Discrete Dynamics in Nature and Society, Vol. 3, pp. 71–74
Reprints available directly from the publisher
Photocopying permitted by license only

Book Review

The Economy as an Evolving Complex System II, edited by W. Brian Arthur, Steven N. Durlauf, and David A. Lane, Santa Fe Institute Studies in the Sciences of Complexity Proceedings Volume XXVII, Addison-Wesley, Reading, Massachusetts, 1997, 583 pp., subject index, $36.00.

This volume constitutes the proceedings of a conference held at the Santa Fe Institute (SFI) in August, 1996 and is a worthy follower of an earlier and influential SFI volume (Anderson, Arrow, and Pines, 1988) which grew from the conference that began the Economic Program at the SFI. Whereas the earlier volume reflected speculations, possibilities, and hypotheses, this newer volume reflects a decade of work in which what can be called the Santa Fe vision of complexity in economics has since developed. It represents achievement, and there is much more coherence as well as depth in this volume than in the earlier work.

A question we need to address before contemplating the contents of the 21 papers in this volume is what are the elements of the "Santa Fe vision of complexity"? This is a non-trivial issue as there are numerous definitions of complexity floating around, possibly as many as 45 according to Seth Lloyd of MIT. The SFIers do not have a specific definition. But popular accounts of their activities (Waldrop, 1992) have generated an image of what their view of it is, even if this is not what we find exactly in this work. The popularization of the work at Santa Fe has in turn triggered a backlash of criticism from some quarters (Horgan, 1997) that pokes especially at the apparent vagueness of the complexity concept with such wisecracks as "complexity leads to perplexity."

As close as anybody comes to giving a definition happens in the Introduction by the editors who list six features of economies that they see as presenting difficulties for the "traditional mathematics used in economics" (p. 3). The first of these, and perhaps the most distinctive, is that of *dispersed interaction*. This means that models focus on the specific interactions between specific agents dispersed in some manner and how these interactions cocreate an aggregate state. This is contrasted with the usual approach in economics in which either one agent is interacting with the aggregate whole or all are simultaneously interacting with all others. This approach has been exemplified in practice by the use of such approaches as artificial life programs, genetic algorithms, mean-field spin glass models, sandpile models, and other approaches used in biological and physical modeling at the SFI. Many of these approaches are amenable to simulation modeling using discrete methods and there are numerous examples of such applications in the papers of this volume.

In many respects the other features listed by the editors arise naturally from this first one. Thus they are, that there is *no global controller*, that there is *cross-cutting hierarchical organization* with many channels of communication and tangled interactions, that there is *continual adaptation* which is not surprising in an approach advertized as being

evolutionary as well as complex, that there is perpetual novelty, and that the systems adjust through *out-of-equilibrium dynamics*, thus showing the influence of such figures as Prigogine and Haken who are not always fully acknowledged. These systems generally are adaptive nonlinear networks.

Although this volume focuses on economics, several of the noneconomist figures at SFI who have played important roles in developing these more general concepts and techniques appear in this volume and did so in the first one, including the computer scientist, John Holland, the biologist, Stuart Kauffman, and the physicists, Philip Anderson and Richard Palmer. The only economists who appear in both volumes are Brian Arthur and William Brock. This may reflect the fact that many of the economists in the first volume were relatively conventional and defending orthodox approaches in contrast with the ideas being presented by those from the other disciplines. The contents of this book suggest that the figures from the other disciplines were successful in convincing the economists to adopt their approaches, which may be why we see such a different cast of characters among the economists this time around.

Broadly the contributors can be divided into three groups. One is a set of mostly fairly well known economists who exhibit shortened versions of their existing wares, often essentially synopses of recent books, with an effort to supply at least a patina of SFI complexity perspective to their discussions. These efforts succeed to varying degrees. Many have their own interest, especially for anyone not already familiar with the authors' works and not up for pursuing their ideas in their original venues.

The second group presents reasonably comprehensive reviews of certain topics and issues. Generally the authors are covering considerable amounts of their own work, but this is kept within a broader perspective of the issues under discussion which generally are close to the cores Santa Fe ideas. The third group present specific applications or adumbrations of concepts that can be viewed as strongly in line with the core SFI complexity vision. This includes most of the papers that have the noneconomists involved in them, usually as coauthors.

