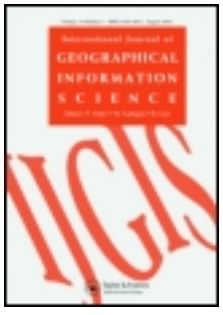

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Agent-based models of geographical systems, edited by Alison J. Heppenstall, Andrew T. Crooks, Linda M. See and Michael Batty

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BOOK REVIEW

Agent-based models of geographical systems, edited by Alison J. Heppenstall, Andrew T. Crooks, Linda M. See and Michael Batty, Dordrecht/Heidelberg/London/New York, Springer, 2012, £179.99, 759 pp., (hardcover), ISBN 978-90-481-8926-7

Students of natural science are brought up in an atmosphere of validation: any model of real-world phenomena remains just an intellectual exercise until it is validated. Numerous aspects of validation (see Chapter 10) express different views regarding the comparison of a model's forecast to the real phenomenon. In a never-ending competition for better prediction, modelers improve old models and develop new ones.

From the validation point of view, mathematics is not a natural science – the theorems are based on axioms and *modus ponens* and if we accept both, we have no choice but to accept the theorems.

Should we consider our Agent-Based (AB) geographic models as aiming to represent the real world, or as mathematical statements? My impression from the editorial and positional chapters in this book is that the editors are very skeptical regarding validation-based competition, that they definitely side with the theoretical approach, and advise students of AB modeling to regard their model as an exploratory rather than a predictive tool. Indeed, the conceptual chapters in this volume as well as the chapters presenting AB modeling basics use examples of pure theoretical models, such as the Schelling model of residential segregation. The review chapters that describe the abilities of various AB models avoid comparison between them. In the chapters devoted to applications, only a few models are presented in sufficient detail to understand what the model actually does and how it does it.

To justify the 'validation skepticism,' mathematicians can say that an AB model of a real-world complex phenomenon inevitably contains many components and dependencies that are established and parameterized by the modeler, and that the parameters can never be properly estimated. Natural scientists can reply that the mathematicians forget their own theory of complex systems, that the dynamics of the 'proper model' must be insensitive to parameterization and governed by order parameters, and that the model as a whole should be verified in situations that are as far as possible from equilibrium. A book review is not the place to continue this hypothetical discussion, but I see the domination of the mathematical view of real-world phenomena as characteristic of the state of the art in AB modeling in geography.

Should AB simulation be considered a kind of mathematical representation of geographic systems? There are serious arguments in favor of such a position. First, we lack operational knowledge about human decision-making behavior, and cannot wait until a plausible description of decision-makers – pedestrians, householders, farmers, or urban developers – becomes available. Second, nowadays validation is based on the aggregate characteristics of the phenomena, such as land-use maps, census data or video records while ignoring the validation of agents' behavior, and one can hardly hope to distinguish between the agents' behavioral rules based on the aggregate data. However, continuing this line of thought, what should I do if some computer nerd, working as an urban planner,

substituted the SimCity infrastructure layers with the 1990 data of the city he or she works for and obtained likely patterns for 2000 and 2010? Should I recommend SimCity (http://www.simcity.com) for planning and decision-making?

I believe that the current state of AB modeling in geography reflects the state of human geography as a whole. Until very recently, human geography was a science of the aggregate data. Human behavior was hypothesized and the hypotheses were called 'a theory.' AB modeling was born within population ecology with its deep tradition of validation, and now we, the geographers, have reached the point where we must decide on this critical issue. My opinion is that of the conservative physicist – to properly utilize Agent-Based Modeling as a working tool for human geography we, the AB modelers, must seek validation at every level of scientific enquiry. The AB modeling ideology should include a framework for model descriptions that are sufficiently detailed for replicating a model. This framework should demand different sets of data be used for estimating parameters and model validation; sharing of data that a model was built on; and operational comparisons and competition between models in predicting the same phenomenon. I sincerely hope that some models will become irrelevant for representing reality because they are based on assumptions that cannot be verified, or are so complicated that the results are not credible.

