EPOS-Epistemological Perspectives on Simulation: An Introduction

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1 Introduction

There is strong evidence that computer simulation is increasingly recognized as an important analytical tool in many social sciences disciplines and fields. During the last ten years, a number of new journals, which are devoted to this field, have been founded and others have increased their influence (i.e., JASSS, CMOT, Social Science Computer Review, Autonomous Agent and Multi-Agent Systems, Journal of Economic Dynamics and Control, Computational Economics, Computational Management Science). Special issues and extensive reviews of the literature have been published in influential and standard journals[1]. At the same time, new international associations and societies were born, with an increasing number of members (i.e., ESSA in Europe, NAACSOS in North America, The Society for Computational Economics), many research centers and institutes have been successfully launched[2], many workshops, conferences and congresses are organized every year (with the first world congress on social simulation held in 2006 in Tokyo and the second one in Washington in 2008), and an open market of tools and simulation platforms (i.e., Swarm, Repast, Ascape, NetLogo), based on a vast community of developers and users, is steadily growing.

[1] Special issues in «American Behavioral Science» in 1999, «Journal of Economic Dynamics and Control» 2001 and 2004, «Computational Economics» 2001 and 2007, «Proceedings of the National Academy of Sciences» 2002, «Journal of Economic Behavior and Organization» 2004, «Journal of Public Economic Theory» 2004, «American Journal of Sociology» 2005; «Advances on Complex Systems» 2008; reviews and/or papers in «Nature», «Science», «Physica A.», «Journal of Theoretical Biology», «American Sociological Review», «Annual Review of Sociology», «Philosophy of the Social Sciences», «Artificial Intelligence Review».

[2] For example: Santa Fe Institute in New Mexico, USA; Center on Social and Economic Dynamics, at the Brookings Institution, Washington, USA; Centre for Policy Modeling in Manchester, UK; Centre for Research in Social Simulation in Guildford, UK; Laboratory of Agent-Based Social Simulation, CNR, Rome, Italy; Center for Social Complexity at George Mason University, Virginia, USA; Center for Computational Analysis of Social and Organizational Systems at Carnegie Mellon, Pittsburgh, USA; Center for the Study of Complex Systems, University of Michigan, USA.

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In these last years, a significant number of influential papers, handbooks, tutorials and books on simulation have been published in many disciplines. For instance, in the social sciences, Axelrod (1997) and Nowak and Sigmund (1998; 2005), independent of each other, launched a very influential research program on the study of cooperation and reciprocity via computer simulation, with numerous followers not only in the social sciences. Epstein (2007) recently suggested a coherent manifesto to what he called "generative social science", where agent-based models are used as the best-suited modeling instrument to formalize micro-macro models of social and economic phenomena. In his influential manifesto of analytical sociology, Hedström (2005) did the same, locating agent-based models at the core of his programmatic argument. Sawyer (2005) argued the relevance of computer simulation to understanding social emergence. From a methodological perspective, de Marchi (2005) suggested a coherent approach to integrate computational methods with statistical and empirical methods in the social sciences.

Agent-based computational economics is a well recognized field, especially by evolutionary, institutional and applied economists (Saviotti 2003; Pyka and Arhweiler 2004), with good examples of relevant handbooks, tutorials or methodological books on computer simulation and modeling (i.e., Kendrick, Mercado and Amman 2005; Tesfatsion and Judd 2006). In geography and urban studies, there is currently an effective cross-fertilization between computer simulations and other methods and tools, like Geographical Information Systems and statistical surveys and data (i.e. Gimblett 2002; Batty 2005). Computer simulation is used also in anthropology, ecology and in environmental studies (Janssen 2002; Volker and Railsback 2005). In organizational and management studies (Prietula, Carley and Gasser 1998; Lomi and Larsen 2000), as well as in business engineering and industrial processes planning and control (i.e. van Elst, Abeker and Dignum 2004), computer simulation is a well-established tool and an innovative method. Scholars in the areas of artificial intelligence and robotics are using simulation to explore and design intelligent cooperative systems (i.e., Bonabeau, Dorigo and Theraulaz 1999). A good number of general textbooks, tutorials and introductory books on the usage of computational tools and modeling have been recently published, contributing to the promotion of such an approach in the new generation of scholars (i.e., Suleiman, Troitzsch and Gilbert 2000; Wooldridge 2002; Gilbert and Troitzsch 2005; Shiflet and Shiflet 2006; Gilbert 2008).

