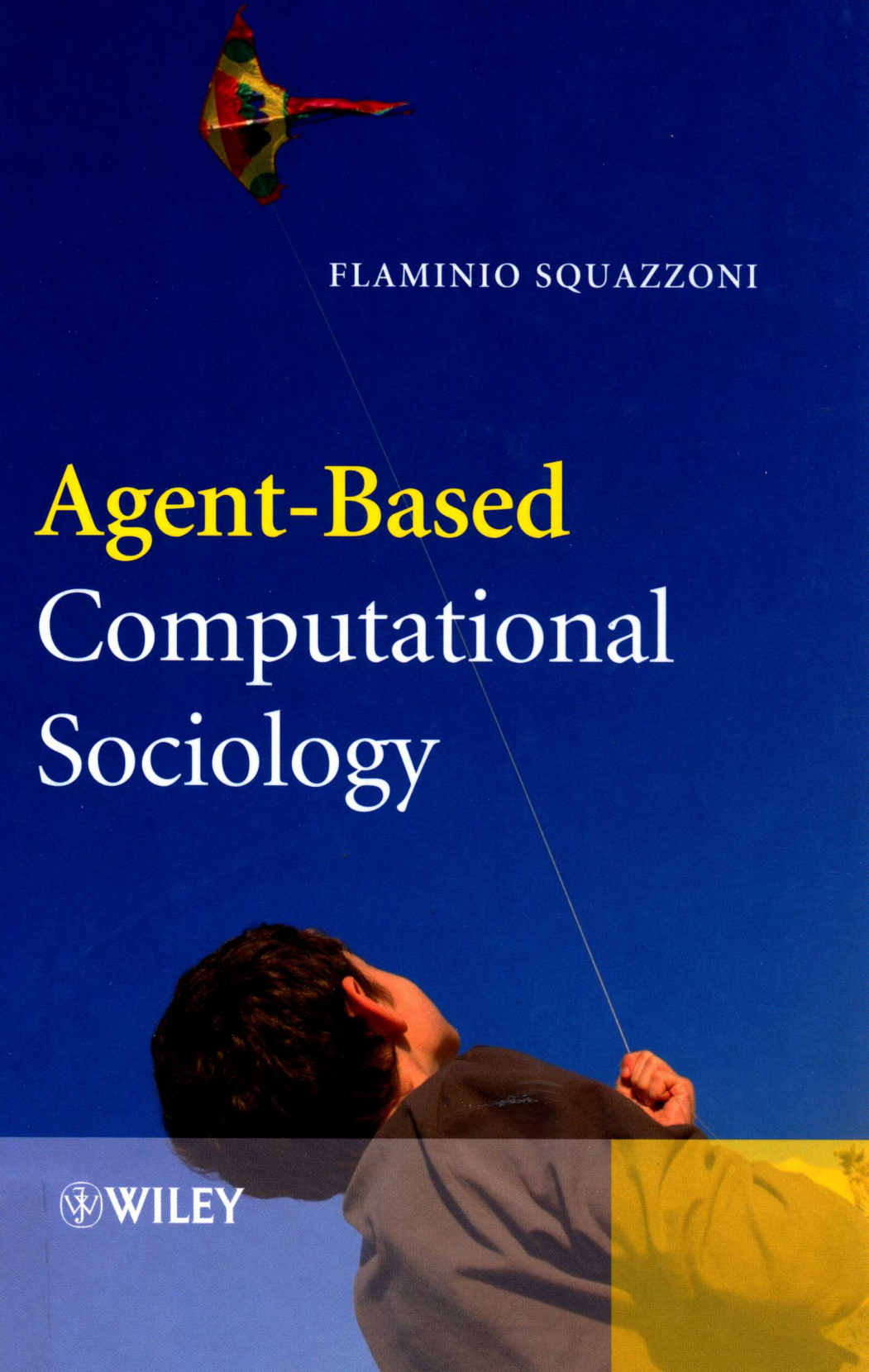
FLAMINIO SQUAZZONI
Agent-Based
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Agent-Based Computational Sociology

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Agent-Based Computational Sociology

To Eleonora, my most inspiring agent

Preface

If you believe that the aim of sociology is to reflect on and delve into the sublime complexity and idiosyncrasy of reality, as for philosophy, history, and literature, I expect this book will disappoint you. In my view, sociology is not a branch of the humanities. Its task is to explain social puzzles by reducing reality to recurrent and simple patterns, as for any other rigorous science. In order to accomplish this task, formalization, modeling and computer simulation can make the same difference here as for physics and evolutionary biology.

