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Book Review

Dynamical Cognitive Science. By L. M. Ward. MIT Press, Cambridge, MA, 2002, xv + 355 pp. IBSN 0-262-23217-0.

In this informative book on the applications of nonlinear dynamics in cognitive science, Ward maintains the three R's of good scientific writing, Readable, Researched and Recommended. Ward's basic tenet is that time plays a crucial role in all psychological processes and so must be included in any viable cognitive theory. He remarks cogently on the tendency for much of cognitive psychology to concentrate on static outcomes of cognitive processes, such as semantic structures, rather than on their temporal evolution.

One aim of the book is to redress the imbalance in cognitive psychology arising from the application of conventional technologies to data analysis and theory. These include experimental techniques, such as analysis of variance that search for causal agents among a set of independent variables, as well as some early cognitive models that emphasize representations in terms of modular structures rather than the time course of their generation. In one challenge to convention in Chapter 16, Ward uses innovative research by Gilden, Thornton and Mallon (1995) to suggest that the temporal fluctuations in dependent variables are possibly more diagnostic of fundamental cognitive processes than any effects of the experimental variables. Based on more recent work by Gilden (2001), residual time series provide evidence for both self-similarity in cognitive processes and perhaps quantification of a cognitive "representation." Surprisingly, as much as 20–30% of the residual variability in cognitive data may be due to nonlinear deterministic processes, rather than being the measurement noise assumed by those using analyses of variance. Perhaps the most important research strategy change is a renewed emphasis on the analysis of single participant data sets, rather than relying on group means. To this extent, dynamic cognitive science reestablishes psychology as the science of the individual, a person with a unique brain and psychological functioning.

Ward's book covers a wide range of topics linking cognitive science with recent developments in dynamic system theory, each compartmentalized into small chunks, known as Chapters (less than 10 pages per chapter on average!). This writing strategy might give the book a discordant impact, but Ward has skillfully arranged the subject matter so that the book flows rather than being disjointed. The book begins with a summary of familiar topics such as serial processes in behavior, brain rhythms, timing of cognitive processes, and then continues with a more formal introduction to dynamical systems theory, and the role of structural models. This is followed by a comparison of these models with more familiar stochastic ones, including the fundamental ideas behind linear time series modeling.

Ward then embarks on a dynamic adventure introducing the reader to possibly unfamiliar material from modern physics, such as the basic properties of "ordinary" and colored noise, stochastic resonance, chaos and, somewhat later in the book, relaxation oscillators. This material is presented in a readable way, unobscured by the complexities of the underlying mathematics. The relevance to cognitive theory is clear from examples such as time estimation, music aesthetics, brain electrophysiology, and visual pattern recognition.

Readers of a dynamics textbook expecting material on chaotic and other nonlinear dynamic processes will not be disappointed. Six of the chapters focus on applications of chaotic systems in human cognition, including the detection of chaos in time estimation data acquired of course from single subjects, and the cognitive prediction of chaotic sequences. The book concludes with a brief summary of contemporary ideas in computational neuroscience and some speculative comments on the "grand-daddy" of all scientific problems, consciousness.

In the chapter on General Systems Theory, Ward highlights the importance of system-environment interaction, a dynamic interplay between nature and nurture that has attained even more importance with the advent of coupled network models, most particularly in computational neuroscience (mentioned in Chapter 18). Ward notes in particular the perplexing nature of complicated systems, such as the brain and behavior, that exhibit "organized complexity."

There are some problems and omissions in a field that is advancing more rapidly than anyone can possibly chronicle. For example, in a discussion of the relative merits of deterministic and stochastic models, there is no reference to the ground-breaking work of Smith (1995) who has successfully solved the difficult technical task of fitting leaky stochastic models to RT distributions in luminosity discrimination tasks. Equation 11.4 is a nonstandard definition of a first-order MA process, the more usual RHS term being a zero-mean white-noise random variable. There are other slight inaccuracies, such as just below Eq. 12.6, the definition of a function as the "parameter" of the model is a bit obscure. On p. 103 a random walk, or diffusion, process is considered to have stationary (infinitesimal) increments if the mean and variance of the steps are time invariant, otherwise the model is a more complex nonstationary one (see Heath, 1992). Also on p. 110 the "master equation" contains no time variable.