Pursuing the goal of adequately representing the current state of AB modeling in geography, the editors of the book pose the hard question of verification and take the mathematician's side. Chapter 1 'Perspectives on Agent-Based Models and Geographical Systems' claims that 'For many systems, we have plausible but non-testable hypotheses about how we think the system works, and if we exclude these simply because we cannot test them against data, then we are guilty of distorting our theory simply due to the expediency of not being able to test it using classical means: against independent data,' and, further, that '. . . models should be run to test whether they are behaving as their originators intended and this has little or nothing to do with how well they might reproduce observable data' (p. 4).

I do not think that all the authors of the 37 chapters aimed to follow the editors' views. The book is essentially heterogeneous. It contains introductory chapters with simple exercises vis-à-vis comprehensive state-of-the-art reviews. In-between are positional chapters in which authors state their views of AB modeling – both as a whole and in regard to the specific fields of AB modeling applications in geography. Some of the chapters are devoted to specific aspects of simulation, such as model validation or error analysis, and some chapters address specific AB modeling applications. To help the reader, the editors provide an introduction and 'A Guide for the Reader where they identify several paths for reading the book, from those fit for a beginner to those for an expert in AB modeling. My view of the book follows this logic too.

For those who want to learn what AB modeling is, I would suggest starting with Chapter 8, 'Designing and Building an Agent-Based Model,' by Mohamed Abdou, Lynne Hamill, and Nigel Gilbert. This is a very well written introduction to AB modeling in geography, with a balanced presentation of general information and technical aspects. The example, the Schelling model of ethnic residential pattern dynamics is presented in detail and includes the NetLogo code. The chapter can be used for introductory lessons in the classroom and demands minimal knowledge of programming. My only concern is that the authors do not stress the necessity to investigate the model after it is developed. To extend the view of approaches to high-resolution spatial modeling, I would continue with Chapter 4, 'Cellular Automata in Urban Spatial Modelling' by Sanna Iltanen. This light review presents the basic definitions of cellular automata (CA) and several examples of CA applications in geography. In Chapter 5, 'Introduction to Agent-Based Modelling,'

Andrew T. Crooks and Alison J. Heppenstall provide the reader with a nowadays' view of the field, touching on all aspects of AB modeling as a tool for geographic enquiry, from the analysis of experimental data for establishing the model dependencies to the visualization of results, and contains numerous references.

The short Chapter 9, 'Modelling Human Behavior in Agent-Based Models' by William G. Kennedy, presents the cognitive science approach to describing and representing agents' behavior in the AB models. This introductory chapter is highly recommended for the student of AB modeling who feels that there should be a huge bulk of reading on the behavior of agents, but does not know how to start.

For those who want to know about the state-of-the-art AB modeling in geography, I would suggest starting with Chapter 3, 'Review of Microsimulation and Hybrid Agent-Based Approaches' by Mark Birkin and Belinda Wu. Birkin and Wu stress that they are discussing Microsimulation (MS) and not AB modeling, and distinguish between them as 'Microsimulation only models one-direction interactions: the impact of the policy on the individuals, but not the impact of individuals on the policy,' while AB models account for both top-down and bottom-up processes. For me, the separation is artificial and this comprehensive and deep review makes me feel much better about the use of 'Microsimulation' as just another title for 'Agent-Based modeling.' Chapter 7, 'Agent-Based Modeling and Complexity' by Steven M. Manson, Shipeng Sun, and Dudley Bonsal, considers the field from the angle of self-organization, emergence, and non-linearity, characteristic of the real-world systems that we model with the help of agents. In addition, this chapter can be considered a good introduction to the complexity theory in geography. Chapter 22, 'Business Applications and Research Questions Using Spatial Agent-Based Models' by William Rand, examines AB modeling from the point of view of business and management. This chapter presents several models that are usually missed in AB modeling reviews, as models of retail consumer behavior in space.