This introduction aims to present an overview on epistemological debates on computer simulation in the social sciences. Does computer simulation mean a new scientific paradigm or is it just a tool? What is the difference between simulation modeling and traditional analytic models? Does simulation allow for a new relation between theory and data? What are the preconditions for a proper use of simulation? These are just a few questions on which the community is recently focusing (Frank and Troitzsch 2005).

In this introduction, we argue that simulation constitutes an inspiring new research perspective in the social sciences. As we see in the following sections, as well as in most chapters of this book, there are sound substantive and methodological reasons for this argument. First, the possibility of using the computer as a tool for formalizing generative models of social phenomena, with the aim to foster theory building, exploration and testing, allows us to enlarge the space of application of analytical approaches in the social sciences. Simulation indeed requires formal models of social phenomena, thereby contributing to a rationalistic approach to research. Thus it provides an alternative to those streams in the social sciences that are dominated by post-modernism and by all those approaches that deny the possibility of using formalized models in the social sciences. Secondly, by deploying computers, simulation offers the chance to produce - and test - patterns of knowledge that would hardly be possible without this tool. Thirdly, agent-based simulation is a way to cope with complexity and to develop rich, differentiated scenarios at the same time, with several positive consequences at the level of realism and empirical foundation of models.

To give a clear picture of this innovation, the second section summarizes a set of epistemological and methodological open issues on which the community is carefully focusing at the present. The debate is mostly expressed in terms of vivid disputes on dichotomies as follows: generative vs. causal explanations via simulation; meanings and forms of emergence, with a confrontation of ontological and epistemological meanings; theoretical abstraction vs. empirical foundations; theoretical vs. practical purposes. As we see, most of these issues have been explicitly addressed by the authors of this book, making possible to undertake some step forward. As a matter of fact, computer simulation helps secularize such philosophical debates by bringing them away from a mere foundational and philosophical to a more pragmatic and evidence-oriented level. The varied, even contradictory, positions are an indication of this burgeoning, innovative field of research.

In the third section, we propose our assessment of the future of this field of research. In particular, according to the relevant issues of the present, we attempt to identify some epistemological, methodological and substantive puzzles which need to be solved. It is our firm belief that the solution to these puzzles would improve the scientific progress of simulation. Finally, the fourth section offers a description of the book chapters, which are all devoted to clarifying relevant epistemological and methodological issues.

2 Epistemological and Methodological Issues

Computer simulations, and specifically agent-based models, should be viewed as an epistemological innovation, because they permit and promote a generative approach to the modeling and the explanation of social phenomena, strengthening an agent-based paradigm to social science (Epstein and Axtell 1996; Epstein 2007). A "generative approach" is based on the following constituents:

1. The target of the model is a macro phenomenon of interest, let us say a given statistical empirical regularity, evidence or a stylized fact;
2. The model comprehends a set of theoretical hypotheses about a population of agents, rules, constraints and interaction structures, which the modeler believes to be a system that maps those generative causal processes that are supposed to be responsible for the phenomenon;
3. The simulation of the model allows us to produce a set of artificial data, which are controlled by means of a set of indicators, and which are also used to adjust and verify the initial hypotheses;
4. These data are then compared to the empirical data, evidence, or to stylized facts that are the explanatory target of the modeler.

The epistemological assumption is if we are able to generate or grow a macro phenomenon via an agent-based model, on the basis of theoretically or empirically plausible assumptions on the micro-foundations, then we can consider these assumptions as sufficient, even if not necessary conditions for explaining it. Therefore, the simulation model is seen as an engine to find *candidate* explanations of macro social phenomena (Epstein 2007). This position is a kind of standard in social simulation.

