

Levent Yilmaz and Tuncer Ören

Agent-Directed Simulation and Systems Engineering



**WILEY-
VCH**

WILEY-VCH Verlag GmbH & Co. KGaA

**Agent-Directed Simulation and
Systems Engineering**

*Edited by
Levent Yilmaz and Tuncer Ören*

Wiley Series in Systems Engineering and Management

Series Editor: Andrew P. Sage

A complete list of the titles in this series appears at the end of this volume.

Levent Yilmaz and Tuncer Ören

Agent-Directed Simulation and Systems Engineering



**WILEY-
VCH**

WILEY-VCH Verlag GmbH & Co. KGaA

The Editors

Prof. Levent Yilmaz

Auburn University
3116 Shelby Center
Computer Science and Software Engineering
College of Engineering
Auburn, AL 36849
USA

Prof. Tuncer Ören

University of Ottawa
Faculty of Engineering
800 King Edward
Ottawa, ON K1N 6N5
Canada

Cover

Spieszdesign,
Neu-Ulm, Germany.

■ All books published by Wiley-VCH are carefully produced. Nevertheless, authors, editors, and publisher do not warrant the information contained in these books, including this book, to be free of errors. Readers are advised to keep in mind that statements, data, illustrations, procedural details or other items may inadvertently be inaccurate.

Library of Congress Card No.: applied for
British Library Cataloguing-in-Publication

Data: A catalogue record for this book is available from the British Library.

**Bibliographic information published
by the Deutsche Nationalbibliothek**

The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available on the Internet at

<<http://dnb.d-nb.de>>.

© 2009 WILEY-VCH Verlag GmbH &
Co. KGaA, Weinheim

All rights reserved (including those of translation into other languages).
No part of this book may be reproduced in any form – by photoprinting, microfilm, or any other means – nor transmitted or translated into a machine language without written permission from the publishers. Registered names, trademarks, etc. used in this book, even when not specifically marked as such, are not to be considered unprotected by law.

Printed in the Federal Republic
of Germany
Printed on acid-free paper

Typesetting le-tex publishing services
GmbH, Leipzig

Printing betz-druck GmbH, Darmstadt

Binding Litges & Dopf GmbH,
Heppenheim

Cover Design Spieszdesign, Neu-Ulm

ISBN 978-3-527-40781-1

To Funda
Levent Yilmaz

To Füsün
Tuncer Ören

Foreword

What makes agent software different from ordinary software? What can modeling and simulation contribute to agent systems? Conversely, is there a role for agents in modeling and simulation? This book is the first extended work to provide in-depth answers to these questions and others like them. Indeed, the term “agent” has become a ubiquitous “buzzword” used in an enormous variety of contexts to refer to a wide range of software attributes. So it is very timely to bring together a group of experts to offer their unique insights into various aspects of agent software as they relate primarily to modeling and simulation and to systems engineering. However, this book is more than a collection of essays on agents in their diverse applications. The editors, Tuncer Ören and Levent Yilmaz, combining depth of experience with bleeding-edge enthusiasm, provide a degree of coherence well beyond that usually seen in edited collections. In addition to writing some of the key chapters, the editors contribute new concepts and organizing principles that illuminate the current state of the art and reveal intriguing possibilities for theory and applications going forward.

The looseness of terminology in information technology is something we have grown to live with as the field has developed. Terms such as “agent” that have broad connotations are useful for such socially important activities as building communities of interest, organizing conferences, and successfully communicating with the nontechnical layperson. However, there comes a point where imprecise terminologies need to be given greater definitiveness so that critical concepts can be delineated and clarified, thereby allowing the field to move forward on a sounder foundation. To address this need, the book opens with a chapter that provides an integrative and comprehensive view of modeling and simulation, laying the basis for the rest of the book. Interspersed in the sequel are chapters that provide similarly foundational discussions of agent concepts, systems engineering, and the application of each one of these areas to the other. Whether you are a software developer, simulation practitioner, or systems engineer, you will find some eye-opening material in this presentation.

The central thesis of the book is that, while simulation in application to agents is fairly well established, the converse application of agents to the enterprise of modeling and simulation is much less appreciated and, as the editors assert, no less important. Indeed, Ören’s taxonomy in the opening chapter alone is worth the

price of admission. His framework enables one to consider the mutual synergies among modeling and simulation, system theories, systems engineering, software agents, and artificial intelligence. I can envision research professors and graduate students being stimulated to explore branches of this tree toward new research directions in proposals or dissertations.

As a contributor of a chapter to the book, I can attest that its title, “Agent-Directed Simulation and Systems Engineering”, challenged me to address its novel theme in the context of my own and fellow authors’ work. Interoperability has become a critical feature in modern systems of systems engineering. Testing for interoperability (the ability of independent systems to effectively communicate) has likewise become a necessary part of the overall system development process. Our work in this context employs foundational modeling and simulation concepts in novel ways. We use models derived from system requirements to execute in real time as agents deployed across a network to observe net-enabled collaboration of participants. In this way, agent, modeling and simulation, and systems engineering, concepts, and technologies are brought together to provide a testing solution that would be difficult to synthesize otherwise.