Sociology is no exception to this rule, nor does it recognize the immense complication of its investigation object, that is, social interaction. The main message of this book is that formalized models that look at agent behavior and interaction are essential elements for sociology, both for theory building and empirical knowledge.

Some years ago, defending the idea that social sciences need the same kind of rigor and mathematical foundations as 'hard' sciences, the Nobel Prize winner Herbert Simon provocatively suggested that social sciences should be considered the 'real' hard science. Understanding human behavior and interaction is the real challenge for 'hard' scientists, Simon claimed.

I have no doubt that all sociologists share this view. The idea that humans do not follow deterministic laws and that social interaction implies higher levels of complexity is obvious. However, most of them use such a claim to deny the advantages of simplification, reduction, modeling and generalization, following the (wrong) idea that social phenomena are too complex to be understood by standard scientific practices.

As far as I can tell, in this way, we have paralyzed the advance of cumulative science, eroded the explanatory capacity of our investigation and undermined a fruitful combination of theory and observation in our discipline. This has reduced sociology to a well-educated descriptive account of the present or a set of 'broad tent view' philosophical speculations. Indeed, the current situation of our discipline dramatically testifies to this: paradigmatic fragmentation, parochial balkanization of research programs and schools, no epistemological and methodological consensus, low prestige of the discipline, low funds, and poor influence on the public sphere. Everything today suggests that something has gone wrong.

Obviously, the refusal of formalization and modeling cannot be the whole cause of this crisis, but I think it is useful to start from here to contemplate a different type of sociology. If sociology is much less influential than other disciplines, such

as economics and psychology, and physicists have started to substitute sociologists in understanding social puzzles, it is because of the type and quality of investigation that we currently undertake, rather than any external conspiracy.

This book refers to the Simonian legacy. It aims to show that formalization and modeling do not necessarily sentence us to excessive reductionism and abstraction or to losing sight of the fundamental ingredients of society. The key point is that from the 1990s onward, some sociologists started to apply sociologically friendly computational techniques to simulate and analyze implications of agent interaction in given social structures. This book reports on this innovation and aims to contribute to its wider recognition.

However, I do not intend to write an apology for this new formalism. This should be clear. First, there is evidence about the dramatic danger in the excessive mythology of the *techné* in science. Secondly, formalization is just one component of sociological investigation, which is a multifaceted set of different interrelated activities. Let me discuss these two points.

I suggest that it is easy to understand the danger of excessive emphasis on formalism for the advance of social science. Looking at mainstream economics is a good example. Generations of well-educated scientists have incrementally developed a fascinating general and abstract model built on complex mathematical scaffolds which does not have any empirical evidence behind it. This book suggests considering formalization and modeling, if and only if they allow us to explain empirical puzzles. This is possible now as agent-based modeling has ontological correspondence with the atoms of social life (i.e., agents) and explicitly addresses agent behavior in social interaction, that is, observable features of our social life.

This ontological correspondence between models and social facts has two relevant consequences. First, agent-based models (from now on ABMs) allow us to prearrange theory towards empirical validation. Indeed, it is easier to empirically validate a well-defined, simple, clear and logically coherent theoretical model which explicitly addresses human behavior and interaction, than un-formalized and descriptive accounts about unobservable social entities, such as 'habitus', 'organizational fields' and 'liquid modernity'. Secondly, by generating artificial data, ABMs can also help to guide empirical research. Indeed, it is easier to question reality and search for empirical data (if available) when research is informed by well-constructed and verified theories about observable entities. This opportunity to discipline and link theory and observation is one of the most important added values of agent-based computational sociology.

