

# Contents

## Part I Introduction

<b>1 Data Science in Action</b> . . . . .	3
1.1 Internet of Events . . . . .	3
1.2 Data Scientist . . . . .	10
1.3 Bridging the Gap Between Process Science and Data Science . . . . .	15
1.4 Outlook . . . . .	20
<b>2 Process Mining: The Missing Link</b> . . . . .	25
2.1 Limitations of Modeling . . . . .	25
2.2 Process Mining . . . . .	30
2.3 Analyzing an Example Log . . . . .	35
2.4 Play-In, Play-Out, and Replay . . . . .	41
2.5 Positioning Process Mining . . . . .	44
2.5.1 How Process Mining Compares to BPM . . . . .	44
2.5.2 How Process Mining Compares to Data Mining . . . . .	46
2.5.3 How Process Mining Compares to Lean Six Sigma . . . . .	46
2.5.4 How Process Mining Compares to BPR . . . . .	49
2.5.5 How Process Mining Compares to Business Intelligence .	49
2.5.6 How Process Mining Compares to CEP . . . . .	50
2.5.7 How Process Mining Compares to GRC . . . . .	50
2.5.8 How Process Mining Compares to ABPD, BPI, WM, . . . . .	51
2.5.9 How Process Mining Compares to Big Data . . . . .	52

## Part II Preliminaries

<b>3 Process Modeling and Analysis</b> . . . . .	55
3.1 The Art of Modeling . . . . .	55
3.2 Process Models . . . . .	57
3.2.1 Transition Systems . . . . .	58
3.2.2 Petri Nets . . . . .	59
3.2.3 Workflow Nets . . . . .	65
3.2.4 YAWL . . . . .	66

3.2.5	Business Process Modeling Notation (BPMN) . . . . .	68
3.2.6	Event-Driven Process Chains (EPCs) . . . . .	70
3.2.7	Causal Nets . . . . .	72
3.2.8	Process Trees . . . . .	78
3.3	Model-Based Process Analysis . . . . .	83
3.3.1	Verification . . . . .	83
3.3.2	Performance Analysis . . . . .	85
3.3.3	Limitations of Model-Based Analysis . . . . .	88
<b>4</b>	<b>Data Mining</b> . . . . .	89
4.1	Classification of Data Mining Techniques . . . . .	89
4.1.1	Data Sets: Instances and Variables . . . . .	90
4.1.2	Supervised Learning: Classification and Regression . . . . .	92
4.1.3	Unsupervised Learning: Clustering and Pattern Discovery . . . . .	94
4.2	Decision Tree Learning . . . . .	94
4.3	$k$ -Means Clustering . . . . .	100
4.4	Association Rule Learning . . . . .	104
4.5	Sequence and Episode Mining . . . . .	107
4.5.1	Sequence Mining . . . . .	107
4.5.2	Episode Mining . . . . .	109
4.5.3	Other Approaches . . . . .	111
4.6	Quality of Resulting Models . . . . .	112
4.6.1	Measuring the Performance of a Classifier . . . . .	113
4.6.2	Cross-Validation . . . . .	115
4.6.3	Occam's Razor . . . . .	118

### Part III From Event Logs to Process Models

<b>5</b>	<b>Getting the Data</b> . . . . .	125
5.1	Data Sources . . . . .	125
5.2	Event Logs . . . . .	128
5.3	XES . . . . .	138
5.4	Data Quality . . . . .	144
5.4.1	Conceptualizing Event Logs . . . . .	145
5.4.2	Classification of Data Quality Issues . . . . .	148
5.4.3	Guidelines for Logging . . . . .	151
5.5	Flattening Reality into Event Logs . . . . .	153
<b>6</b>	<b>Process Discovery: An Introduction</b> . . . . .	163
6.1	Problem Statement . . . . .	163
6.2	A Simple Algorithm for Process Discovery . . . . .	167
6.2.1	Basic Idea . . . . .	167
6.2.2	Algorithm . . . . .	171
6.2.3	Limitations of the $\alpha$ -Algorithm . . . . .	174
6.2.4	Taking the Transactional Life-Cycle into Account . . . . .	177
6.3	Rediscovering Process Models . . . . .	178
6.4	Challenges . . . . .	182

6.4.1	Representational Bias . . . . .	183
6.4.2	Noise and Incompleteness . . . . .	185
6.4.3	Four Competing Quality Criteria . . . . .	188
6.4.4	Taking the Right 2-D Slice of a 3-D Reality . . . . .	192
<b>7</b>	<b>Advanced Process Discovery Techniques . . . . .</b>	<b>195</b>
7.1	Overview . . . . .	195
7.1.1	Characteristic 1: Representational Bias . . . . .	197
7.1.2	Characteristic 2: Ability to Deal With Noise . . . . .	198
7.1.3	Characteristic 3: Completeness Notion Assumed . . . . .	199
7.1.4	Characteristic 4: Approach Used . . . . .	199
7.2	Heuristic Mining . . . . .	201
7.2.1	Causal Nets Revisited . . . . .	201
7.2.2	Learning the Dependency Graph . . . . .	202
7.2.3	Learning Splits and Joins . . . . .	205
7.3	Genetic Process Mining . . . . .	207
7.4	Region-Based Mining . . . . .	212
7.4.1	Learning Transition Systems . . . . .	212
7.4.2	Process Discovery Using State-Based Regions . . . . .	216
7.4.3	Process Discovery Using Language-Based Regions . . . . .	218
7.5	Inductive Mining . . . . .	222
7.5.1	Inductive Miner Based on Event Log Splitting . . . . .	222
7.5.2	Characteristics of the Inductive Miner . . . . .	229
7.5.3	Extensions and Scalability . . . . .	233
7.6	Historical Perspective . . . . .	236
<b>Part IV Beyond Process Discovery</b>		
<b>8</b>	<b>Conformance Checking . . . . .</b>	<b>243</b>
8.1	Business Alignment and Auditing . . . . .	243
8.2	Token Replay . . . . .	246
8.3	Alignments . . . . .	256
8.4	Comparing Footprints . . . . .	263
8.5	Other Applications of Conformance Checking . . . . .	268
8.5.1	Repairing Models . . . . .	268
8.5.2	Evaluating Process Discovery Algorithms . . . . .	269
8.5.3	Connecting Event Log and Process Model . . . . .	272
<b>9</b>	<b>Mining Additional Perspectives . . . . .</b>	<b>275</b>
9.1	Perspectives . . . . .	275
9.2	Attributes: A Helicopter View . . . . .	277
9.3	Organizational Mining . . . . .	281
9.3.1	Social Network Analysis . . . . .	282
9.3.2	Discovering Organizational Structures . . . . .	287
9.3.3	Analyzing Resource Behavior . . . . .	288
9.4	Time and Probabilities . . . . .	290
9.5	Decision Mining . . . . .	294
9.6	Bringing It All Together . . . . .	297