We used the term “agent-implemented” in our title (Chapter 13) to suggest the particular flavor of support provided by agents in this context. By all means, let the reader be challenged to find new species of agent-directed, enabled, oriented, or driven simulation to further the goals of model-based systems engineering. And conversely!

December 2008

Bernard P. Zeigler

Contents

Foreword VII

Preface XIX

List of Contributors XXIII

Part One Background 1

1 Modeling and Simulation: a Comprehensive and Integrative View 3

Tuncer I. Ören

- 1.1 Introduction 3
- 1.2 Simulation: Several Perspectives 4
 - 1.2.1 Purpose of Use 4
 - 1.2.2 Problem to Be Solved 8
 - 1.2.3 Connectivity of Operations 9
 - 1.2.4 M&S as a Type of Knowledge Processing 9
 - 1.2.5 M&S from the Perspective of Philosophy of Science 13
- 1.3 Model-Based Activities 13
 - 1.3.1 Model Building 15
 - 1.3.2 Model-Base Management 15
 - 1.3.3 Model Processing 15
 - 1.3.4 Behavior Generation 17
- 1.4 Synergies of M&S: Mutual and Higher-Order Contributions 20
- 1.5 Advancement of M&S 20
- 1.6 Preeminence of M&S 24
 - 1.6.1 Physical Tools 27
 - 1.6.2 Knowledge-Based or Soft Tools 27
 - 1.6.3 Knowledge Generation Tools 30
- 1.7 Summary and Conclusions 32

2 Autonomic Introspective Simulation Systems 37

Levent Yilmaz and Bradley Mitchell

- 2.1 Introduction 37
- 2.2 Perspective and Background on Autonomic Systems 39
- 2.3 Decentralized Autonomic Simulation Systems: Prospects and Issues 41

2.3.1	Motivating Scenario: Adaptive Experience Management in Distributed Mission Training	41
2.3.2	An Architectural Framework for Decentralized Autonomic Simulation Systems	42
2.3.3	Challenges and Issues	44
2.4	Symbiotic Adaptive Multisimulation: An Autonomic Simulation System	47
2.4.1	Metamodels for Introspection Layer Design	48
2.4.2	Local Adaptation: First-Order Change via Particle Swarm Optimizer	50
2.4.3	The Learning Layer: Genetic Search of Potential System Configurations	51
2.4.4	SAMS Component Architecture	52
2.5	Case Study: UAV Search and Attack Scenario	55
2.5.1	Input Factors	56
2.5.2	Agent Specifications	57
2.6	Validation and Preliminary Experimentation with SAMS	64
2.6.1	Face Validity of the UAV Model	65
2.6.2	Experiments with the Parallel SAMS Application	67
2.7	Summary	70

Part Two Agents and Modeling and Simulation 73

3	Agents: Agenthood, Agent Architectures, and Agent Taxonomies	75
	<i>Andreas Tolk and Adelinde M. Uhrmacher</i>	
3.1	Introduction	75
3.2	Agenthood	76
3.2.1	Defining Agents	76
3.2.2	Situated Environment and Agent Society	78
3.3	Agent Architectures	79
3.3.1	Realizing Situatedness	79
3.3.2	Realizing Autonomy	81
3.3.3	Realizing Flexibility	82
3.3.4	Architectures and Characteristics	84
3.4	Agenthood Implications for Practical Applications	86
3.4.1	Systems Engineering, Simulation, and Agents	87
3.4.2	Modeling and Simulating Human Behavior for Systems Engineering	88
3.4.3	Simulation-Based Testing in Systems Engineering	91
3.4.4	Simulation as Support for Decision Making in Systems Engineering	93
3.4.5	Implications for Modeling and Simulation Methods	94
3.5	Agent Taxonomies	96
3.5.1	History and Application-Specific Taxonomies	96
3.5.2	Categorizing the Agent Space	99
3.6	Concluding Discussion	101