Chapter 16 discusses the role of 1/f noise in human cognition, a proposal confirmed by Gilden (2001) in production tasks and by Kelly et al. (2001) in a four-choice RT task. Interestingly, Smithson's (1997) work on the prediction of chaotic time series suggests that people are sensitive to the Hurst exponent, a measure of the tendency for time-series values to persist or to alternate (antipersistence). This result implies a concomitant sensitivity to the power-law slope. So people may be sensitive to time scale invariant phenomena that exist throughout the physical world, such sensitivity perhaps applying also to the pain-pleasure centers of the brain (p. 136).

Mimicking 1/f spectra using MA processes, described on p. 141, was also proposed by Pressing (2000), although combining AR processes dates a little further back (p. 170). Ward's suggested limiting case of three processes aggregated at different time scales is consistent with this idea, but the 1/f outcome is not quite linear as can be seen from Fig. 19.2.

Ward presents the interesting result that the 1/f slope decreases as the number of choices in an RT task increases. One possible interpretation of this finding is that the lower slope represents a process with more noise, possibly emanating from motor, rather than decision, processes. Ward also suggests that the change in slope relates to mental scanning processes operating at a midrange temporal scale. One resolution to this theoretical difficulty would be to estimate movement and home button release (decision) times separately and show that the change in slope was markedly reduced for release time but not for movement time. It would be interesting to examine how the attractors in phase space change with an increase in the number of choices. A viable alternative is a queuing or working memory process (see p. 168) since the greater the queue length the less the 1/f slope, a result consistent with the CRT data.

Eq. (18.7) needs further explanation and there is some symbolic inconsistency. On p. 166 the Nyquist limit suggests for a 0.1 Hz process, a measurement time of 20 sec rather than 10 sec. The section on surrogate data in Chapter 25 requires expanding to include recent developments by Schreiber and Schmitz (2000), such as stating the Null Hypothesis as a linear Gaussian system with the same power spectrum as the experimental data. Such a technique uses phase randomization to generate replicates rather than random shuffling.

In Chapter 26 the use of the BDS statistic is inappropriate for "bleached," i.e. linearly filtered, data (see Theiler & Eubank, 1993). It is better to use an alternative procedure such as Approximate Entopy, a quantitative index more in tune with nonlinear determinism in the time series. It is also worth noting that detecting chaos in experimental data, even via a sophisticated prediction method, is not easy, unless the data are noise–reduced.

In recognition of the important role nonlinear dynamics plays in our understanding of psychopathology, Ward suggests that "a white noise time series occurs when the patient's behavior is under control of fluctuating external stimuli, whereas nonlinear deterministic dynamics imply the existence of an externally controlled process unfolding without much influence of external stimuli' (p. 235). This general principle is confirmed when the 1/f slope is greater for pathology than normalcy, the latter's greater noise producing a slope closer to the zero value characteristic of white noise. An interesting result confirming this proposal was obtained for bipolar clients when compared with their matched controls (Gottschalk, Bauer, & Whybrow, 1995).

Dimensionality analysis can provide relative comparisons of behavioral data such as RT and mood time series, provided there are at least 2000 observations, as Ward recognizes on p. 241. The major problem of course is with nonstationarity for which Gregson's (2002) procedure, based on a discrete form of the Schwartzian derivative, holds considerable promise.

In Chapter 27, Ward's discussion of evidence for chaos in the brain is complicated by the difficulty in demonstrating clearly that a strange attractor represents the effects of a single stimulus. According to Gilden (2001), it more likely represents a mental state, or representation, possibly created by more than one type of stimulus. The possibility of the brain entering a lower dimensional (less complex) state following an environmental change is analogous to psychophysical models based on control of chaos (Heath, 2000b).