In Chapter 18, 'Agent Tools, Techniques and Methods for Macro and Microscopic Simulation," Ateen Patel and Andrew Hudson-Smith start with their view of AB modeling, which, in many aspects, repeats the review chapters that are already mentioned. I highly recommend the second part of the chapter, which presents a thorough and user-oriented review of the recent achievements in crowd dynamics simulation and of the software that can be employed for this purpose. In the short Chapter 21, 'Applied Pedestrian Modeling," Anders Johansson and Tobias Kretz discuss the problems of this field, but provide little comment on how these problems can be resolved; it can be considered as complementary to Chapter 18. Chapter 20, 'Urban Geosimulation" by Paul Torrens, presents a very personal review of the field and stresses the importance of high-resolution GIS databases for AB simulation of urban dynamics and urban residential patterns. In the brief Chapter 24, 'Simulating Spatial Health Inequalities," Dianna M. Smith presents the major aspects of agent-based simulation in spatial epidemiology, including epidemic dynamics and spatial patterns of health services. This huge field could benefit from a more detailed review.

The reader who wants to delve deeper into the finer details of AB modeling will definitely enjoy Chapter 10, 'Calibration and Validation of Agent-Based Models of Land Cover Change," by The An Ngo and Linda See. The chapter provides a comprehensive and very carefully written review of the major aspects of validation for simulation models in social science, with special stress on AB modeling. It contains a clear scheme of how to check if your model (after debugging) accurately represents the real-world spatial phenomenon that inspired you to build it. The authors include many useful examples, including their own research that is also considered in more detail in Chapter 30 (see below). The short Chapter 11, 'Networks in Agent-Based Social Simulation," by Shah Jamal Alam

and Armando Geller, points to networks as the natural representation of the relationships between agents in AB models.

Chapter 12, 'The Integration of Agent-Based Modelling and Geographical Information for Geospatial Simulation' by Andrew T. Crooks and Christian J. E. Castle, nicely sorts the relationships between GIS databases, as suppliers of the high-resolution spatial information on agents and objects participating in geographic simulations, and the conceptual and technical ways of coupling GIS with dynamic simulations. The separation among Loose–Moderate–Tight coupling between the GIS database and the AB model is very convenient and is supported by meaningful examples, as well as the description of the development stages when considering agents and their environment (Table 12.2). The chapter also contains a thorough review of the AB modeling software and references to important papers that describe the use of this software for specific models. I would welcome the authors' comments on disadvantages of particular software tools and the ease of learning the environment, but they decided not to touch these aspects. I would also raise the rating for the long-existing and, regretfully, expensive AnyLogic software. Chapter 13, 'Space in Agent-Based Models" by Kiril Stanilov, complements Chapter 12 by discussing the raster–vector duality in representing spatial objects and using irregular tessellations, including a real-world parcel coverage in the AB models.

Chapter 14, 'Large Scale Agent-Based Modelling: A Review and Guidelines for Model Scaling" by Hazel R. Parry and Mike Bithell, provides an answer to the critical question – what can we do when an AB model performs poorly? The study of simulations performed by a dynamic model demands, usually, thousands of runs. All goes well if each simulation takes seconds, but becomes a nightmare if it takes hours or days. The authors review current approaches to improving AB modeling performance, and focus on two main methods – using 'Super Agents" and reprogramming the simulation for parallel computing. They present the available software for model scaling together with meaningful examples. From the practical point of view, I lacked enough clues to help me in defining Super Agent as well as the comparison of the Super Agent approach to the old but gold mean-field approximation. With regard to parallel computing, recent cloud-oriented tools such as Apache Hadoop http://en.wikipedia.org/wiki/Hadoop and MapReduce http://en.wikipedia.org/wiki/MapReduce should be definitely mentioned.

Andrew Evans focuses on model validation in Chapter 15, 'Uncertainty and Error,', presenting an excellent continuation from Chapter 10. Evans reviews the issues involved in understanding model error, covering a broad range of methodologies and viewpoints from across the spatial modeling sciences. The review is comprehensive and contains many meaningful examples and references.