4	Agent-directed Simulation	111
	<i>Levent Yilmaz and Tuncer I. Ören</i>	
4.1	Introduction	111
4.2	Background	113
4.2.1	Software Agents	113
4.2.2	Complexity	113
4.2.3	Complex Systems of Systems	114
4.2.4	Software Agents within the Spectrum of Computational Paradigms	115
4.3	Categorizing the Use of Agents in Simulation	118
4.3.1	Agent Simulation	118
4.3.2	Agent-Based Simulation	119
4.3.3	Agent-Supported Simulation	119
4.4	Agent Simulation	120
4.4.1	A Metamodel for Agent System Models	120
4.4.2	A Taxonomy for Modeling Agent System Models	122
4.4.3	Using Agents as Model Design Metaphors: Agent-Based Modeling	123
4.4.4	Simulation of Agent Systems	127
4.5	Agent-Based Simulation	129
4.5.1	Autonomic Introspective Simulation	130
4.5.2	Agent-Coordinated Simulator for Exploratory Multisimulation	131
4.6	Agent-Supported Simulation	134
4.6.1	Agent-Mediated Interoperation of Simulations	135
4.6.2	Agent-Supported Simulation for Decision Support	139
4.7	Summary	141
 Part Three Systems Engineering and Quality Assurance for Agent-Directed Simulation 145		
5	Systems Engineering: Basic Concepts and Life Cycle	147
	<i>Steven M. Biemer and Andrew P. Sage</i>	
5.1	Introduction	147
5.2	Agent-Based Systems Engineering	148
5.3	Systems Engineering Definition and Attributes	148
5.3.1	Knowledge	149
5.3.2	People and Information Management	150
5.3.3	Processes	151
5.3.4	Methods and Tools	156
5.3.5	The Need for Systems Engineering	157
5.4	The System Life Cycle	157
5.4.1	Conceptual Design (Requirements Analysis)	160
5.4.2	Preliminary Design (Systems Architecting)	161
5.4.3	Detailed Design and Development	161
5.4.4	Production and Construction	163
5.4.5	Operational Use and System Support	164
5.5	Key Concepts of Systems Engineering	164
5.5.1	Integrating Perspectives into the Whole	164

5.5.2	Risk Management	165
5.5.3	Decisions and Trade Studies (the Strength of Alternatives)	166
5.5.4	Modeling and Evaluating the System	168
5.6	Summary	169
6	Quality Assurance of Simulation Studies of Complex Networked Agent Systems	173
	<i>Osman Balci, William F. Ormsby, and Levent Yilmaz</i>	
6.1	Introduction	173
6.2	Characteristics of Open Agent Systems	174
6.3	Issues in the Quality Assurance of Agent Simulations	175
6.4	Large-Scale Open Complex Systems – The Network-Centric System Metaphor	177
6.5	M&S Challenges for Large-Scale Open Complex Systems	179
6.6	Quality Assessment of Simulations of Large-Scale Open Systems	181
6.7	Conclusions	186
7	Failure Avoidance in Agent-directed Simulation: Beyond Conventional v&v and qa	189
	<i>Tuncer I. Ören and Levent Yilmaz</i>	
7.1	Introduction	189
7.1.1	The Need for a Fresh Look	189
7.1.2	Basic Terms	191
7.2	What Can Go Wrong	192
7.2.1	Increasing Importance of M&S	192
7.2.2	Contributions of Simulation to Failure Avoidance	192
7.2.3	Need for Failure Avoidance in Simulation Studies	194
7.2.4	Some Sources of Failure in M&S	196
7.3	Assessment for M&S	198
7.3.1	Types of Assessment	198
7.3.2	Criteria for Assessment	200
7.3.3	Elements of M&S to be Studied	200
7.4	Need for Multiparadigm Approach for Successful M&S Projects	200
7.4.1	V&V Paradigm for Successful M&S Projects	201
7.4.2	QA Paradigm for Successful M&S Projects	203
7.4.3	Failure Avoidance Paradigm for Successful M&S Projects	204
7.4.4	Lessons Learned and Best Practices for Successful M&S Projects	204
7.5	Failure Avoidance for Agent-Based Modeling	206
7.5.1	Failure Avoidance in Rule-Based Systems	207
7.5.2	Failure Avoidance in Autonomous Systems	208
7.5.3	Failure Avoidance in Agents with Personality, Emotions, and Cultural Background	209
7.5.4	Failure Avoidance in Inputs	210
7.6	Failure Avoidance for Systems Engineering	212
7.7	Conclusion	213

8	Toward Systems Engineering for Agent-directed Simulation	219
	<i>Levent Yilmaz</i>	
8.1	Introduction	219
8.2	What Is a System?	220
8.2.1	What Is Systems Engineering?	220
8.2.2	The Functions of Systems Engineering	220
8.3	Modeling and Simulation	221
8.4	The Synergy of M&S and SE	221
8.4.1	The Role of M&S in Systems	221
8.4.2	Why Does M&S Require SE?	222
8.4.3	Why Is SSE Necessary?	222
8.5	Toward Systems Engineering for Agent-Directed Simulation	222
8.5.1	The Essence of Complex Adaptive Open Systems (CAOS)	223
8.5.2	The Merits of ADS	224
8.5.3	Systems Engineering for Agent-Directed Simulation	225
8.6	Sociocognitive Framework for ADS-SE	225
8.6.1	Social-Cognitive View	226
8.6.2	The Dimensions of Representation	227
8.6.3	The Functions for Analysis	228
8.7	Case Study: Human-Centered Work Systems	228
8.7.1	Operational Level – Organizational Subsystem	229
8.7.2	Operational Level – Organizational Subsystem	230
8.7.3	Operational Level – Integration of Organization and Social Subsystems	232
8.7.4	The Technical Level	232
8.8	Conclusions	235
9	Design and Analysis of Organization Adaptation in Agent Systems	237
	<i>Virginia Dignum, Frank Dignum, and Liz Sonenberg</i>	
9.1	Introduction	237
9.2	Organizational Model	239
9.3	Organizational Structure	240
9.3.1	Organizational Structures in Organization Theory	240
9.3.2	Organizational Structures in Multiagent Systems	241
9.4	Organization and Environment	242
9.4.1	Environment Characteristics	242
9.4.2	Congruence	244
9.5	Organization and Autonomy	245
9.6	Reorganization	247
9.6.1	Organizational Utility	247
9.6.2	Organizational Change	248
9.7	Organizational Design	250
9.7.1	Designing Organizational Simulations	252
9.7.2	Application Scenario	253
9.8	Understanding Simulation of Reorganization	256

