PREFACE

Purpose

The explosive growth in computer power over the past several decades offers new tools and opportunities for economists. Volume 1 of the Handbook of Computational Economics [Amman et al. (1996)] surveyed the growing literature on computational methods for solving standard economic models such as Arrow–Debreu–McKenzie general equilibrium models and rational expectations models. This second volume focuses on *Agent-based Computational Economics (ACE)*, a computationally intensive method for developing and exploring new kinds of economic models.

ACE is the computational study of economic processes modeled as dynamic systems of interacting agents who do not necessarily possess perfect rationality and information. Whereas standard economic models tend to stress equilibria, ACE models stress economic processes, local interactions among traders and other economic agents, and out-of-equilibrium dynamics that may or may not lead to equilibria in the long run. Whereas standard economic models require a careful consideration of equilibrium properties, ACE models require detailed specifications of structural conditions, institutional arrangements, and behavioral dispositions.

Although the tools and language may differ, the agendas of standard economics and ACE are thus complementary. For example, many ACE modelers study the processes by which prices are set in decentralized market economies, a problem not considered in standard equilibrium modeling. Moreover, the two modeling approaches share the long-run goal of understanding more fully the dynamic properties of realistically rendered economic systems, an understanding that requires knowledge of potential equilibria *together* with their basins of attraction.

As noted in the preface of Volume 1, there is no clearly defined field that we call Computational Economics. However, the body of ACE research focusing on core topics is now substantial, and it is a good time to take stock of where we are and to communicate this summary to a wider audience of economists.

Moreover, having an ACE handbook at this time also serves an important pedagogical purpose. The ACE approach to economic problems is novel. ACE research requires training in computational modeling skills that few graduate economic programs currently provide, and that relatively few professional economists currently possess. Individuals desiring to take this path will therefore need to have a certain amount of boldness, a willingness to take risks, a willingness to operate outside the boxes outlined

by those who have gone before. This ACE Handbook is dedicated to the support and encouragement of these individuals.

Organization

The ACE Handbook is divided into sixteen research reviews, six perspective essays, and a guideline for newcomers to agent-based modeling. These materials cover the following topics.

In the first two chapters, the Editors present overviews of the substantive aims of the ACE literature and the relationship of the ACE methodology to more standard economic modeling. Chapter 16, by L. Tesfatsion, discusses the ACE approach to the study of economic systems and contrasts this approach with more standard equilibrium approaches using a relatively simple two-sector decentralized market economy for concrete illustration. In Chapter 17, K.L. Judd focuses on the problems of determining and communicating the economic content of the results of computationally intensive research, and the trade-offs between standard approaches and computational methods. These two introductory pieces are intended as gateways into the handbook for economists new to ACE modeling.

Chapter 18, by T. Brenner, discusses the key role played in ACE models by learning agents and critically surveys a wide variety of possible agent learning representations. In Chapter 19, J. Duffy examines the potential synergies between experiments conducted with human subjects and experiments conducted with computational agents, with a stress on empirical validation issues.

The determination of agent interaction patterns is a basic foundation for all ACE models. In Chapter 20, A. Wilhite undertakes a series of experiments to explore how bilateral trading and other forms of economic interactions are influenced when conducted within alternative types of networks (e.g., a small-world network). N. Vriend extends this focus in Chapter 21 by considering how ACE researchers have modeled the *endogenous* formation of interaction networks. In the latter models, agents have some degree of choice regarding not only how to behave in any given interaction but also with whom to interact and with what regularity. In Chapter 22, H.P. Young presents and concretely illustrates a rigorous method for analyzing the long-run behavior of systems constituting large numbers of interacting agents with widely differing characteristics.

Financial economics is one of the more active ACE research areas. Chapters 23 and 24 provide extensive surveys of financial market research in which the endogeneous heterogeneity of dynamic investment behavior appears to be critically important for the explanation of observed regularities in financial time series. In Chapter 23, C. Hommes focuses on relatively simple financial market models that are at least partly tractable by analytic methods and that are being used as benchmarks in support of more complex ACE modeling efforts. In contrast, B. LeBaron in Chapter 24 focuses on ACE financial market studies for which the complexity of the models requires the intensive use of computational tools.

Technological change and innovation concern the generation and diffusion of new knowledge, technologies, and products. In Chapter 25, H. Dawid discusses the current and potential contributions of the ACE modeling approach to this difficult topic area. For example, he demonstrates how several empirically established stylized facts regarding technological change and innovation, viewed as puzzles within standard equilibrium modeling, emerge quite naturally in agent-based models.

Organizations are collections of agents who interact with each other within the confines of some formally or informally structured set of rules, and whose activities are guided in part by personal preferences and in part by collective objectives. In Chapter 26, M. Chang and J. Harrington survey a wide variety of organization models, including models of multi-agent firms, multi-plant manufacturers, and retail chains. They develop their chapter around a set of research questions common to the organization literature, comparing and contrasting traditional and agent-based modeling approaches and highlighting new insights afforded by the latter approach.

