not necessarily as dominant elements of, diverse ant communities in their native ranges (Tennant; Majer; Patterson). A topic touched on in many chapters is the nature of the ecological mechanisms involved in the displacement or replacement of resident ant species by invading species. Though it is frequently assumed that local reductions in individual abundance or species diversity of natives follow from direct competition or predation by exotics, Majer and Wojcik point out, as have others, that such reductions may be correlated responses to changes in other factors that favor the exotic and disfavor the natives, such as increased habitat disturbance. A high point of the volume is Passera's description of the social and breeding habits of tramp ants that are important for successful invasion. Meier shows that opportunistic feeding habits coupled with efficient, chemically based recruitment systems can be added to Passera's list.

The volume is not without disappointments. There is no explicit conceptual framework that organizes it. The order of the chapters seems largely haphazard and several seem not to belong at all. There is little indication of how studies of exotic ants can help us understand general ecological and evolutionary processes, which is unfortunate because the best studied exotic ant, the fire ant *Solenopsis invicta*, is emerging as a major model system in this regard. Nor does the book contribute significantly toward the development of an ecological theory of invasion. Thus it likely will have little appeal outside a narrow community of researchers who focus on ant introductions and their immediate consequences.

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Vignettes: Eye-Opening

I am convinced that the story of the universe that has come out of three centuries of modern scientific work will be recognized as a supreme human achievement, the scientific enterprise's central gift to humanity, a revelation having a status equal to that of the great religious revelations of the past.

—*Brian Swimme*, as quoted in *Evolution Extended: Biological Debates on the Meaning of Life* (Connie Barlow, Ed.; MIT Press)

It has been said that science demystifies the world. It is closer to the truth to say that science, when it is at its best, opens the world up for us, bringing daily realities under a kind of magic spell and providing the means to see the limits of what we think we know, and the scope of what we do not at all understand.

—*Claus Emmeche*, in *The Garden in the Machine: The Emerging Science of Artificial Life* (Princeton University Press)

Next Values

Time Series Prediction. Forecasting the Future and Understanding the Past. ANDREAS S. WEIGEND and NEIL A. GERSHENFELD, Eds. Addison-Wesley, Reading, MA, 1993. xx, 643 pp., illus. $49.50; paper, $32.25. Santa Fe Institute Studies in the Sciences of Complexity, vol. 15. From a workshop, Santa Fe, NM, May 1992.

The publication in 1970 of *Time Series Analysis: Forecasting and Control* by George Box and Gwilym Jenkins was a landmark in time series analysis. Building on the work of Yule, Bartlett, and others, the authors laid out a methodology for parametric time series analysis. This methodology covers linear time series models. An example of such a model is the first-order autoregressive process, in which the current value is a linear function of the previous value plus a random error. Since 1970, time series modeling has progressed in many directions including extensions to non-Gaussian and multivariate time series, models with non-constant parameters, and models that accommodate measurement error.

Although the family of linear models is quite rich, it is necessary on scientific grounds to consider nonlinear models. An example is the first-order nonlinear autoregressive process, in which the current value is a nonlinear function of the previous value plus a random error. There are two broad approaches to nonlinear time series analysis: parametric and nonparametric. The parametric approach essentially extends the Box-Jenkins approach to parametric families of nonlinear models. This extension involves new methods of data analysis. For example, a nonlinear process cannot be fully characterized by its mean and autocovariance function (or, equivalently, its spectrum) alone. The parametric approach to nonlinear time series analysis is covered in books by M. B. Priestley (1988) and Howell Tong (1990).

There are again two broad approaches to nonparametric modeling: the statistical approach and the dynamical systems approach. In the statistical approach, the relationship between the current value and previous values is estimated by nonparametric regression. In experienced hands, the statistical approach can exploit recent developments in nonparametric modeling outside the area of time series analysis. Some scientific understanding of the underlying processes also does not hurt.

A little background helps to understand the dynamical systems approach. Whitney's theorem in topology says that a smooth, compact manifold of dimension d can be embedded in a Euclidean space of dimension $2d+1$. Takens extended this theory to the embedding of a dynamical system. The practical result is that, if the original system evolves along an attractor, the topology of the attractor can be recovered in the behavior of multidimensional "histories" of an observable time series generated by the system. A history or delay is a finite vector of lagged values of a time series. This result establishes a link between nonlinear autoregressive models and time series generated by dynamical systems, in the sense that the former focuses on multidimensional histories.

