

Contents

1. Introduction	15
1.1. Motivation	15
1.2. Objectives and Contributions of the Thesis	17
1.2.1. Research Questions	17
1.2.2. Conceptual Framework	18
1.2.3. Techniques, Tools, and Case Studies	19
1.3. Outline of the Thesis	21
I. Foundations and State of the Art	25
2. Modeling and Simulation	27
2.1. Basic System Theory	27
2.1.1. Complexity and Emergence	27
2.1.2. Models	29
2.2. Computer Simulation	29
2.2.1. Classification of Simulation Models	30
2.2.2. World Views of Discrete Event Simulation	32
2.3. Modeling Techniques	33
2.3.1. UML 2	34
2.3.2. Petri Nets	39
2.3.3. Workflow Modeling and Patterns	48
2.4. Experimentation, Analysis, and Validation	50
2.4.1. Experimentation	50
2.4.2. Output Analysis	51
2.4.3. Validation	53
3. Agent-Based Simulation	59
3.1. Agents and Multi-Agent Systems	59
3.1.1. Agents	59
3.1.2. Agent Architectures	62
3.1.3. Multi-Agent Systems	63
3.2. The Agent-Based Simulation World View	64
3.2.1. Relations between Agents and Simulation	64
3.2.2. Components of Agent-Based Models	65
3.2.3. Coparison with other Simulation World Views	69
3.3. Modeling Techniques for Agent-Based Simulation	71
3.3.1. Declarative Modeling	71
3.3.2. UML-Based Modeling	74

3.3.3.	Petri Nets and Mulan	79
3.4.	Implementation of Agent-Based Models	88
3.4.1.	JADE Agent Platform	89
3.4.2.	MadKit Agent Platform and Simulation Framework	90
3.4.3.	SeSAM Simulation System	90
3.4.4.	FAMOS and DESMO-J	91
3.4.5.	Capa Agent Platform	94
3.5.	The Problem of Analysis and Validation	95
4.	Data Mining and Process Mining	97
4.1.	Data Mining	97
4.1.1.	The KDD Process	98
4.1.2.	Classification of Data Mining Techniques	99
4.1.3.	Model Validity in Data Mining	102
4.1.4.	Exemplary Data Mining Techniques	106
4.1.5.	Tools for Data Mining	112
4.2.	Process Mining	118
4.2.1.	Definitions	118
4.2.2.	Classification of Process Mining Techniques	119
4.2.3.	Control Flow Mining	128
4.2.4.	Organizational Perspective	148
4.2.5.	Further Perspectives and Tasks	153
4.2.6.	Tools and Applications	164
5.	Related Work	169
5.1.	Analysis and Validation of MABS	169
5.1.1.	Methodologies for MABS Validation	169
5.1.2.	Techniques	178
5.2.	Data Mining in Multi-Agent Systems and Simulations	186
5.2.1.	Relations between Data Mining and MAS	186
5.2.2.	Data Mining in MABS	187
5.2.3.	Data Mining in Other Simulation World-Views	196
5.2.4.	Data Mining in MAS	197
5.3.	Process Mining in Software Engineering and Simulation	200
5.3.1.	Process Mining in Software Engineering	200
5.3.2.	Mining Message Sequence Graphs	202
5.3.3.	Web Service and Interaction Mining	203
5.3.4.	Process Mining for Agents and Simulation	209
5.4.	Scientific Workflows for Simulation and Process Mining	216
5.4.1.	Scientific Workflow Support for Process Mining	216
5.4.2.	Scientific Workflow Support for Simulation	217

II. Concepts, Tools, and Case Studies	221
6. Conceptual Framework	223
6.1. Motivation and Overview	223
6.2. Analysis Perspectives	225
6.2.1. Decision Perspective	227
6.2.2. Internal Control Perspective	229
6.2.3. Structural Perspective	231
6.2.4. External Control Perspective	235
6.2.5. Adaptivity Perspective	238
6.2.6. Level-Encompassing Perspective	242
6.2.7. Domain-Specific Perspectives	246
6.3. Use Cases within the Model Building Cycle	248
6.3.1. Real System Analysis	249
6.3.2. Exploratory Analysis of Model Behavior	252
6.3.3. Validation and Verification	254
6.3.4. Optimization and Calibration	258
6.3.5. Design of Adaptive Agents	260
6.3.6. Analysis of the Model Building Cycle	263
6.4. Simulation-specific Requirements	266
6.4.1. Robustness and Degree of Generalization	267
6.4.2. Relevant Control Flow Constructs	268
6.4.3. Usability of Mining Techniques for Simulation Practitioners	268
6.4.4. Handling of Multiple Stochastic Simulation Runs	269
6.5. Summary and Contributions	271
7. Process Mining in PAOSE	273
7.1. Process Mining and the Mulan Framework	273
7.1.1. Introduction and Motivation	273
7.1.2. Analysis Perspectives and MULAN	274
7.1.3. Support for Analysis Use Cases	281
7.2. Reconstruction of Basic Interaction Protocols	289
7.2.1. Basic Interaction Mining Chain	290
7.2.2. Message Aggregation	291
7.2.3. Conversation Clustering and Role Mining	293
7.2.4. Control Flow Mining	296
7.2.5. Results and Discussion	300
7.3. Reconstruction of Higher Order Protocols	304
7.3.1. Extended Interaction Mining Chain	306
7.3.2. Log Segmentation and Role Mining	307
7.3.3. Control Flow Mining	308
7.3.4. Multiple Instantiation and Cardinalities	310
7.3.5. Result Representation	311
7.4. Tool Support	312
7.4.1. Mulan Sniffer Tool	313
7.4.2. Analysis Framework and Mining Chains	313
7.5. Summary	318

8. Process Mining in a Discrete Event Simulation Study	321
8.1. Courier Service Study	321
8.1.1. Problem Description	322
8.1.2. Agent-Based Courier Service Models	322
8.1.3. Implementation with FAMOS and DESMO-J	328
8.1.4. Data Collection and Result Analysis	330
8.1.5. Validation and Calibration	331
8.1.6. Results and Discussion	338
8.2. Application of Process Mining	341
8.2.1. Objectives and Methodology	341
8.2.2. Analysis Tasks	342
8.2.3. Evaluation Criteria	343
8.2.4. Data Collection and Preprocessing	344
8.2.5. Perspectives and Algorithms	348
8.3. Process Mining Experiments and Results	350
8.3.1. External Control Perspective	350
8.3.2. Internal Control Perspective	368
8.3.3. Decision Perspective	377
8.3.4. Summary and Discussion	379
8.4. Integration into an Experimentation Environment	384
8.4.1. Motivation and Introduction	384
8.4.2. Design and Implementation	385
8.4.3. Scientific Workflows with KNIME and ProM	387
9. Summary, Discussion, and Outlook	389
9.1. Summary of Contributions	389
9.2. Discussion	390
9.2.1. Attainment of Research Goals	391
9.2.2. Comparison to Related Work	397
9.3. Outlook	403