<b>10 Operational Support . . . . .</b>	301
10.1 Refined Process Mining Framework . . . . .	301
10.1.1 Cartography . . . . .	303
10.1.2 Auditing . . . . .	304
10.1.3 Navigation . . . . .	305
10.2 Online Process Mining . . . . .	305
10.3 Detect . . . . .	307
10.4 Predict . . . . .	311
10.5 Recommend . . . . .	316
10.6 Processes Are Not in Steady State! . . . . .	318
10.6.1 Daily, Weekly and Seasonal Patterns in Processes . . . . .	318
10.6.2 Contextual Factors . . . . .	318
10.6.3 Concept Drift in Processes . . . . .	320
10.7 Process Mining Spectrum . . . . .	321

## Part V Putting Process Mining to Work

<b>11 Process Mining Software . . . . .</b>	325
11.1 Process Mining Not Included! . . . . .	325
11.2 Different Types of Process Mining Tools . . . . .	327
11.3 ProM: An Open-Source Process Mining Platform . . . . .	331
11.3.1 Historical Context . . . . .	331
11.3.2 Example ProM Plug-Ins . . . . .	333
11.3.3 Other Non-commercial Tools . . . . .	337
11.4 Commercial Software . . . . .	339
11.4.1 Available Products . . . . .	339
11.4.2 Strengths and Weaknesses . . . . .	345
11.5 Outlook . . . . .	352
<b>12 Process Mining in the Large . . . . .</b>	353
12.1 Big Event Data . . . . .	353
12.1.1 $N = \text{All}$ . . . . .	354
12.1.2 Hardware and Software Developments . . . . .	356
12.1.3 Characterizing Event Logs . . . . .	364
12.2 Case-Based Decomposition . . . . .	368
12.2.1 Conformance Checking Using Case-Based Decomposition . . . . .	369
12.2.2 Process Discovery Using Case-Based Decomposition . . . . .	370
12.3 Activity-Based Decomposition . . . . .	373
12.3.1 Conformance Checking Using Activity-Based Decomposition . . . . .	374
12.3.2 Process Discovery Using Activity-Based Decomposition . . . . .	376
12.4 Process Cubes . . . . .	378
12.5 Streaming Process Mining . . . . .	381
12.6 Beyond the Hype . . . . .	384

<b>13 Analyzing “Lasagna Processes” . . . . .</b>	387
13.1 Characterization of “Lasagna Processes” . . . . .	387
13.2 Use Cases . . . . .	391
13.3 Approach . . . . .	392
13.3.1 Stage 0: Plan and Justify . . . . .	393
13.3.2 Stage 1: Extract . . . . .	395
13.3.3 Stage 2: Create Control-Flow Model and Connect Event Log . . . . .	395
13.3.4 Stage 3: Create Integrated Process Model . . . . .	396
13.3.5 Stage 4: Operational Support . . . . .	396
13.4 Applications . . . . .	397
13.4.1 Process Mining Opportunities per Functional Area . . . . .	397
13.4.2 Process Mining Opportunities per Sector . . . . .	398
13.4.3 Two Lasagna Processes . . . . .	402
<b>14 Analyzing “Spaghetti Processes” . . . . .</b>	411
14.1 Characterization of “Spaghetti Processes” . . . . .	411
14.2 Approach . . . . .	415
14.3 Applications . . . . .	418
14.3.1 Process Mining Opportunities for Spaghetti Processes . . . . .	418
14.3.2 Examples of Spaghetti Processes . . . . .	420
<b>Part VI Reflection</b>	
<b>15 Cartography and Navigation . . . . .</b>	431
15.1 Business Process Maps . . . . .	431
15.1.1 Map Quality . . . . .	432
15.1.2 Aggregation and Abstraction . . . . .	432
15.1.3 Seamless Zoom . . . . .	434
15.1.4 Size, Color, and Layout . . . . .	438
15.1.5 Customization . . . . .	440
15.2 Process Mining: TomTom for Business Processes? . . . . .	441
15.2.1 Projecting Dynamic Information on Business Process Maps . . . . .	441
15.2.2 Arrival Time Prediction . . . . .	444
15.2.3 Guidance Rather than Control . . . . .	444
<b>16 Epilogue . . . . .</b>	447
16.1 Process Mining as a Bridge Between Data Mining and Business Process Management . . . . .	447
16.2 Challenges . . . . .	449
16.3 Start Today! . . . . .	451
<b>References . . . . .</b>	453
<b>Index . . . . .</b>	463