Chapter 17, 'Designing, Formulating, and Communicating Agent-Based Models' by Volker Grimm and Steven F. Railsback, describes, in a condensed form, their popular 'Overview, Design concept, Details' (ODD) protocol for presenting AB models in publications (that is successfully used in Chapters 29, 30, 32, and 33). They also introduce the concept of pattern-oriented modeling (POM). Students of computer science will immediately relate ODD and POM to the concept of Design Patterns and Universal Modeling Language (UML). Until the latter two become a part of the standard curriculum for AB modeling, the use of ODD and POM will definitely improve both the ability of developers to represent, and the ability of readers to understand AB models, regardless of whether we intend to fully employ the concepts of OOD and POM or just use them as a posteriori framework for model representation.

Several chapters present ongoing unfinished projects: In Chapter 16, 'Agent-Based Extensions to a Spatial Microsimulation Model of Demographic Change', Belinda M. Wu

and Mark H. Birkin offer a short description of an AB-extension of the spatially explicit model of UK population dynamics 30 years into the future. Chapter 25, 'Agent-Based Modelling of Residential Mobility, Housing Choice and Regeneration' by René Jordan, Mark Birkin, and Andrew Evans, aims at relating a Shelling-like model of residential dynamics with real survey data, and makes a first step in this direction. Chapter 26, 'Do Land Markets Matter? A Modeling Ontology and Experimental Design to Test the Effects of Land Markets for an Agent-Based Model of Ex-Urban Residential Land-Use Change' by Dawn C. Parker, Daniel G. Brown, Tatiana Filatova, Rick Riolo, Derek T. Robinson, and Shipeng Sun, presents a conceptual scheme of an AB model of residential land-use development that combines economic and land-use decisions. In contrast, Nicholas R. Magliocca presents an economic model of urban housing and land markets that is built but awaits investigation in Chapter 27, 'Exploring Coupled Housing and Land Market Interactions Through an Economic Agent-Based Model (CHALMS).' The great advantage of this chapter is in the detailed mathematical presentation of the economic assumptions and rules implemented in the model. At the same time, I miss confirmation that the model replicates some real-world housing and land economics. Chapter 28, 'Exploring Urban Dynamics in Latin American Cities Using an Agent-Based Simulation Approach' by Joana Barros, discusses the relationship between the Schelling model and urban residential dynamics in Latin American cities; Chapter 29, 'An Agent-Based/Network Approach to Spatial Epidemics' by Joana A. Simoes, presents an AB model of epidemic dynamics that demands further validation and study.

The chapters that present developed and, in some respect, validated modeling exercises are of special importance. This is the fundamental truth of AB modeling and the editors succeeded in bringing together several attractive and convincing examples. I will only comment briefly on these chapters because the reader interested in how-to-do-that examples has no choice but to read each chapter in depth. Nicolas Malleson includes an interesting review of AB modeling in criminology in Chapter 19, 'Using Agent-Based Models to Simulate Crime'. In addition to presenting the model itself, Malleson examines an important example that implements two (instead of the customary one) types of interacting agents – citizens and thefts. Chapter 23, 'Using Agent-Based Models for Education Planning: Is the UK Education System Agent Based?' by Kirk Harland and Alison J. Heppenstall, explores the UK education market. Their model demonstrates that commonsensical rules regarding the choice of school can provide acceptable results, with over 60% of pupils being allocated to the correct schools and 75% of schools containing at least 50% of the correct pupils when compared to observed data. Chapter 30, 'An Agent-Based Modelling Application of Shifting Cultivation' by The An Ngo, Frances Drake, and Linda See, is an excellent example of properly documented model development. The chapter describes the choice of a relatively simple real-world system for modeling, model development, validation, investigation, and presentation of the results. Chapter 32, 'A Logistic Based Cellular Automata Model for Continuous Urban Growth Simulation: A Case Study of the Gold Coast City, Australia' by Yan Liu and Yongjiu Feng, is one more great example of how to develop and represent a model. In their CA model, transition probabilities between land uses are represented by means of the logistic regression, and the results of the model investigation clearly point to the advantages and disadvantages of this approach. Chapter 33, 'Exploring Demographic and Lot Effects in an ABM/LUCC of Agriculture in the Brazilian Amazon' by A. Raymond Cabrera, Peter Deadman, Emilio Moran, Eduardo S. Brondízio, and Leah K. Vanwey, is an interesting and well-presented example of simulating farming over the deforested areas in the Brazilian Amazon during 1970–2000. I lack an attempt to relate model results with the reality. In Chapter 36, 'Multi-agent