That said, it must be clarified that this book does not support any absolutistic view, nor does it aim to add parochialism to an already fragmented discipline such as sociology. I do not want to convey the message that this type of research is the only way, or the most correct way of doing sociology. Other types of sociology, such as qualitative, quantitative, mathematical or critical sociology, can bring plenty of useful findings and intuitions to advance our discipline. With this book, I want only to suggest, first, that considering sociology closer to other types of science in advocating the added value of formalization and modeling is worth pursuing as least as much as other ways. Secondly, I want to emphasize that this type of research may contribute

to reducing balkanization by helping to cross-fertilize qualitative and quantitative approaches and deductive and inductive reasoning.

It must also be clarified that the line I have taken in this book does not suggest that the 'analytical' approach typical of agent-based computational sociology is expected to exclude any other type of sociological approach. Observing from statistical data, inquiring into the field in different ways, reasoning and theorizing, describing in qualitative terms, are all important aspects of this endeavor we call science. After all, heterogeneity has an incommensurable heuristic value for our discipline, being an advantage for all species for long-term adaptation and evolution.

If this is so, in my view it is hard to understand why the only type of sociology so largely neglected by most traditional sociologists and so dramatically underrepresented in our community, is that which is closer to the standards of other more influential and reputed sciences. This book aims to suggest turning this page, showing that there are more benefits than disadvantages in doing so.

Let me further expand on formalization. So far, most sociologists have viewed formalized models as synonymous of simplified mathematical approaches, where unrealistic assumptions about human behavior and interaction are made for analytic tractability. The classic example is economics, where the fiction of the representative agent, perfect rationality and no direct interaction between economic agents is assumed to mathematically guarantee equilibrium solutions. Others view modeling as synonymous of a set of assumptions about variables and statistical correlations from empirical datasets. The first approach is more concerned with deduction, the second one with induction.

As I will try to show in this book, agent-based computational sociology is poised to dramatically change these views. ABMs are a new type of formalism that exploit the flexibility of programming languages to model human behavior and social interaction which mimic social reality, with agents who are heterogeneous, rule-followers, boundedly rational, embedded in social structures (e.g., social networks, spatial neighborhoods or institutional scaffolds) and subject to social influence. Therefore, they allow us to relax the abstracted and unrealistic assumptions of analytic models and to work with more realistic models which move deduction closer to observation.

This is not all. By running the model on a computer, macro social aggregates are simulated, which look at complex dynamics impossible to observe directly, either with analytic, statistical or descriptive models. Therefore, computer simulation is used to generate (artificial) data which can be analyzed by induction. This allows us to make intuitions and reveal unforeseen insights from social interaction. It is a technological breakthrough which could have significant implications for social research.

All in all, there is one thing that makes me confident that in this was we are heading in the right direction. Generally, when I meet supporters of mathematics and analytic models, the criticism against ABMs is that they are dirty models, too far from mathematics, too complicated and realistic and not concerned enough with clear and definitive analytic solutions. On the other hand, supporters of qualitative research claim that ABMs are not complex enough to look at social reality in detail, are too abstract and oversimplified.

This leads me to think that agent-based computational sociologists are in an interesting unexcluded middle position where different viewpoints and types of research can ensure good synthesis, providing room for cross-fertilization, which is difficult in sociology.

I hope that the reader will appreciate certain examples reported in this book which builds a bridge between quantification and quality, numbers and insights and raw statistical data and qualitative intuition. In my view, even if only for this reason, agent-based computational sociology deserves a good standing in our discipline.

Finally, let us move on to the presentation of the book's contents. The first chapter introduces agent-based computational sociology and the idea of agent-based modeling. I have defined agent-based computational sociology as *the study of social patterns by computer models of social interaction between heterogeneous agents embedded in given social structures (e.g., social networks, spatial neighborhoods, or institutional scaffolds)*. Particular attention has been given here to the founding fathers of this type of research and to reconstructing its position compared with other approaches. The reader will discover, perhaps surprisingly, that some of the most influential sociologists of the past century are closely associated with agent-based computational sociology. People like James S. Coleman, Raymond Boudon, Thomas Schelling, and Mark Granovetter have all left their mark. It has been surprising to see retrospectively that they were more or less motivated by the same understanding of what sociological research should be like.