The first group includes papers by Nobel Prize winner, Douglas North, on some historical cases of institutional emergence, by Axel Leijonhufvud on turbulent dynamics in high inflations, by John Geanokoplos on how the demand for collateral affects equilibrium, and by Martin Shubik on game theoretic approaches to the evolution of money and financial institutions.

The second group includes Charles Manski on econometric difficulties in distinguishing endogenous interactions, contextual interactions, and correlated effects. Paul Krugman discusses his idiosyncratic views of the "new economic geography." At least in this account Krugman identifies the model of Schelling (1971) on urban residential segregation as a main precursor to the Santa Fe approach in its demonstration of dispersed interactions among immediate neighbors generating aggregative structures, although this model is noted and cited in many other papers in the volume.

Also in the second group, and much closer to the Santa Fe core, are closely related papers by Steven Durlauf and William Brock. They are colleagues at the University of Wisconsin-Madison and also coauthors of an unpublished but much cited paper in this volume (Brock and Durlauf, 1995). Their work draws on the "mean-field" (also known as "spin glass" or "interacting particle systems (IPS)") approach, originally introduced into economics by Föllmer (1974). This is a popular favorite with many of the contributors in this volume, along with its close competitor, the sandpile or "self-organized criticality" model of Per Bak (1996). This latter can be construed as perhaps being closer to the "edge of chaos" ideas often publicized as being the essential Santa Fe idea, but which finds itself somewhat subordinated in this volume, although hardly absent. Durlauf's paper focuses particularly on the derivation and applications of the mean-field approach, showing a variety of applications including the emergence of social stratification in

neighborhoods and divergences in long-run growth patterns. Brock's paper is more focused on questions dealing with financial market phenomena irregardless of the particular method of analysis. Brock's broad perspective reflects his position as the only author whose credentials include a serious development of chaos theory, widely thought to be the immediate intellectual predecessor of complexity theory, however one defines it.

Perhaps the most innovative of those in this second group is a paper by Yannis Ioannides who has long been involved in urban and regional modeling. Drawing on recently published work of his own he proposes the use of random graphs (Erdös and Renyi, 1960; Evstigneev, 1988) to analyze the evolution of trading structures that may have a spatial component. This paper ably links with the discussions of mean-field approaches and also links with the paper by Alan Kirman in this volume.

The rather more diverse third group includes papers by Darley and Kauffman on natural rationality within a dispersed interactive agent framework with game theoretic and mean-field foci, Lawrence Blume on population games and the problems of defining time horizons associated with such models, Kollman, Miller, and Page on a model of computational political economy that shows some promise, Lane and Maxfield on strategy in the telecommunications industry, Lane showing how in information contagion models what is good for one may not be good for all, John Padgett applying the interesting ideas from hypercycle theory to the evolution of the acquisition of skills, Leigh Tesfatsion shows how "economists can get a life" by using the artificial life program, one of the mainstays of the general Santa Fe menagerie, and Philip Anderson warns in a concluding note that averages may not be as important as extremal cases in determining the nature of reality.

This leaves us with two related papers from the third group that stand out as especially important. One is by Kristian Lindgren which shows how strategies evolve in an open-ended game-theoretic environment. Lindgren considers the classic prisoner's dilemma game with allowing for adaptive adjustments of strategies by heterogeneous players. Generally there is no convergence to any specific set of preferred strategies, even with mean-field effects and Kauffman-like NK adaptive adjustment mechanisms. However, Lindgren shows that lattice models and mean-fleld models do not generate similar results.

Finally we have the second piece in the volume which is arguably its most substantial entry. This represents the latest incarnation of a long-running research project by Brian Arthur, John Holland, Blake LeBaron, Richard Palmer, and Paul Tayler regarding an artificial stock market model that draws on many of the ideas and themes running throughout the volume. In a nutshell this model of heterogeneous agents learning trading strategies in the stock market shows broadly two outcomes. One is where convergent behavior dominates in which the unique rational expectations equilibrium predominates, even if the system does not necessarily converge fully to it. The other arises when search behaviors and "bandwagon" effects become sufficiently significant with much more complicated dynamics arising as bubbles appear and disappear in succession. This paper links deeply with an emerging strand of financial economics literature that suggests that there are critical points in market behavior between stable zones and more complicated zones. An underlying issue in this paper is that of the issue of how cognition interacts with the selection of strategies, a topic of special interest to Arthur (1995). An analytical analogue of this model that shows a wide array of complex phenomena is due to Brock and Hommes (1997).