Embedding theory has also been used as the basis for a geometric approach to time series prediction. The idea is this. If I knew the attractor of a dynamical system and I knew the trajectory that the system was on, I could predict the future by projecting the trajectory along the attractor. In the case of chaos, trajectories diverge, so this scheme only works in the short term unless the trajectory is known precisely. Embedding theory says that this idea can be applied in the Euclidean space of histories. For example, if I want to predict the next value of a time series, I just find previous values that had similar histories and see where those values ended up one period later. For this approach to succeed, it is necessary that the dimension of the system be small (remember that the dimension of the topologically equivalent Euclidean space is higher) or that the time series be very long: otherwise, the curse of dimensionality ensures that there will be no points in the time series with similar histories.

The development of these ideas, particularly in the area of dynamical systems, has been extremely rapid, and, in the words of Andreas Weigend and Neil Gershenfeld, the literature is fragmented and anecdotal. In an effort to sort things out, Weigend and Gershenfeld ran a competition in which participants analyzed four data sets. Upon the completion of the competition, a NATO Advanced Research Workshop on Comparative Time Series Analysis was held at the Sante Fe Institute to discuss the results. The present volume is a report of that workshop.

The volume begins with an introduction by Gershenfeld and Weigend covering many aspects of nonlinear time series analysis, the theory of dynamical systems, neural nets, and their own theories about learning and understanding. Reading it is a bit like taking a three-day tour of eight countries: you only know where you are if you have been there before. The balance of the volume is divided into four sections. Section 1 describes the four data sets used in the competition: emissions of NH_3 lasers, a multivariate physiological time series, exchange rate variations, and brightness variations in a white dwarf star. After the competition, a mathematical representation of an unfinished Bach fugue was added, which, in my view, comes perilously close to failing the cuteness test.

The competition had two goals: prediction and characterization. Sections 3 and 4 report on successful entries under these two headings. For prediction, the reports can be grouped into three rough categories: geometric methods, statistical methods, and methods based on neural networks. The distinction between the latter two is illusory. A neural net is essentially nonlinear regression in a black box. For time series analysis, the black box should simulate the brain of a good statistician with an understanding of the process to be modeled. Some may come close. Many don't. But why accept substitutes? Characterization refers to dimension estimation, identifying chaotic dynamics (for example, by estimating the largest Lyapunov exponent), and detecting determinism and nonlinearity. The final section contains some miscellaneous papers, including two on the difficult problem of spatial chaos.

This book is interesting, entertaining, and more than occasionally instructive. I particularly liked Sauer's paper on geometric prediction and the cautionary paper by Theiler, Linsay, and Rubin on the spurious detection of nonlinearity in linear models with long-range dependence. None of the papers is bad. Now to complaints. First, the volume does not manage to sort out the aforementioned fragmented and anecdotal literature. Though this would have been a monumental undertaking, a little more progress might have been made. Part of the problem is the sheer enthusiasm of the contributors. Apart from Theiler *et al.* and Lewis, Ray, and Stevens, who rain ever so gently on the neural net parade, skepticism is not much in evidence. Second, to make the analyses convincing to a wide range of scientists it would have been useful to consider somewhat messier data. There is no shortage. Third, on the technical side, the attitude toward noise in much of this work is rather cavalier. Noise can enter through the process itself (for example, turning a first-order difference equation into a first-order autoregressive process). It can also be observational, so that the process itself is never actually observed. As innocuous as this distinction may seem, it can have important implications for data analysis and modeling. Whole books have been written on the subject. Most of the methods described in this book are based on implicit assumptions (some quite bizarre) about the way in which noise enters the system, and no attention is devoted to the consequences of the alternatives. Finally, I have to wonder whether this exercise is not a little premature. So many basic statistical issues are left unraised—the treatment of noise being just one—that a little more work with pencil and paper seems in order. Despite these reservations, this volume is well worth a look for those interested in modern time series analysis. It may not be the next Box and Jenkins, but it is certainly a step in the right direction.

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