9.8.1	Reorganization Dimensions	257
9.8.2	Analyzing Simulation Case Studies	257
9.9	Conclusions	263
10	Programming Languages, Environments, and Tools for Agent-directed Simulation	269
	<i>Yu Zhang, Mark Lewis, and Maarten Sierhuis</i>	
10.1	Introduction	269
10.2	Architectural Style for ADS	271
10.3	Agent-Directed Simulation – An Overview	272
10.3.1	Language	273
10.3.2	Environment	275
10.3.3	Service	276
10.3.4	Application	276
10.4	A Survey of Five ADS Platforms	277
10.4.1	Ascape	277
10.4.2	NetLogo	280
10.4.3	Repast	283
10.4.4	Swarm	286
10.4.5	Mason	289
10.5	Brahms – A Multiagent Simulation for Work System Analysis and Design	291
10.5.1	Language	291
10.5.2	Environment	295
10.5.3	Service	298
10.5.4	Application	299
10.6	CASESim – A Multiagent Simulation for Cognitive Agents for Social Environment	300
10.6.1	Language	302
10.6.2	Environment	302
10.6.3	Service	306
10.6.4	Application	310
10.7	Conclusion	312
11	Simulation for Systems Engineering	317
	<i>Joachim Fuchs</i>	
11.1	Introduction	317
11.2	The Systems Engineering Process	317
11.3	Modeling and Simulation Support	318
11.4	Facilities	320
11.5	An Industrial Use Case: Space Systems	321
11.5.1	Simulators for Analysis and Design	323
11.5.2	Facility for Spacecraft Qualification and Acceptance	325
11.5.3	Facility for Ground System Qualification and Testing and Operations	325
11.6	Outlook	325
11.7	Conclusions	327

12	Agent-directed Simulation for Systems Engineering	329
	<i>Philip S. Barry, Matthew T.K. Koehler, and Brian F. Tivnan</i>	
12.1	Introduction	329
12.2	New Approaches Are Needed	331
12.2.1	Employing ADS Through the Framework of Empirical Relevance	332
12.2.2	Simulating Systems of Systems	334
12.3	Agent-Directed Simulation for the Systems Engineering of Human Complex Systems	336
12.3.1	A Call for Agents in the Study of Human Complex Systems	337
12.3.2	Noteworthy Agent-Directed Simulations in the Science of Human Complex Systems	338
12.4	A Model-Centered Science of Human Complex Systems	338
12.5	An Infrastructure for the Engineering of Human Complex Systems	339
12.5.1	Components of the Infrastructure for Complex Systems Engineering	339
12.5.2	Modeling Goodness	341
12.5.3	The Genetic Algorithm Optimization Toolkit	341
12.6	Case Studies	344
12.6.1	Case Study 1: Defending The Stadium	345
12.6.2	Case Study 2: Secondary Effects from Pandemic Influenza	350
12.7	Summary	355
Part Four	Agent-Directed Simulation for Systems Engineering	361
13	Agent-implemented Experimental Frames for Net-centric Systems Test and Evaluation	363
	<i>Bernard P. Zeigler, Dane Hall, and Manuel Salas</i>	
13.1	Introduction	363
13.2	The Need for Verification Requirements	364
13.3	Experimental Frames and System Entity Structures	366
13.4	Decomposition and Design of System Architecture	371
13.5	Employing Agents in M&S-Based Design, Verification and Validation	376
13.6	Experimental Frame Concepts for Agent Implementation	378
13.7	Agent-Implemented Experimental Frames	381
13.8	DEVS/SOA: Net-Centric Execution Using Simulation Service	382
13.8.1	Automation of Agent Attachment to System Components	382
13.8.2	DEVS-Agent Communications/Coordination	384
13.8.3	DEVS-Agent Endomorphic Models	386
13.9	Summary and Conclusions	388
13.A	cAutoDEVS – A Tool for the Bifurcated Methodology	391
14	Agents and Decision Support Systems	399
	<i>Andreas Tolk, Poornima Madhavan, Jeffrey W. Tweeddale, and Lakhmi C. Jain</i>	
14.1	Introduction	399
14.1.1	History	399

