

The Art of Agent-Oriented Modeling

Leon S. Sterling and Kuldar Taveter



The Art of Agent-Oriented Modeling

Intelligent Robotics and Autonomous Agents

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Leon Sterling and Kuldar Taveter

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To Miriam, Danya, Sara, and Emily

To Siiri, Eliise, and Sanne

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Foreword

The software systems that we need to run our society in the twenty-first century are becoming increasingly complex. We need to build large systems by integrating existing systems and components from a range of suppliers. These systems have to be responsive, dependable, and secure. Our reductionist, top-down software engineering techniques—which have helped us create the large, reliable software systems that we depend upon—are now struggling to cope. To meet the demands for twenty-first century systems, we need new approaches to software engineering that can cope autonomously with a rapidly changing environment and that can take advantage of new features as they become available. We need systems that can cope with the unexpected—in terms of both reacting autonomously to problems and communicating these problems to other agents in the system. Agent-oriented software engineering is an important emerging technology that can help us build such systems.

In any developing technology, books in the area go through stages. Initially, the only works are the proceedings of specialist conferences for researchers, where the book includes advanced research papers. The second stage is typified by multiauthor books and specialist books aimed at researchers and early adopters, which focus on a specific topic. These works assume that readers understand basic concepts and principles. Finally, student textbooks are written, aimed at people who need to start from the beginning. Agent-oriented software engineering has now reached this final stage of maturity. This book is one of the first textbooks on agent-oriented software engineering. It aims to disseminate knowledge about this important topic to a wide audience.

The Art of Agent-Oriented Modeling is an introduction to agent-oriented software development for students and for software developers who are interested in learning about new software engineering techniques. Although the principal focus of the book is agent-oriented modeling, it is an excellent general introduction to all aspects of practical, agent-oriented software engineering. Building on Leon Sterling's and Kuldar Taveter's courses in this topic, this book uses everyday examples to illustrate the notion of agents and how agents can interact to create complex, distributed systems.

A key difference between this book and other books in the field is that this book recognizes that if agent-oriented development is to enter the mainstream, it must be done with consideration of practical software engineering issues. As well as delivering the required functionality, agent-oriented systems have to be reliable and secure; their development has to fit into a software engineering life cycle, where systems must meet externally imposed requirements and have to be maintained over many years.

This book has many important insights and it is perhaps invidious to pick on only one of them as an example. However, I think the key point that Leon and Kuldar make in this book is that agent-oriented technology is an effective way to construct sociotechnical systems, which take into account organizational and human issues as well as technical issues. Agents are a useful abstraction that helps us think about how sociotechnical systems deliver the services required by their users. We should think about this without regard to whether the agents that deliver these services are people or automated systems. Modeling a system as agents gives us a way of establishing flexible boundaries for the automated system that can be extended as our understanding of human tasks improve. Over time, these systems can evolve with more and more functionality being taken over by automated agents.

Barry Boehm, one of the most respected software engineering researchers and practitioners, has called the twenty-first century the “software century.” The challenges for humanity are to improve the lives of people around the world without making unsustainable demands on the environment. We can achieve this only with the help of large and small software systems that coordinate resources from different places and different providers and that break down cultural barriers between different civilizations. Many of these systems will be agent-oriented and Leon Sterling and Kuldar Taveter have made an important contribution in this book to the development of agent-oriented software engineering.

Ian Sommerville, *St. Andrews, Scotland, July 2008*

Preface

The introduction of the personal computer changed society's view of computer systems. No longer was a computer a complicated machine doing a task, tucked away in a separate room or a far-off corner of an office or work environment. A computer was a machine on your desk that was ready for daily interaction. No longer was a computer only for specialist programmers—it was a tool to be used by virtually all office workers.

The rapid rise of the World Wide Web in the mid-1990s changed society's view still further. No longer was the personal computer restricted to a desk or a small office network. The machine on your desk could be part of a global network. In addition, the use of computers at home skyrocketed. Almost every home in the developed world acquired a computer. Laptops were mandated for school children in many schools. The volume and visibility of email addresses and domain names exploded.

In the mid-2000s, as this book is written, our interaction with computers is ever-expanding. Businesses depend on software for many—if not most—of their core activities. Cars and appliances have embedded software of which we are barely aware. Teenagers and young adults engage in social networking, and share music and videos on Web sites such as LimeWire and YouTube. We look up knowledge on Wikipedia. Skype is a common method for making telephone calls over the Internet.