2.1 Generative Explanation

As the readers will see by going through some chapters of this book, the generative assumption has been both criticized and developed on two main facets: the difference between a generative and a causal explanation and the difference between a "pure" theoretical explanation and a multi-level empirically-founded model.

Regarding the first facet, it is standard practice to assume that a generative explanation would differ from a standard covering law, a statistical or a narrative explanation because the former would be based on a mechanisms-based explanation (Goldthorpe 2000; George and Bennett 2004). In this perspective, explaining a macro empirical phenomenon of interest means referring to a set of entities and processes (agents, action and interaction) that are spatially and temporally organised in such a way that they regularly bring about that phenomenon (Hedström and Swedberg 1998). In other words, a social mechanism is "a constellation of entities and activities that are linked to one another in such a way that they regularly bring about a particular type of outcome" (Hedström 2005, 11). As George and Bennett correctly pointed out (2004, 141), the difference between a law and a mechanism means a difference between a static correlation ("If X, then Y") and a specification process ("X leads to Y though steps A, B, C") (George and Bennett 2004, 141).

In order to take such a process into account in the social sciences, it is necessary to identify what James Coleman (1990) defined as the chains of macro-micro-macro links: macro-micro situation mechanisms, micro-micro interaction mechanisms, and micro-macro transformation mechanism. According to the so called "Coleman bath tub", a mechanisms-based explanation should first dissect and then combine the jointed action of situational mechanisms (macro-micro), action-formation mechanisms (micro-micro), and transformational mechanisms (micro-macro). The analogy of the bath tub symbolizes that macro outcomes are what can be seen on surface, hopefully expressed in formal terms of empirical regularities, such as statistical properties or stylised facts. But, to understand why and how the surface moves, researchers should go under the surface, to see the causal engine of the movement (Squazzoni 2008).

It is well known that mechanisms are often brought about by bundles or configurations of mechanisms, "some of which contribute to the effect and some of which may operate to counteract the effect or reduce its magnitude". The following is a simple example, which has been reported by Paul Humphreys:

> "a car went off a road at a curve because of excessive speed and the presence of sand on the road and despite clear visibility and an alert driver. He notes that the addition of another mechanism or contextual factor can change a contributing cause to a counter-acting one, or vice-versa: sand decreases traction on a dry road, but increases traction when there is ice on the road" (George and Bennett 2004, 145-146).

If this is true, how is it possible to specify what kind of mechanism is working in the phenomenon of interest, and in what direction they are conducting the bath tub? There is no space to get into more detail on this point, but the argument we would like to emphasize here is as follows: a) the possibility to use an agent-based model to generate a phenomenon does not automatically mean to be in a position to have a causal explanation; b) given the famous arguments of the so-called "multiple realizability" (George and Bennett 2004; Sawyer 2005), according to which a mechanisms-based explanation closely depends on the capability of combining theoretical assumptions and empirical specifications. This is based on the famous arguments of the so-called "multiple realizability" (George and Bennett 2004; Sawyer 2005): the same micro-mechanism could produce different macro outcomes, and the same macro outcome could be produced by different micro mechanisms, Just the reference to empirical evidence can help discriminate among potential alternative theoretical explanations.

2.2 Empirical Foundations and Validation of Simulation Models

There is growing literature on the quest of the empirical foundations and validation of computer simulation models, in particular in the field of agent-based models (i.e., Boero and Squazzoni 2005; Windrum, Fagiolo and Moneta 2007). As the reader will see, four of the chapters of this book deal exactly with this topic. The question is: is the theory behind a model really enough to do good science?

Social simulation researchers seem implicitly split on this question. One faction considers computer simulation as a method for theory building and exploration, as though the computer is a complete substitute for laboratory experiments and empirical analyses. The other faction denies that computer simulation is a self-exhaustive experimental tool and believe that the purpose of social science, also that of computational social science, is primarily to explain empirical phenomena, with the recourse to empirical data.