14.1.2	Motivating Agent-Directed Decision Support Simulation Systems	401
14.1.3	Working Definitions	403
14.2	Cognitive Foundations for Decision Support	405
14.2.1	Decision Support Systems as Social Actors	406
14.2.2	How to Present the System to the User and Improve Trust	407
14.2.3	Relevance for the Engineer	410
14.3	Technical Foundations for Decision Support	411
14.3.1	Machine-Based Understanding for Decision Support	412
14.3.2	Requirements for Systems When Being Used for Decision Support	413
14.3.3	Agent-Directed Multimodel and Multisimulation Support	417
14.3.4	Methods Applicable to Support Agent-Directed Decision Support Simulation Systems	418
14.4	Examples for Intelligent and Agent-Directed Decision Support Simulation Systems	421
14.4.1	Supporting Command and Control	421
14.4.2	Supporting Inventory Control and Integrated Logistics	423
14.5	Conclusion	426
15	Agent Simulation for Software Process Performance Analysis	433
	<i>Levent Yilmaz and Jared Phillips</i>	
15.1	Introduction	433
15.2	Related Work	435
15.2.1	Organization-Theoretic Perspective for Simulation-Based Analysis of Software Processes	435
15.2.2	Simulation Methods for Software Process Performance Analysis	436
15.3	Team-RUP: A Framework for Agent Simulation of Software Development Organizations	437
15.3.1	Organization Structure	437
15.3.2	Team-RUP Task Model	438
15.3.3	Team-RUP Team Archetypes and Cooperation Mechanisms	439
15.3.4	Reward Mechanism in Team-RUP	440
15.4	Design and Implementation of Team-RUP	441
15.4.1	Performance Metrics	443
15.4.2	Validation of the Model	444
15.5	Results and Discussion	445
15.6	Conclusions	447
16	Agent-Directed Simulation for Manufacturing System Engineering	451
	<i>Jeffrey S. Smith, Erdal Sahin, and Levent Yilmaz</i>	
16.1	Introduction	451
16.1.1	Manufacturing Systems	452
16.1.2	Agent-Based Modeling	453
16.2	Simulation Modeling and Analysis for Manufacturing Systems	454
16.2.1	Manufacturing System Design	455
16.2.2	Manufacturing Operation	458
16.3	Agent-Directed Simulation for Manufacturing Systems	463

16.3.1	Emergent Approaches	463
16.3.2	Agent-Based Manufacturing	464
16.3.3	The Holonic Approach: Hierarchic Open Agent Systems	466
16.4	Summary	468
17	Organization and Work Systems Design and Engineering: from Simulation to Implementation of Multiagent Systems	475
	<i>Maarten Sierhuis, William J. Clancey, and Chin H. Seah</i>	
17.1	Introduction	475
17.2	Work Systems Design	475
17.2.1	Existing Work System Design Methods	476
17.2.2	A Brief History of Work Systems Design	477
17.3	Modeling and Simulation of Work Systems	478
17.3.1	Designing Work Systems: What Is the Purpose and What Can Go Wrong?	478
17.3.2	The Difficulty of Convincing Management	479
17.4	Work Practice Modeling and Simulation	480
17.4.1	Practice vs. Process	481
17.4.2	Modeling Work Practice	481
17.5	The Brahms Language	487
17.5.1	Simulation or Execution with Brahms	488
17.5.2	Modeling People and Organizations	489
17.5.3	Modeling Artifacts and Data Objects	490
17.5.4	Modeling Communication	492
17.5.5	Modeling Location and Movement	493
17.5.6	Java Integration	495
17.6	Systems Engineering: From Simulation to Implementation	496
17.6.1	A Cyclic Approach	498
17.6.2	Modeling Current Operations	499
17.6.3	Modeling Future Operations	501
17.6.4	MAS Implementation	502
17.7	A Case Study: The OCA Mirroring System	503
17.7.1	Mission Control as a Socio-Technical Work System	504
17.7.2	The OCA Officer's Work System	505
17.7.3	Simulating the Current OCA Work System	505
17.7.4	Designing the Future OCA Work System	510
17.7.5	Simulating the Future OCA Work System	511
17.7.6	Implementing OCAMS	511
17.8	Conclusion	514
	Index	517

Preface

Simulation is the enabling technology for hundreds of very important application areas requiring any type of decision support (such as prediction, evaluation, testing, planning, acquisition, and proof of concept), understanding, and education, as well as training to develop and/or enhance motor skills to gain proficiency in the use of equipment, decision making and communication skills, and operational skills by getting real-life-like experience in controlled environments.

The maturity of simulation is (1) *facilitated* by the advances of computer hardware, software engineering, artificial intelligence, software agents, and system theories; (2) *due* to the dedicated contributions of several simulationists, the requirements of advanced users, and the support of influential people who realize its importance; and (3) *achieved* through developments, improvements, and especially through several paradigm shifts. As presented by Thomas Kuhn in his seminal book *The Structure of Scientific Revolutions*, three stages are necessary for a paradigm shift to occur. In the first stage, a paradigm becomes dominant. In the second stage, limitations or problems with the dominant paradigm are observed or better anticipated. In the third stage, a new paradigm that would surpass these limitations and problems is proposed and after some delay becomes the new dominant paradigm.