So how do we develop computer software to interact with the ever-increasing complexity of the technical world and the increased fluidity of social organizations? It is not an easy task. Having been involved in research and teaching of software engineering and software development projects, we find a need for changing conceptual models. We want to develop software that is open, intelligent, and adaptive. We are becoming convinced that such software needs to be conceived, designed, and developed differently from existing applications that assume fixed requirements and an unchanging environment.

One consideration we believe is important is the need to take a systems view. The system of people and technology has a life cycle of inception, design, implementation,

testing, and maintenance. Processes need to be understood for each of the stages of the life cycle. A systems view implies being able to take a holistic approach and to include considerations of all stakeholders.

In this book, we advocate an agent-oriented view. An *agent* is a concept and metaphor that is familiar for people with and without technical background or interest. An agent allows the blurring of the boundary between people and technology to allow more people to be engaged with the process of building software. Thinking in terms of agents can change the way that people think of software and the tasks it can perform.

The concept of an agent is not new to computing. Agents have been discussed in regard to artificial intelligence (AI) from its early days. More recently, agents have been discussed in the context of object-oriented technology, with many researchers and practitioners viewing them as an extension of object-oriented technology. Agent models have been added to established object-oriented modeling approaches, most notably based around UML (Unified Modeling Language). Agent programming extensions have been developed for languages such as Java and Prolog.

We prefer viewing an agent-oriented approach as different from an object-oriented approach. Agent-oriented models need to be described independently of object-oriented models, though sensible reuse of notation is advisable. The reason for differentiation is that people can be sometimes trapped into thinking only in ways familiar to them. As the saying goes, if all you have is a hammer, everything looks like a nail. In our experience, thinking in terms of agents requires a different mindset. Students and practitioners who insist in thinking about building from their existing (object-oriented) methods are less successful in developing agent-oriented applications.

Our interest in writing this book is to encourage a wide variety of stakeholders in the software development process to engage with an agent-oriented approach. This is a challenge. Software developers, software acquirers, software users, and software maintainers have different concerns. Models are needed that are understandable for all stakeholders. The variety of concerns suggests a variety of models. If the models are understandable, the stakeholder is more likely to be engaged. We believe that engagement throughout the process will improve the development of systems consisting of people and software that will interoperate and evolve successfully.

So why another book? One factor in the adoption of a technology is having textbook material in support. There has been an increase in agent-oriented theory, language, and methodology books over the past several years. This progress is to be encouraged. Nonetheless we feel that this book fills a niche not currently being filled.

There are three main features of this book that we feel add significantly to the literature. The first is the presentation of substantial new examples that range from requirements through design to deployment. The more examples that potential users

of technology see, the more likely a technology is to be adopted. The second is the use of abstract agent-oriented models at various levels of abstraction and geared to different stakeholders. The models relate to a range of agent-oriented software engineering methodologies that are being actively developed. The third is related—namely, the emphasis on models rather than languages—and the philosophy that models can be mapped to a variety of deployment platforms, possibly including conventional languages, makes the concepts accessible to a wider audience. Our recent discussions with colleagues in both academia and industry have reinforced our appreciation for the need for different models for open, distributed domains.

There are often forces working against trying to show how an approach covers a range of implementation languages. Agent language vendors want companies to be locked into their technology. Indeed, one of the initial motivations for the research underlying this book was a request by an industrial partner on what agent models would be “future-proof.” The industry partner had been burned by using an agent-based vendor platform that was no longer supported. Research groups also want to encourage others to use their specific methods. Though this motivation is understandable, the agent community will benefit from broadly supportable models.

Why do we use the word “art” in the title of the book? We have experienced modeling as a creative process that does not always follow clear-cut rules. Many decisions are left to the discretion of the modeler and his or her background and intuition. Modeling is also iterative. Usually one cannot—and should not—end up with final models right away. Even some of the models in the book would improve through further rounds of iteration. Given that we cannot give definitive advice on building “perfect” models, we settle for the more modest aim of providing guidance for creating models.

Having explained some of the motivation that prompted the book, we address the issue of timing. Why now? We have each been working with agent applications for the past ten years. Only now, in our opinion, do we perceive that agent concepts are known widely enough to allow agent-oriented modeling. Modeling tools are emerging: an essential development, if agent concepts are to be used by industry. Also, recent developments in the research areas of autonomic systems, event-based systems, and multiagent systems seem to indicate that the paradigm of peer-to-peer computing in the broad sense is gaining momentum.