After reconstructing predecessors and historical origins, I have presented the six most striking ideas of agent-based computational sociology. These are: the primacy of models over theorizing and descriptive accounts, the generative approach to explanation, a pragmatic approach to the micro–macro link, the importance of process and change as key elements of sociological investigation, the pursuit of an unexcluded middle position between deduction and induction, theory and data and a tendency towards a trans-disciplinary/issue-oriented style of research. These ideas are discussed in detail as they answer certain critical points of current sociology.

The chapter ends with a categorization that can help the reader to understand different ABM usages in sociology. My interest here has been strictly 'analytical' and so I did not address policy issues, nor have I given examples of applied models. However, there are interesting examples which testify to the growing interest of policy makers and business managers in this type of research to solve crucial problems and help manage complex organizations. In my view, sociologists are being called on to play a role in these practical aspects, breaking out of an ivory tower. This is discussed in the last chapter.

In the second and third chapters, I have extensively reviewed the literature. I must confess that this will require a certain amount of patience on behalf of the reader. The detail is to allow the reader to fully understand the premises, working and consequences of the issue. As I want to emphasize the advantage of model replication and extension for sociology development (i.e., in the fourth chapter), I have also reported in detail subsequent studies which originated from exemplary and influential models. I am confident that the game is worth the effort for the reader.

Another caveat is that all examples have been categorized according to the topic investigated rather than to the approach followed by modelers. Generally speaking,

these examples follow two approaches, according to their level of analysis. There are (1) studies which investigate the emergence of global macro patterns from local agent interaction (i.e., more micro-to-macro oriented) and (2) others which investigate in more detail the impact of social patterns on agent interaction (i.e., more macro-to-micro oriented). It is worth noting that in some cases both directions were jointly investigated. As a result, these level-concerned explanatory aspects have been distinguished on a case-by-case basis, whereas examples have been grouped around issue specificity.

More specifically, in the second chapter I have reported on cooperation and social norms. Here, the literature is quite ample with examples where ABMs, game theory and experimental research have been fruitfully crossed over. This field allows us to spotlight certain social mechanisms which have wide implications for the spontaneous emergence of social order, one of the most important challenges for sociologists and social scientists in general.

The examples I have selected focus on the following cooperation mechanisms: direct reciprocity, social sanctions, social conventions, cultural transmission, partner selection in dynamic social networks and reputation. They provide a coherent picture of the heterogeneity of human behavior and motivations in social interaction, as well as interesting insights into the role played by social structures on the emergence of pro-social behavior. Most of the examples revolve around abstract models (with more or less experimental foundations), but I hope that the reader will appreciate some which combine experimental data and computational models.

In the third chapter, I have investigated social influence. The focus has been on themes such as residential segregation, collective opinions, culture, and market dynamics. I think that these examples are useful to understand that, when social influence is involved, the explanation of aggregate behavior is largely dependent upon micro details which are difficult to look at without modeling and simulating.

Sociological explanation is more informative, complete and thought provoking when it deals with individual behavior in social interaction, rather than with macro variables and structural factors. I have also included a couple of examples of my own research, which deals with social reflexivity, a complicated typology of social influence. Here, the idea is that the action of other people and specific features of the social contexts where agents are embedded could be the object of cognitive interpretation by agents which could in turn dramatically influence their behavior.

I also want to emphasize that these examples are inspired by a radically different picture of human behavior from economics. Indeed, when social interaction is seriously considered, such as in agent-based computational sociology, social outcomes cannot be understood by assuming representative agents, perfect information and individuals as utility maximizers. Social interaction implies agent heterogeneity, imperfect information, local adaptation and nonlinear effects between agents. Rather than economics and rational choice theory, here the reference for agent-based computational sociology is experimental behavioral science and social psychology. This is a new alliance that agent-based computational sociologists should seriously nurture.