This book emphasizes the benefits of a double synergy: first, the synergy of modeling and simulation with software engineering, which leads to agent-directed simulation; and then the synergy of agent-directed simulation with systems engineering.

The use of agents in computational modeling has now become pervasive. The power of agents comes partly from their ability to conceptualize problems and devise solutions in terms of interacting entities that communicate, collaborate, coordinate, and intentionally deliberate their actions and reactions. The significant benefit gained by an event-based interactive computing perspective over algorithmic computation is due to our new understanding of complex systems and the universal principles, as well as patterns underlying their mechanisms. This coherent theme about the significance of interaction spans complex systems from cellular mechanisms in systems biology, physiology, brain dynamics, organizational dynamics, ecosystems, as well as patterns of human behavior and culture that define the dynamics of sociotechnical, cognitive, and cultural systems. The call for decentralized problem solving, adaptation, and flexibility in systems engineering

is also resulting in increased use of agent technologies to engineer robustness and resilience into complex artificial systems, while increasing our ability to explore and understand information processes underlying natural systems.

The motivation behind this book, however, goes beyond recognition of these observations. Since its adoption by the simulation modeling and systems engineering communities, the use of agents, unfortunately, has been limited to development of models that use agents as design metaphors. Yet this limited treatment of agents in simulation and systems engineering misses opportunities where agent and simulation technologies are together a central theme. Thus this book aims to fill a gap in the agent, modeling and simulation, and systems engineering communities. By expanding our horizons on the use of agents in modeling and simulation to build, explore, and understand both artificial and natural systems, the book presents a comprehensive framework, called agent-directed simulation, that consists of three distinct, yet related, areas that can be grouped under two categories as follows.

1. Simulation for sagents (agent simulation): simulation of agent systems in engineering, human and social dynamics, military applications, etc.
2. Agents for simulation: agent-supported simulation deals with the use of agents as a support facility to enable computer assistance in problem solving, experimentation, or enhancing cognitive capabilities; agent-based simulation focuses on the use of agents for the generation of model behavior in a simulation study.

While agent-based modeling is widely appreciated and used in model-based science and engineering, the potential use of agents in developing next-generation intelligent and adaptive simulators and their inclusion in the simulation frontend or backend interfaces are not yet as widely acknowledged. Furthermore, the growth of new advanced distributed computing standards along with the rapid rise of service orientation is providing a new context that acts as a critical driver for the development of next-generation systems. These standards revolve around pervasive computing, Web services, grid, autonomic computing, ambient intelligence, etc. The supporting role that intelligent agents can play in the design and development of such systems is becoming pervasive, and simulation plays a critical role in the analysis and design of such systems. The synergy between systems engineering, simulation modeling, and agent technologies is examined in this book to facilitate mutual advancement of each area.

To explore interrelations between systems engineering, simulation modeling, and agent technologies, the book is comprised of three parts. First, we start with a background section that includes a comprehensive overview of modeling and simulation, agent paradigm, systems engineering, and quality assurance. In the second part, we examine the use of systems engineering principles, formal methods, tools, toolkits, and environments for developing agent-directed simulation systems. The final section focuses on the role that agent-directed simulation can play in various systems engineering problems such as testing and evaluation, process performance analysis, decision support, and organization and work system engineering.

Writing this book would not have been possible without the support of many people. The efforts of the referees were instrumental in shaping the contents. Esther Dörring, Anja Tschörtner, and other staff members at Wiley were also very helpful in facilitating the process as well as in supporting the production and final camera-ready copy. Special thanks to authors, since without their intellectual work and creative contributions this book could not exist.

We hope that the introduction of agent-directed simulation and systems engineering as a comprehensive framework that expands our horizons on the mutual contributions of modeling and simulation, software agents, and systems engineering will achieve a broader impact of the associated theories, methodologies, and applications and that challenging and complex problems can be tackled more appropriately. We both wish everyone a pleasant and fruitful time reading and using this book.