The first faction believes in the intrinsic added value of the "artificial societies" as a means to strengthen the theoretical foundations of social sciences. This faction believes that the problem with the development of the social sciences lies in the weakness of the theoretical pillars. This faction believes in the "synthetic" features of simulation, i.e. in the use of computer simulation to synthesize all the aspects of the complex nature of social life. The second faction believes that computer simulation is just a tool that allows the social scientist to explain empirical phenomena, a tool that should be used with other tools and empirical methods. This faction believes that the problem lies in the excess of theoretical accounts and models, and the need for strengthening the capacity of modeling and understanding specific empirical phenomena.

This is basically the epistemological side of the debate on the empirical foundations and validation of simulation models. Some chapters of this book explicitly or implicitly focus on this side (Chapter 2 by Rosaria Conte, Chapter 4 by Scott Moss and Chapter 10 by Paul Ormerod and Bridget Rosewell). Regarding the methodological side, a good number of contributions and examples have recently started to elucidate part of the complicated implications of available methodological practices (i.e., Moss and Edmonds 2005; de Marchi 2005; Windrum, Fagiolo and Moneta 2007). For instance, given the micro-macro link that dominates the social phenomena, an interesting methodological issue is the need for a multi-level validation of the model, where empirical data on the macro level are combined with empirical data on the micro level (Boero and Squazzoni 2005). The challenge is to understand how to foster standard methodological practices of validation that could be shared and tested by the community.

2.3 Emergence

The concept of emergence is tied up with the concept of simulation (Sawyer 2005). Two of the chapters in this book try to explicitly deepen such a tie (Chapters 5 and 6 by Alex Schmid and Martin Neumann). In fact, emergence is closely related to "properties", "structures", "regularities", "patterns" and "phenomena" that are macro consequences of basic generative processes that can only be explored via simulations (Bedau 1997). Therefore, it seems that simulation is a suitable approach to reconstruct and explain emergence.

From an epistemological viewpoint, the debate in social simulation seems to be stuck in the middle of two extremes (Squazzoni 2008): the ontological meaning of emergence and the micro-reductionism.

A first faction of social scientists vindicates the reductionistic approach to simulation, refusing any possible ontological meaning of emergence (Hedström 2005; Epstein 2007). The position is extremely coherent: if a theoretical explanation of a macro social phenomenon of interest means the creation of a simulation model to explore plausible theoretical micro assumptions that generate and explain the phenomenon, then macro patterns, phenomena, or processes under study are the resultant implications of micro-assumptions explored inside a formalised model. Particularly, counter-intuitive and intriguing macro phenomena, which would be said "to emerge" by the supporters of social emergence, can be in principle and *de facto* reduced to a set of mechanisms at the lower level (Kim 2006). In the social sciences, such a position totally conforms to the methodological individualism (Coleman 1990), where the ontological existence of "invisibles" or "social entities" and their supposed "causal power" are ontologically and methodologically rejected (Hedström 2005). It is recognized that social science theory requires the explicit generative reference to individual action and interaction to avoid the risk of reifying and evoking macro categorical concepts, such as "class", "culture", or "system", which are often used as explanatory categories in a tautological way. The division between the micro and the macro levels of a model and the analysis of their relation are simply epistemological practices executed by the scientist for analytic purposes, and not an ontological feature of the social reality in itself (Gilbert 2005; Squazzoni 2008).

On the contrary, a second faction of scientists suggests a kind of radical emergentism (Sawyer 2005). Strongly based on a long tradition in philosophy, as well as on classic macro sociology, this faction argues the ontological nature of social emergence. Societal phenomena would belong to a different ontological level of reality compared to individual phenomena. This results in social scientists replacing the causal determinism of the micro level of the reductionists with the causal determinism of the macro level, assigning macro causal power and ontological autonomy to social entities.