Over the past thirty years a whole new field of study has blossomed within economics, called *market design*. The normative focus of this field is how institutional rules governing trade can be treated as variables subject to optimization. To date, however, tractability concerns have forced many researchers to restrict attention to equilibrium models in which the strategic options open to traders are severely constrained ex ante.

In Chapter 27, R. Marks first reviews in general terms the manner in which ACE models with strategic learning agents have been used to evaluate market designs from a dynamic perspective. He then highlights ten papers that exemplify recent progress in this topic area, with a particular emphasis on the evaluation of electricity market designs. Chapter 28, by J. Mackie-Mason and M. Wellman, also addresses market design issues. In contrast to Marks, however, the authors focus their attention on automated markets with software trading agents. Their primary concern is the direct use of agent-based tools to achieve a complete effective automation of the various components of market transactions.

A particularly exciting aspect of the ACE methodology is the encouragement and facility it provides for integrative modeling. In keeping with the reasonable Einstein dictum "a scientific theory should be as simple as possible but no simpler," researchers generally tailor their models to the type of issue under study, stressing some features while downplaying or omitting others. But critical model features do not always fall tidily along conventional disciplinary lines.

Chapters 29 and 30 focus on issues of importance to economists for which political concerns are paramount. In Chapter 29, K. Kollman and S. Page critically survey a range of agent-based models developed by economists and political scientists to address collective action problems, pie-splitting problems, electoral competitions, and security and communal stability issues at both the national and sub-national levels. In Chapter 30, M. Janssen and E. Ostrom survey ACE research addressing the governance of systems

comprising social and biophysical agents. A key aim of the latter research has been increased understanding of institutional arrangements conducive to the cooperative use of collective ecological resources (e.g., fisheries) in the face of extensive behavioral uncertainty.

In Chapter 31, C. Dibble discusses the potential of computational laboratories for facilitating the design and exploratory analysis of agent-based models with spatial aspects. Illustrative examples include spatial small-world network models, social norm diffusion models, and epidemiology models for the control of infectious diseases.

The next section of the handbook consists of six essays offering perspectives on agent-based modeling. Alphabetically ordered by author, these essays elaborate on the following themes.

W.B. Arthur explains why the movement now under way towards agent-based modeling is not simply an adjunct to neoclassical economics but a major shift to a more general out-of-equilibrium economics. R. Axelrod uses some of his own personal experiences to exemplify how agent-based modeling can help overcome the somewhat arbitrary boundaries between disciplines. J. Epstein argues that the central contribution of agent-based modeling to the scientific enterprise is the facilitation of generative explanation: How can an observed regularity be generated through the autonomous local interactions of heterogeneous boundedly-rational agents?

P. Howitt contends that current economic growth research focuses too exclusively on individual incentives and choice, ignoring critical coordination issues. He advocates the use of agent-based modeling tools as a way of seeing beyond the "individual dots" of an economic system to the overall patterns that emerge from simple interactions among a large number of interacting agents. Following a critique of modern macro theory, A. Leijonhufvud argues that agent-based methods should be used to revive the traditional core of macroeconomics: namely, supply and demand interactions in markets with adaptive boundedly-rational participants. He concludes, in particular, that agent-based methods provide the only means for exploring the self-regulating capabilities of complex dynamic economies, and for advancing our understanding of the adaptive dynamics of actual economies.

In the final perspectives essay, T. Schelling takes the reader back to an airplane trip in the 1960s during which, for amusement, he began experimenting with x's and o's on a penciled-in checkerboard on a piece of paper. His purpose was to see what might result from the repeated location choices of the x and o agents under variously assumed intensities of preference for residing among neighbors of their own type. Out of such musings, the now-famous Schelling City Segregation Model was born.

The handbook concludes with an Appendix by R. Axelrod and L. Tesfatsion offering a general guideline for newcomers to agent-based modeling in the social sciences. The guideline provides a short annotated list of suggested introductory readings.

It also provides pointers to additional readings and software materials to help interested readers get started on their own agent-based research.

LEIGH TESFATSION *
Department of Economics, 260 Heady Hall, Iowa State University, Ames, IA 50011-1070, USA
e-mail: tesfatsi@iastate.edu; url: http://www.econ.iastate.edu/tesfatsi/

KENNETH L. JUDD
Hoover Institution, Stanford, CA 94305, USA
e-mail: judd@hoover.stanford.edu; url: http://bucky.stanford.edu/

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Reference

Amman, H.M., Kendrick, D.A., Rust, J. (Eds.) (1996). Handbook of Computational Economics. Handbooks in Economics Series, vol. 1. North-Holland, Amsterdam, the Netherlands.

* Corresponding author.