December 2008

Levent Yilmaz and Tuncer Ören

List of Contributors

Osman Balci

Virginia Tech
Department of Computer Science
3160B Torgersen Hall, MC 0106
Blacksburg, VA 24061
USA

Philip S. Barry

MiTRE Corporation
McLean, VA 22101
USA

Steven M. Biemer

Johns Hopkins University
Whiting School of Engineering
3400 North Charles Street
Baltimore, MD 21218-2608
USA

William J. Clancey

NASA Ames Research Center
Intelligent Systems Division
Moffett Field, CA 94035
USA

Frank Dignum

Utrecht University
Department of Information
and Computing Sciences
Centrumgebouw Noord
Padualaan 14
De Uithof/3584 CH Utrecht
The Netherlands

Virginia Dignum

Utrecht University
Department of Information
and Computing Sciences
Centrumgebouw Noord
Padualaan 14
De Uithof/3584 CH Utrecht
The Netherlands

Joachim Fuchs

European Space Agency
2200 AG Noordwijk
The Netherlands

Dane Hall

BAE Systems
Sierra Vista, AZ 85706
USA

Lakhmi C. Jain

University of South Australia
School of Electrical and
Information Engineering
Mawson Lakes Campus
Mawson Lakes, SA 5095
Australia

Matthew T.K. Koehler

MiTRE Corporation
McLean, VA 22101
USA

Mark Lewis

Trinity University
Department of Computer Science
San Antonio, TX 78212-7400
USA

Poornima Madhavan

Old Dominion University
Department of Engineering
Management and Systems
Engineering
Kaufman Hall
Norfolk, VA 23529
USA

Bradley Mitchell

Auburn University
3116 Shelby Center
Computer Science
and Software Engineering
College of Engineering
Auburn, AL 36849
USA

William F. Ormsby

Naval Surface Warfare Center
6149 Welsh Road, Suite 203
Dahlgren, VA 22448
USA

Tuncer I. Ören

University of Ottawa
Faculty of Engineering
800 King Edward
Ottawa, ON, K1N 6N5
Canada

Jared Phillips

Auburn University
3116 Shelby Center
Computer Science
and Software Engineering
College of Engineering
Auburn, AL 36849
USA

Andrew P. Sage

George Mason University
Systems Engineering &
Operations Research
MS4A6
4400 University Drive
Fairfax, VA 22030
USA

Erdal Sahin

Auburn University
3116 Shelby Center
Computer Science
and Software Engineering
College of Engineering
Auburn, AL 36849
USA

Manuel Salas

Modular Mining Systems, Inc.
3289 Hemisphere Loop
Tucson, AZ 85706-5028
USA

Maarten Sierhuis

NASA Ames Research Center
Carnegie Mellon Silicon Valley
Moffett Field, CA 94035-1000
USA

Liz Sonenberg

The University of Melbourne
Department of Information Systems
Victoria 3010
Melbourne
Australia

Chin H. Seah

NASA Ames Research Center
SGT, Inc.
Moffett Field, CA 94035-1000
USA

- material handling 457
 - metamodel 412
 - metasimulator 132
 - model analysis 15
 - model base 375
 - model-based activity 11, 13
 - model-based management 13
 - model-building 13
 - model processing 13
 - behavior generation 15
 - model analysis 15
 - model transformation 15
 - model-based management 11, 15
 - model behavior 19
 - point behavior 19
 - structural behavior 19
 - trajectory behavior 19
 - model-driven enterprise information systems 11
 - model transformation 16
 - modeling 3
 - multiagent systems 241, 269
 - designed 241
 - emergent 241
 - multicriteria decision making 185
 - multimodel 132, 411, 415, 417
 - multi-aspect multimodel 132
 - multistage multimodel 132
 - multisimulation 131–132, 411, 417, 423
 - metasimulator 132
 - model recommendation 133
 - multistage models 417
- n**
- net-centric infrastructure 380
 - NetLogo 271, 280–281
 - network-centric system 177
 - Common Open Policy Service 177
 - Directory Enabled Networking 177
 - Internet Protocol Security Policy 177
 - Network Data Management Protocol 177
 - Simple Object Access Protocol 177
- o**
- open system architectures 180, 186
 - open systems 174
 - autonomy 174
 - dynamism 175
 - heterogeneity 175
 - operational view 180
 - organization 238, 434
 - computational organization 238
 - organizational change 248
 - organizational structure 240
 - adhocracy 240
 - entrepreneurial 240
 - machine 240
 - professional 240
 - resource capacity 243
 - task complexity 243
 - volatility 243
 - organizational utility 247
 - organization theory 240
 - organizational design 240
 - organizational structure 237
- p**
- partial model ensemble 48
 - particle swarm optimization 50
 - perception 99, 401, 410, 412
 - performance estimation 318–319
 - Petri-net 436
 - pruned entity structure 385
- q**
- quality 173
 - quality assessment 184
 - quality assurance 176
- r**
- reflection 81
 - reliability 407, 424–425
 - reorganization 238, 244
 - RePast 271, 283
 - requirements analysis 153, 318–319
 - requirements management and verification 326
 - resolution 412–413
 - risk 165
 - robustness 41
- s**
- scope 412–413
 - self-organization 40, 50
 - self-organizing system 40
 - sense-making 80
 - service-oriented architecture 306
 - simulation 3
 - simulation-based augmented reality 13
 - simulation-based decision support 38
 - simulation for agents 112
 - situated environment 78, 100
 - situatedness 77
 - sociotechnical work system 504
 - software agents 113
 - software engineering 20, 184, 433