Moreover, the examples of these two chapters help us to zero in on an important point addressed also in the first chapter. Although the book introduces many models, agent-based computational sociology is more than a mere repository of models and

examples. Although it does not offer a coherent picture or paradigm of social interaction yet, it can be considered as a meta-theory which provides precise preliminary foundations for theory building when social interaction is involved. Furthermore, there are social mechanisms which allow us to explain the role played by social interaction to determine social outcomes.

Obviously, only future developments will help to systematize more coherently our knowledge on social interaction and provide a comprehensive picture of the sociological foundations of human behavior. However, although incomplete, I think that for the time being, the picture depicted of agent-based computational sociology is a concrete advance for our discipline.

Having said that, ABMs are performed differently by sociologists and social scientists generally. This will be more easily understood as we progress through the book. Some scientists use ABMs as an extension of mathematical conventional models, that is, to complement the impossibility of finding analytic solutions to equation-based models. Some quantitative sociologists use them to bring agent interaction into statistical models, that is, to shift from 'factors to actors'. Some use them to explore the implications of empirical/experimental evidence in more complex, large-scale simulated systems. In general, many of us use them to completely substitute equation models, where agent heterogeneity and complex forms of interaction should be taken into account and no equation can fruitfully represent system behavior. Therefore, although we are all interested in explaining social outcomes in terms of social interaction, there are different approaches and different degrees of distance between conventional science and the ABM approach.

Furthermore, there is not even a common definition of an agent and those irreducible properties which make a computer code behave like a social agent. This type of research is still in its infancy and we should expected pluralism and diversity. This also reflects extremely sensitive definitional issues. For instance, some contributions make the difference between ABMs and equation-based models and others speculate on the minimal cognitive requirement which makes a computer code realistically behave like a human being. Some others defend the idea that rich cognitive models are needed to look at social interaction and this distinguishes their approach from reductive, physics-oriented approaches.

I must confess that as time goes by I have become skeptical about the time lost in definitional issues and I have become more catholic on this point. This is why I have not spent too much time on definitional issues in this book. The reader will not find a single word on the minimal cognitive requirements to talk about social agents, nor will he/she find extensive epistemological digressions on emergence, emergent properties, differences between first- and second-order properties, supervenience, immergence and the like.

My only interest has been to show the explanatory capacity of a model of crucial sociological puzzles by looking at agent behavior and interaction in (more or less realistic) social structures. Learned cognitive scientists could call this behavioralism. Some could consider this a rough view, but I wonder whether a model which includes equations or not, and rings ten behavioral parameters instead of three, should definitively matter more than its capacity to explain something.

Obviously, explanation requires methodology and this is the topic of the fourth chapter. It is worth noting that attention to methodological issues has recently improved and most methodological problems have been seriously tackled by the ABM community. Here, I have discussed the main methodological steps, such as the definition of research questions in ABM terms and specification of model building blocks to model reporting and publication.

I have focused especially on two crucial aspects: replication and multi-level validation. Replication is *the process of how a model is independently scrutinized by peers by re-running it*. Multi-level empirical validation is *the process by means relevant model parameters are informed by and simulation findings are evaluated against empirical data*.

In my view, one of the crucial points which makes this type of research so beneficial for sociology, is that ABMs favor inter-subjective tests. This makes finding cumulativeness a truly collective scientific enterprise and disciplines investigation by strengthening logical rigor and openness to peer scrutiny. I have insisted in many parts of this book on this point, as I see that it is a serious weakness in current sociology.

Unfortunately, as most scientists can attest, replication is seldom rewarded. On the contrary, I think that replication is crucial to defend the idea that theoretical findings should be replicable, empirically testable and generalizable. Obviously, there is a lot of work still to be done to make replication an easy, well-organized and an ordinary task in the community, but significant advance has already been made.