The account of sequence perception in Chapter 28 presupposes the validity of an evolutionary approach to explaining environmental influences on prediction performance. As Horgan (1999, p. 194) has aptly stated "Evolutionists can take any set of psychological and social data and show how they can be explained in Darwinian terms." We know very little about the statistical properties of real events of significance to behavior and we will never know how these properties have changed over the ages. This critique also applies to Ward's suggestion on p. 291 that: "complex systems poised at the 'edge of chaos' are the most able to adapt and change through the processes of mutation and natural selection."

The results from the Budescu (1987) experiment are not clearly presented. Interestingly however, Kareev's (1992) work suggests that production of "random" sequences depends on short-term memory capacity. This idea is further expanded by reference to a model by Treisman and Faulkner (1987) which uses processes such as stabilization and tracking, suggesting the usefulness of the adaptive Kalman filter for tracking nonstationary time series parameters (Heath, 2000a).

In Ward's account of the prediction of chaotic sequences, when people try to predict a logistic attractor they generate a lumpy phase plot that cannot be represented by a noisy logistic process. However some, but not all, features of the data can be fit more adequately by the fuzzy memory-pairs model devised by Ward and West (1998). This suggestion was confirmed somewhat using a nonlinear prediction test (Casdagli, 1991). However this is not a convincing argument since no attempt at parameter estimation was made. Nevertheless, the result does suggest that to approximate chaos, people use heuristic procedures that are ripe for further experimental investigation.

The last five chapters adopt a more speculative approach and head off into relatively unexplored dynamic territory. In Chapter 31, the important theoretical role played by relaxation oscillators is emphasized in areas such as computational neuroscience and in temporal modeling of motor processes, such as tapping etc. So it is no wonder Ward considers it a worthwhile model for general brain function, provided adequate behavioral evidence can be acquired. Relaxation oscillators are ideal for synchronization of brain processes with external inputs, perhaps being the basis for all perceptual and memory processes. Longtin's equations (31.6) bear a superficial similarity to Gregson's (1988) Gamma model with its cubic nonlinearity. Synchronization once again plays an important role for binding of mental associations, in particular. Appropriately, Ward suggests that "[t]he promise is that modeling human cognitive phenomena with relaxation oscillators will allow current and future neural models to be coupled to behavioral models, bringing dynamical modeling to a new level of complexity and usefulness." (p. 283) The interested reader should also consult Pikovsky, Rosenblum and Kurths (2001) for an excellent contemporary account of synchronization theory.

In a discussion on the role of brain imaging in Chapter 33, Ward correctly emphasizes the importance of integrating brain imaging time series (multidimensional) and those emanating from cognitive processes. The idea that gamma (fast) and theta (slow) EEG frequencies interact leading to working memory limitations, has been confirmed recently by Raffone and van Leeuwen (2001). Furthermore, the use of chaos as a computational device, possibly important for brain function, is an interesting suggestion. This idea has been used successfully in secure communication systems and so may be needed for efficient brain function.

As is common these days, Ward concludes the book with some speculative comments on how consciousness might arise from the binding or coherence of brain processes. One interesting implication of the suggestion that consciousness depends on 40 Hz brain activity is that it corresponds approximately with the human threshold for simultaneity versus successiveness, i.e.

25 msec. Synchronization of brain activity at this frequency could indeed be responsible for binding concurrent neural activity and therefore offering the impression of reality.

Readers of Ward's book will come away with some new insights into how cognitive science is likely to proceed in the new millenium. They will discern the importance of a multidisciplinary convergence between psychology (for the fundamental phenomena and data), neuroscience (for the basis of all brain dynamics), physics (for novel insights into possible dynamic mechanisms and for mathematical and computational modeling of nonlinear processes), as well as the clinical and social sciences (for innovative applications that will enhance human welfare). Selecting any of the book's Chapters as starting points will lead inevitably to an exciting exploration of new approaches to cognition and to the behavioral sciences in general. The impact of such an exploration will be evident for many years to come.

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Richard Heath
Department of Psychology
School of Social Sciences
Kingston University
Penrhyn Road
Kingston upon Thames
Surrey KT1 2EE
United Kingdom
E-mail: r.heath@kingston.ac.uk