪ *Multi-consumer queues* 228
- 14.2 Stream processing 229
 - Queues and workers* 230 ▪ *Queues-and-workers pitfalls* 231
- 14.3 Higher-level, one-at-a-time stream processing 231
 - Storm model* 232 ▪ *Guaranteeing message processing* 236
- 14.4 SuperWebAnalytics.com speed layer 238
 - Topology structure* 240
- 14.5 Summary 241

15 *Queuing and stream processing: Illustration* 242

- 15.1 Defining topologies with Apache Storm 242
- 15.2 Apache Storm clusters and deployment 245
- 15.3 Guaranteeing message processing 247

- 15.4 Implementing the SuperWebAnalytics.com uniques-over-time speed layer 249
- 15.5 Summary 253

16 *Micro-batch stream processing* 254

- 16.1 Achieving exactly-once semantics 255
 - Strongly ordered processing* 255 ▪ *Micro-batch stream processing* 256 ▪ *Micro-batch processing topologies* 257
- 16.2 Core concepts of micro-batch stream processing 259
- 16.3 Extending pipe diagrams for micro-batch processing 260
- 16.4 Finishing the speed layer for SuperWebAnalytics.com 262
 - Pageviews over time* 262 ▪ *Bounce-rate analysis* 263
- 16.5 Another look at the bounce-rate-analysis example 267
- 16.6 Summary 268

17 *Micro-batch stream processing: Illustration* 269

- 17.1 Using Trident 270
- 17.2 Finishing the SuperWebAnalytics.com speed layer 273
 - Pageviews over time* 273 ▪ *Bounce-rate analysis* 275
- 17.3 Fully fault-tolerant, in-memory, micro-batch processing 281
- 17.4 Summary 283

18 *Lambda Architecture in depth* 284

- 18.1 Defining data systems 285
- 18.2 Batch and serving layers 286
 - Incremental batch processing* 286 ▪ *Measuring and optimizing batch layer resource usage* 293
- 18.3 Speed layer 297
- 18.4 Query layer 298
- 18.5 Summary 299
- index* 301