- software process simulation models 436
 - software processes 433
 - software systems engineering 433
 - software validation facility 324
 - spacecraft qualification and acceptance 325
 - specification 318
 - standards 153
 - EIA-STD-632 153
 - IEEE-1220 153
 - ISO 155
 - ISO-IEC-IEEE-STD-15288 153
 - ISO/EIC 15288 159
 - MIL-STD-499B 153
 - Swarm 271, 286
 - synthesis 153
 - SysML 326
 - system analysis 153
 - system architecture 180
 - open system architectures 180
 - operational view 180
 - system view 180
 - system communication 409
 - system complexity 408
 - system concept simulator 324
 - System dynamics 436
 - System Entity Structure 369
 - system sciences 11
 - complex systems 11
 - discrete-event systems 11
 - system theory 11
 - system view 180
 - systems engineering 20, 147, 149, 220, 317
 - agent-based systems engineering 148
 - detailed design 162
 - life cycle 158
 - preliminary design 161
 - process 157
 - requirements analysis 160
 - risk management 165
 - simulation system engineering 222
 - simulation systems engineering
 - agent-directed simulation systems 226
 - systems of systems 86, 329
- t**
- technical view 180
 - technology 149
 - test 318
 - trust 400, 406–407
- u**
- updating knowledge base 274
- v**
- validation 174, 318
 - Vee model 331
 - Vee Model of systems engineering 372
- w**
- work practice 434, 475
 - work system design 475
 - Brahms 475
 - cognitive work analysis 477
 - contextual design 476
 - sociotechnical work system 504
 - soft systems methodology 476
 - work practice 475
 - community of practice 482

WILEY SERIES IN SYSTEMS ENGINEERING AND MANAGEMENT

Andrew P. Sage, Editor

ANDREW P. SAGE and JAMES D. PALMER

Software Systems Engineering

WILLIAM B. ROUSE

**Design for Success: A Human-Centered Approach to Designing Successful Products
and Systems**

LEONARD ADELMAN

Evaluating Decision Support and Expert System Technology

ANDREW P. SAGE

Decision Support Systems Engineering

YEFIM FASSER and DONALD BRETTNER

Process Improvement in the Electronics Industry, 2/e

WILLIAM B. ROUSE

Strategies for Innovation

ANDREW P. SAGE

Systems Engineering

HORST TEMPELMEIER and HEINRICH KUHN

Flexible Manufacturing Systems: Decision Support for Design and Operation

WILLIAM B. ROUSE

Catalysts for Change: Concepts and Principles for Enabling Innovation

LIPING FANG, KEITH W. HIPEL, and D. MARC KILGOUR

Interactive Decision Making: The Graph Model for Conflict Resolution

DAVID A. SCHUM

Evidential Foundations of Probabilistic Reasoning

JENS RASMUSSEN ANELISE MARK PEJTERSEN, and LEONARD P. GOODSTEIN

Cognitive Systems Engineering

ANDREW P. SAGE

Systems Management for Information Technology and Software Engineering

ALPHONSE CHAPANIS

Human Factors in Systems Engineering

YACOV Y. HAIMES

Risk Modeling, Assessment, and Management, 2/e

DENNIS M. BUEDE

The Engineering Design of Systems: Models and Methods

ANDREW P. SAGE and JAMES E. ARMSTRONG, Jr.

Introduction to Systems Engineering

WILLIAM B. ROUSE

Essential Challenges of Strategic Management

YEFIM FASSER and DONALD BRETTNER

Management for Quality in High-Technology Enterprises

THOMAS B. SHERIDAN

Humans and Automation: System Design and Research Issues

ALEXANDER KOSSIAKOFF and WILLIAM N. SWEET

Systems Engineering Principles and Practice

HAROLD R. BOOHER

Handbook of Human Systems Integration

JEFFREY T. POLLOCK and RALPH HODGSON

**Adaptive Information: Improving Business Through Semantic Interoperability,
Grid Computing, and Enterprise Integration**

ALAN L. PORTER and SCOTT W. CUNNINGHAM

Tech Mining: Exploiting New Technologies for Competitive Advantage

REX BROWN

Rational Choice and Judgment: Decision Analysis for the Decider

WILLIAM B. ROUSE and KENNETH R. BOFF (editors)

Organizational Simulation

HOWARD EISNER

Managing Complex Systems: Thinking Outside the Box

STEVE BELL

Lean Enterprise Systems: Using IT for Continuous Improvement

J. JERRY KAUFMAN and ROY WOODHEAD

Stimulating Innovation in Products and Services With Function Analysis and Mapping

WILLIAM B. ROUSE

Enterprise Transformation: Understanding and Enabling Fundamental Change

JOHN E. GIBSON, WILLIAM T. SCHERER, and WILLIAM F. GIBSON

How to Do Systems Analysis

WILLIAM F. CHRISTOPHER

Holistic Management: Managing What Matters for Company Success

WILLIAM B. ROUSE

People and Organizations: Explorations of Human-Centered Design