In the middle, there is the pragmatic attitude of many social simulation researchers who see emergent properties and phenomena simply as epistemological features of the scientific inquiry. This last faction refuses to accept the ontological meaning of emergence, the supposed causal power of macro social entities, and even the idea that emergence properties are intrinsic features of the reality (Bedau 1997). They instead believe that emergence is a concept with an epistemological value in itself and is created by the scientist with the aim to identify and refer to macro dynamics and change in quantitative and qualitative terms (Gilbert 2002; 2005). Social simulation strengthens links and integrative frameworks, and "secularises" this dispute, by bringing it away from a foundational and philosophical level to a more pragmatic one (Squazzoni 2008). In any case, as some of the chapters of this book demonstrate (Chapter 3 by Rosaria Conte and the three chapters on emergence by Alex Schmid, Martin Neumann and Camille Roth), the dispute is still wide open and deserves further contributions.

3 Future Prospects

The relation between theory, models and empirical validation should be considered as the next frontier for the advancement of social simulation. If theoretical abstraction should be naturally viewed as an essential part of scientific research, the development of computer simulations in the social sciences should be related to their capacity to foster the explanation of empirical phenomena. This is to avoid the risk of the self-referential nature of theoretical models as well.

If this is true, a challenge for the future is the appropriate combination of computer simulation with other methods. Instead of seeing computer simulation as a different method, or as an exhaustive method *per se*, a good practice would be to work towards combining different formal, experimental, statistical and empirical methods and try to exploit the best of each one (de Marchi 2005). The epistemological consequence would be also to expand upon the analysis of the qualities and properties that perhaps make computer simulation different from other methods and tools. But the recognition of these prospective differences does not imply, as thought by many computational social scientists, that computer simulation models should be necessarily judged outside the standard framework and practices of science.

From a methodological viewpoint, many scholars have already recognized a future prospect in the field of verification/ validation/ sharing/ communication of models and results (Axelrod 2006; Windrum, Fagiolo and Moneta 2007). As Gintis correctly outlined (2007), computer simulation models, in particular agent-based models, are profoundly penalized within the standard scientific community because of many problems of scientific communication and inter-subjective control. The case of economics is emblematic. In economics, agent-based models are sometimes introduced as theoretical models to be used as an alternative to formal analytical economic theory, sometimes as empirical models from which one could infer properties that could be analytically systematized, or on which one could build comparisons among particular cases. In any case, the lack of transparency and the impossibility/difficulty to enter in all the details of a model and of a set of simulations make evaluation of a simulation model often impossible. Only an expert in the computer language used or the expert who designed precisely those simulations presented in that paper understand the details. The result may be that referees of journals are forced to take the author's assertions on faith alone. This is where standard analytic models are superior to agent-based computational ones at the present. Moreover, let us suppose that a model is the result of a collaboration between a social scientist and a computer scientist, as often happens. In such a case, the problem of the verification is generally underestimated. Nuno David correctly emphasizes this in his chapter: there is a risk of underestimating possible misunderstandings and hidden differences between the theoretical and the implemented model, which are a natural source of theoretical invalidation of simulation results and, as a consequence, of the theoretical inferences conducted on them.

This observation strongly supports our final claim that the future of social simulation and the appropriate usage of computer simulation in the social sciences will depend on the investment that the leading scholars and institutions in this field will do on the training and education of young scholars, PhD and undergraduate students in simulation languages. This is necessary for raising a generation of young social scientists able to advance the scientific frontier of social simulation and to embed computer simulation in the standard toolkit of the social scientist of the 21st century. What is needed is to slowly but surely get out of the current "hand-crafted" phase, to be able to enter in a new phase, where standard practices, methods and scientific communication can get stronger and cumulate step-by-step.

4 Summary of the Book

The chapters of this book are very heterogeneous in their contents, but they can all be subsumed under the same general purpose. They are good examples of the present quest for the pre-conditions, processes and consequences of computer simulation in the social sciences, combined with the methodological, epistemological and substantive issues.