Our conclusion that agent concepts have matured sufficiently has been developed through our delivering of seminars and courses on agent technology in academia and industry. We have been involved in teaching graduate students (and advanced undergraduates) for more than ten years. In 2000, Leon was involved in an Australian government project on the rapid diffusion of technology from academia to industry using agent technology as an example. With the benefit of hindsight, the project was

premature. Providing students with the models presented in this book has greatly increased their ability to conceptualize and design agent-oriented systems. The models have been progressively polished over the past three years and are now ready for broader engagement. By the time the reader finishes reading this book, we hope that his or her capacity and confidence for the design and modeling of agent-oriented systems will have improved.

Leon Sterling, *Melbourne, Australia, November 2008*

Kuldar Taveter, *Tallinn, Estonia, November 2008*

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Any book that is of this length and that has taken almost two years to write owes its appearance to many people, events, and circumstances. We gladly take this opportunity to acknowledge and thank the many people who have contributed to this book, in ways both big and small. Doubtless there will be people who have contributed that we have unintentionally omitted from mention. For that we request forgiveness in advance.

First and foremost, we acknowledge the dedication and support of our families. Leon appreciates the love and support of his wife Miriam over his career, and the interactions with his daughters Danya, Sara, and Emily. They have had a positive impact on the book in many ways, including influencing examples.

Kuldar appreciates the love and patience of his wife Siiri, who, not too long after Kuldar's Ph.D. thesis writing process, went through a similar experience. Of enormous importance for the content of this book were Kuldar's interactions with his daughters Eliise and Sanne, now 10 and 7, who at the request of Daddy made experiments with Tamagotchis and consulted Daddy. Kuldar is also thankful to his parents for their prayers and thoughts. And last but not least, Kuldar thanks God for blessing the authors and their families and for providing us with the opportunity to write this book.

We next thank our colleagues who have been instrumental in the appearance of this book. For Leon, the story starts with his return to Melbourne to a professorship in Computer Science and the establishment of the Intelligent Agent Lab, jointly with Professor Liz Sonenberg. Liz and Leon co-taught an Intelligent Agents graduate class in 1996, and to a large extent, the origins of the book lie in the lack of an appropriate textbook for that class. Liz has been a tremendous colleague and indirectly affected the book in many ways. Over the past twelve years, many people have influenced the book's direction. Silvio Salom from Adacel Technologies gave substantial support. The Intelligent Home examples arose from a consulting project with Silvio and many related discussions. The ROADMAP methodology was a response to Silvio's request for a vendor-free agent methodology. There was extensive interaction

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Internationally, a special thanks to the Italian Logic Programming Community for inviting Leon to the Italian summer school in 1997, which initiated an ongoing collaboration with researchers at the University of Genoa led by Maurizio Martelli, and supported by Viviana Mascardi and Floriano Zini during their Ph.D. research. Leon has also enjoyed attending two workshops at Dagstuhl in Germany, at the first of which Leon met Kuldar.

For Kuldar, his initial interest in agent-oriented modeling was focused and shaped by Gerd Wagner, currently a professor at Brandenburg University of Technology in Cottbus, Germany. Their collaboration started in 1999 and Gerd later became a co-supervisor of Kuldar's Ph.D. thesis. The cooperation with Gerd over many years has been very influential in the emergence of this book, and is certainly reflected by the contents of the book. It is also not possible to underestimate the contribution of the Academician Boris Tamm, the late supervisor of Kuldar's thesis. He helped Kuldar in getting the real-life case study of manufacturing simulation, which is also present in this book, and was also instrumental in obtaining research funding from the Estonian Science Foundation.

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oriented software engineering more broadly. Cooperation with the Lochard and Jeppesen companies in Melbourne has been a good sequel to Kuldar's earlier innovation projects. Kuldar would also like to thank Professors Brian Henderson-Sellers and Aditya Ghose from Australia, Dr. Jens Dietrich from New Zealand, and Professor Eric Yu from Canada for the opportunities to give seminars and receive useful feedback at their universities.

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I MODELS

This book presents an approach for modeling complex systems consisting of people, devices, and software agents in changing environments. In part I, a set of models is presented at three levels of abstraction: a motivation layer, where the purpose, goals, and requirements of the system are described; a design layer; and an implementation layer. The first chapter advocates conceiving of the world in which software operates as a multiagent system operating in an environment subject to rules and policies. The conceptual space that we look at will be discussed in more detail in chapter 2. The models themselves will be presented in chapter 3 and applied in later chapters. Chapter 4 focuses on nonfunctional requirements or quality goals. Chapter 5 describes four different platforms, and chapter 6 presents a viewpoint framework that is used in part II to analyze methodologies.

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