To underline this point, I have focused in detail on a couple of recent replication querelles. The first one was published in the *American Journal of Sociology* and dealt with residential segregation. The second one was published in *The Journal of Artificial Societies and Social Simulation* and dealt with trust and cooperation between strangers in markets. In both cases, peers replicated a previous model, discovered limitations and extended original findings. The original authors had the chance to specify important aspects of their model better and improve it. In both cases, the result was a better understanding for everyone on the particular issue at stake.

Another point is that of linking models and empirical data. This means calibrating simulation input and validating simulation output on empirical data. The twofold link is important as in sociology we do not have all-embracing theories about micro level processes and the descriptive adequacy of 'situations' where agents interact (i.e., context-specific macro constraints) is often decisive in discriminating between alternative explanations.

Therefore, the challenge is not only to replicate/generate observed statistical regularities at the macro level, but also to do it starting from empirically well-specified micro assumptions. On the one hand, the advantage here is that ABMs are data-generating tools, that is, they generate artificial data patterns which may be easily compared with real ones. On the other hand, it is always difficult to gather well-controlled and complete data for micro foundations.

To suggest ways to do this, I have listed various methods for data gathering, such as experimental, stakeholder, qualitative and quantitative approaches and provided examples of empirically calibrated and validated ABMs. Obviously, stable methodological and technical standards have not been developed yet, but

these examples can provide guidelines and practices for empirically oriented sociologists.

In the last chapter, I have returned to the most important points presented both here and in the first chapter, to provide a prospective view of agent-based computational sociology. I have focused on future challenges for our community. I will outline that we cannot escape from the microscopic nature of sociology. To understand the emergence of social patterns, rather than looking only at the macroscopic scale, we need to discover behavioral and interactional details that really matter. There is a dramatic mismatch between observation scales in social systems.

Agent-based computational sociology helps us to understand that complex social puzzles are not always due to complicated agent behavior, but are the result of agent interaction based on relatively simple behavior. This can help traditional quantitative sociologists to realize that considering seriously the micro foundations does not mean looking at complicated cognitive or psychological investigations without any sociological implication.

Finally, I have added an Appendix that consists of two parts. The first aims to supply additional information to learn about or to do ABM research in sociology. I have provided a list of research centers where this type of research can be done, some associations where to meet ABM scientists, the most representative journals, where ABM research is regularly published and a brief guide to simulation tools, which can help the reader to understand where to start.

The second part includes simulation codes of some models described in the second and third chapters. I have included only examples of my work. To help the reader to practise with other examples, I have created a supporting material book web page, which is accessible at: <www.eco.unibs.it/computationalsociology>. Here, the reader will find more information and descriptions of most of the examples included in this book. I hope this will encourage young scholars to work with ABMs and follow rigorous methodological standard.

I also want to underline that each argument I have developed here has benefited considerably from discussions, opinions and suggestions with many colleagues who were kind enough to share their concerns and enthusiasm with me. Obviously, I cannot thank them all individually, but I would like at least to let them know that they have been incommensurably important for me. I acknowledge comments and suggestions on different chapter drafts or on papers related to some book chapters by Ahmadreza Asgharpour, Giangiacomo Bravo, Rosaria Conte, Peter Davis, Simone Gabbriellini, Nigel Gilbert, David Lane, Gianluca Manzo, Károly Takács, Pietro Terna and Klaus G. Troitzsch. I thank Riccardo Boero and Claudio Gandelli for their help on the simulation codes reported in the Appendix. Besides them, other colleagues have also played an important role for my adventure in this type of research. Among them, I especially thank Giancarlo Provasi who gave me my first introduction to this type of research when I was starting my PhD.

I also want to thank PhD students and young scholars with whom I have had the chance to discuss the main topics of this book over the last few years. They have been important to me and this book is primarily intended for an audience of this kind, that is, those venturing into sociology with enthusiasm and expectation for

innovation. First, I would like to thank the PhD students of my annual course on social simulation here in Brescia, who have motivated me to specify any epistemological and methodological implications of this type of sociology and appreciate the benefits of combining ABM with other more traditional social science methods.