The second chapter, "The Epistemologies of the Social Simulation Research" is an invited contribution by Nigel Gilbert and Petra Ahrweiler. The authors aim to fertilize the epistemological debate on social simulation with the philosophical debate in the social sciences. They conclude with a critical and pragmatic position on the need for an epistemological and methodological unified perspective, arguing that evaluation criteria for simulation research need to be tuned to research aims, methodological positions and domains of study, rather than being conditioned by epistemological and/or methodological pre-established viewpoints.

The third chapter, "From Simulation to Theory (and Backward)" is an invited contribution by Rosaria Conte. It focusses on the "generative approach" to computational social sciences, which has been synthesized in the recent "generativist manifesto" by Epstein (2007). The author argues against the tendency to conflate theory and simulation, as well as explanation and computational generativeness. She proposes a body of arguments to emphasize the relevance of a computational social science theory that should be able to combine bottom-up theory of general local rules and top-down downward causation. In doing so, she locates herself in the recent debate on the distinctive features of social emergence (Sawyer 2005).

The fourth chapter, "Talking about ABSS: Functional Descriptions of Models", by Scott Moss, attempts to integrate empirical and abstracted models, with the aim of reducing the divide between the practices and the approaches of empirical and theoretical analyses in social simulation. The author suggests a framework to foster the discussion of epistemological issues, such as prediction, validation and verification.

The fifth, sixth and seventh chapters constitute a sub-section focused on emergence. Alex Schmid proposes a review of ontological and epistemological meanings of emergence, with a contextualization of the particular role of computer simulation as an analytical tool for studying emergent properties and processes, while Martin Neumann reassesses the literature to propose a conceptual framework for understanding the autonomy of the emergent properties in social spheres. Finally, Camille Roth argues that reductionism and emergentism fail at the same time in detecting ill-conceived modeling ontology.

The eighth chapter, "Narrative Scenarios, Mediating Formalisms, and the Agent-Based Simulation of Land Use Change" by Nick Gotts and J. Gary Polhill, inaugurates the methodological chapters of this book. The authors move on from the evidence that the kinds of systems studied through agent-based models in the social sciences are first understood in terms of narrative languages and descriptions, with the consequence that a set of problems arise because of the difference between the semantics of natural language and programming languages. Using examples taken from simulation of land use change, they articulate an ontological framework and a formalism to mediate between the two. The following two chapters focus on the relevant quest of the verification/validation of simulation models. Nuno David suggests distinguishing between verification and validation, as well as clarifying their meanings and their relation. Moreover, he tries to embed the methodological debate on the relevant quest of what "truth" and what "knowledge" are generated by means of simulations. Paul Ormerod and Bridget Rosewell cope with the quest of the empirical validation of agent-based models in the social sciences. They reconstruct some of the difficulties in establishing verification and validation of agent-based models, and suggest simplifying the theoretical building blocks of the models at most, so that comparison and acceptance of models could be improved. Moreover, they bring empirical evidence that supports the so called KISS (Keep It Simple, Stupid) principle of agent-based modeling, namely that agents in real situations tend to act intuitively rather than rationally. In this perspective, they criticize the supposed "naturality" of the cognitive approach to agent-based models.

The eleventh chapter, "Abductive Fallacies with Agent-Based Models and System Dynamics" by Tobias Lorenz, elaborates on the abductive nature of simulation, with particular attention to the role of simulation methodologies in conditioning the modeling process. The twelfth chapter, "Algorithmic Analysis of Production Systems Used as Agent-Based Social Simulation Models" by Jim Doran, is an exploration of the algorithmic analysis of simulation models as a means to systematize model abstraction. To demonstrate the potential of his exploration, the author refers to an applied example, namely the Iruba model of a guerrilla war. Last but not least, the thirteenth chapter, "The Nature of Noise", by Bruce Edmonds, works up a comprehensive exploration on the concept of noise. The author argues that noise and randomness are *not* the same and thoughtlessly conflating them can result in misleading assumptions. This exploration has relevant implication for the modeling and understanding of complex phenomena.

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