System Modelling for Urban Systems: The Series of SIMPOP Models', Denise Pumain presents the version-by-version development of a model in order to establish a comprehensive description of urban systems dynamics, from the level of the neighborhood and settlement to the entire country level.

Some of the chapters discuss employing AB models for studying theoretical questions, of which two deal with the power law. Chapter 34, 'Beyond Zipf: An Agent-Based Understanding of City Size Distributions' by Timothy R. Gulden and Ross A. Hammond, presents a model of city population growth that is based on bounded rational population migration in respect to the city size and generates Zipf distribution. Chapter 31, 'Towards New Metrics for Urban Road Networks: Some Preliminary Evidence from Agent-Based Simulations' by Arnaud Banos and Cyrille Genre-Grandpierre, presents the first steps towards a model of traffic regulation in a city. They investigate the influence of the number of traffic lights on the aggregate characteristics of traffic in an abstract city. In Chapter 35, 'The Relationship of Dynamic Entropy Maximising and Agent-Based Approaches in Urban Modelling', Joel Dearden and Alan Wilson compare a Boltzmann–Lotka–Volterra model of urban retail developed by Harris and Wilson in 1978 to an AB model of urban retail and demonstrate that the results are similar when applied to the metropolitan county of Yorkshire, United Kingdom.

The goal of the positional chapters is to inspire discussion, and they succeed in doing that. Despite disagreeing with many of the claims made in these chapters, I truly enjoyed reading them. In Chapter 2, 'A Generic Framework for Computational Spatial Modelling', Michael Batty presents his view of AB spatial simulations in the general context of complex dynamic system modeling and discusses the conflict between the modeler's inherent tendency to simplify and complexity of the real systems. He then illustrates these views with the Land Use Transportation Interaction (LUTI) models that can be implemented as CA or AB model, and provides a short review of recently implemented models of this kind. Analyzing the LUTI modeling, Michael Batty concludes that '. . . evident complexity is so great that plausibility rather than validity may be the real quest'.

Chapter 6, 'Agent-Based Models – Because They're Worth It?' by David O'Sullivan, James Millington, George Perry, and John Wainwright, focuses on identifying the circumstances in which AB models have advantages over other types of modeling. They point to the situations in which the heterogeneity of the agents' decision-making and interactions are important, but ignore the aspects of data supply and parameter estimates for heterogeneous population of agents. At the same time, they take it for granted that the hypothetical AB modeler has similar experience with other simulation techniques, which, for me, is doubtful. In this respect, I would not consider elementary model spatial units ('grains') and model characteristic time as something that is special for AB models. They are essential for any model. As I have already mentioned above, the best way to decide which model works best is to develop both and compare them.

And, finally, the editors' views of the field are presented in the first two chapters – Chapter 1, 'Perspectives on Agent-Based Models and Geographical Systems' by Michael Batty, Andrew T. Crooks, Linda M. See, and Alison J. Heppenstall; and Chapter 2, 'Reflections and Conclusions: Geographical Models to Address Grand Challenges' by Alison J. Heppenstall, Andrew T. Crooks, Michael Batty, and Linda M. See. I started this review with my response to these chapters.

To conclude, the 37 chapters of this fundamental volume provide a comprehensive perspective of the state of the art in the intensively developing field of modern geographic enquiry to the community of AB modelers in geography. I enjoyed reading the book and

I am sure it will have an essential influence on the AB modeling community and inspire numerous further developments in the field.

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