I found challenging audiences when I taught 'Complex Systems and Social Simulation' at the CEU Summer University in Budapest, July 2008, when I met a group of Dutch PhD students for the 'Advanced Course on Agent-Based Simulation', held in Utrecht, February 2011 and when I taught 'Experimentally Grounded Social Simulation' at the Second ESSA Summer School in Social Simulation, held in Guildford, July 2011. I would like to thank Laszlo Gulyas, Gyorgy Kampis, Virginia and Frank Dignum and Nigel Gilbert for inviting me.

Finally, special thanks go to Riccardo Boero, Giangiacomo Bravo and Marco Castellani, my colleagues at GECS, where we are combining experimental and ABM research. I am grateful to them for sharing objectives, passions and time, always enriching my understanding of research issues from diverse perspectives. I only hope that this book will contribute to the diffusion of our ideas and allows us to find new fellow travelers.

Finally, given that many parts of this book have been presented in the form of papers and talks at different meetings, I want to list here the most important ones: the 8th Conference of the Society for Computational Economics, Aix-en-Provence, 2002; RASTA 2002 International Workshop on Regulated Agent-Based Social Systems, Bologna, 2002; EMAEE 2003 Conference on 'The Knowledge-Based Economies. New Challenges in Methodology, Theory and Policy', Augsburg, 2003; EPOS 2004 Workshop (Epistemological Perspectives on Simulation), Koblenz, 2004; EMAEE 2007 Conference on 'Globalization, Services and Innovation: The Changing Dynamics of the Knowledge Economy', Manchester, 2007; The Fourth Conference of the European Social Simulation Association, Toulouse, 2007; The Workshop on Computational and Mathematical Approaches to Societal Transitions, Leiden, 2008; The Fifth Conference of the European Social Simulation Association, Brescia, 2008; The First ICORE Conference on Reputation, Gargonza, 2009; The International Workshop on Mechanisms and Analytical Sociology, Torino, 2009; the Sixth Conference of the European Social Simulation Association, Guildford, 2009; and the Third World Congress on Social Simulation, Kassel, 2010.

In these conferences, I have benefited tremendously from discussions with many colleagues who have indirectly or directly influenced my view on sociology, modeling and explanation. I thank them, as they made me understand what it means when we say that science is a truly collective enterprise.

Last but not least, I wish to thank the Wiley team, especially Ilaria Meliconi for her confidence in the idea of this book, Heather Kay for her support, and Richard Davies for being so patient with latecomer writers. Special thanks go to Robert Coates and Judith Gorham for revising my Italianate English and helping me to improve the readability of the text.

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1

What is agent-based computational sociology all about?

There is no doubt that the last twenty years have brought radical changes to the use of computers in social research (Heise and Simmons 1985; Gilbert and Abbott 2005). In the past (and even still today), social scientists used computers to provide analytic solutions to complicated equation systems that represented a given system's structure, or more generally to estimate statistical models for data. From the 1990s onward, they started to use advanced computational techniques in an innovative way to simulate and analyze implications of agent interaction in social structures (e.g., Epstein and Axtell 1996; Axelrod 1997a; Epstein 2006; Miller and Page 2007).

Computational sociology, that is, the use of computationally intensive methods to model social phenomena, is not a recent development (Brainbridge 2007). It is a branch of sociology that has a long and, to a certain extent, venerable tradition that goes back to the 1960s. At that time, under the influence of systems theory and structural functionalism, computer simulation was used to model control and feedback mechanisms in systems, such as organizations, cities, or global populations. The idea was to simulate complicated differential equation models to predict population distribution as a function of systemic factors, such as urban traffic, migration, demographic change, or disease transmission. Inspired by Forrester's work on world dynamics (Forrester 1971) and the idea of systems theory and cybernetics, the focus was on systems and aggregates rather than on agents and behavior, and on prediction rather than understanding and explanation (Sawyer 2005).

Nevertheless, against this trend, some pioneers started to use computer simulation to investigate models of micro social processes. In the 1960s, James S. Coleman led the most active research center for computer research in sociology in the US.

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