So where does this plethora of output leave us in terms of the broader evolution of these ideas? John Horgan (1997) has dismissed the whole Santa Fe complexity approach as simply the latest stage of a hopelessly long-running fad, the "four C's," cybernetics, catastrophe, chaos, and complexity. In this view each of these in turn has been shown to be either a misguided or irrelevant approach which was nevertheless hopelessly hyped during its pathetic heyday. Such a view is far too facile. There

is deep truth in it in that there has indeed been an intellectual succession with these approaches following each other in a not entirely unrelated manner, often with certain individuals being involved in more than one of these stages, several such individuals serving in editorial board positions with this journal.

Ironically, while the weakest link in this chain is from cybernetics to catastrophe theory, it can be argued that the former has had an implicit revival in the generally more complicated and adaptive models that one finds with the dispersed interactive agent models of the Santa Fe complexity approach, although this connection is unacknowledged in this volume, being by now rather distant. Catastrophe theory has, of course, received much condemnation and ridicule at the hands of many observers. However, its essential message of the importance of discontinuities and sudden structural shifts in dynamical systems is very much alive in this volume, its place having been largely taken over by the mean-field approach with its phase transitions at critical values of control parameters within a more stochastic framework. Although not generally explicitly pursued, chaos theory also holds its own in the varieties of complicated dynamical patterns that arise from these models, even if they do not generally represent the outcomes of relatively simple deterministic equation systems, however nonlinear.

In this regard the complexity approach can be seen as a bifurcation of this older strand of analyses of bifurcating dynamical systems. It would seem upon closer examination that the crucial element of this bifurcation is the emphasis on heterogeneous agents whose actions depend on those of at least some of their neighbors. This seemingly simple idea has opened up a wide variety of possibilities within discrete dynamical systems, and not just within economics as the wide variety of offerings in the SFI Proceedings series indicates.

Within this broader perspective this volume stands out as an especially well done example of what the Santa Fe complexity approach can lead to. There is much here of significance and depth, even if it can be argued that there is insufficient recognition of parallel efforts coming out of Brussels and Stuttgart and that some of the papers get off onto tangents. In general the papers show respect to their antecedents and roots as well as reaching for their stars and future implications. This is an admirable piece of work, one worthy of careful study not only by economists but by individuals of other disciplines who seek to understand the Santa Fe approach to complexity theory in dynamical systems.

References

Anderson, P.W., Arrow, K.J. and Pines, D. (Eds.) (1988). *The Economy as an Evolving Complex System*. Addison-Wesley, Redwood City, CA.

Arthur, W.B. (1995). Complexity in economic and financial markets. *Complexity* **1**, 20–25.

Bak, P. (1996). *How Nature Works: The Science of Self-Organized Criticality*. Copernicus Press for Springer-Verlag, New York.

Brock, W.A. and Durlauf, S.N. (1995). Discrete choice with social interactions I: Theory. SSRI Working Paper, Department of Economics, University of Wisconsin-Madison.

Brock, W.A. and Hommes, C.A. (1997). A rational route to randomness. *Econometrica* **65**, 1059–1095.

Erdös, P. and Renyi, A. (1960). On the evolution of random graphs. *Publications of the Mathematical Institute of the Hungarian Academy of Sciences* **5**, 17–61.

Evstigneev, I.V. (1988). Stochastic extremal problems and the strong Markov property of random fields. *Russian Mathematical Surveys* **43**, 1–49.

Föllmer, H. (1974). Random economies with many interacting agents. *Journal of Mathematical Economics* **1**, 51–62.

Horgan, J. (1997). *The End of Science: Facing the Limits of Knowledge in the Twilight of the Scientific Age*, paperback ed. Broadwy Books, New York.

Schelling, T. (1971). Dynamic models of segregation. *Journal of Mathematical Sociology* **1**, 143–186.

Waldrop, W.M. (1992). *Complexity: The Emerging Science at the Edge of Order and Chaos*. Simon & Schuster, New York.

J. Barkley Rosser, Jr.
Program in Economics
James Madison University
Harrisonburg, VA 22807, USA
E-mail: rosserjb@jmu.edu.