Progress in Applied Nonlinear Dynamics: Welcome to NDPLS Volume 8

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Welcome to Volume 8 of *Nonlinear Dynamics, Psychology, and Life Sciences* (*NDPLS*). There have been many important developments in our field of science, and our mission remains unchanged. The mission of *NDPLS* is to accelerate the study of the applications of a core group of mathematical constructs and related research methodologies to a broad range of topics in psychology, the social and policy sciences, and the biological sciences. The core elements include attractors, bifurcations, chaos, fractals, solitons, catastrophes, self-organizing processes, cellular automata, genetic algorithms and related evolutionary processes, and neural networks. The broad mixture of the disciplines represented here indicates that many bodies of knowledge share common principles. By juxtaposing developments in different fields within the life and social sciences, the scientific communities may obtain fresh perspectives on those common principles and their implications.

The following is a brief overview of the recent developments in nonlinear dynamical systems (NDS) and their applications. The summary is necessarily confined to the portions of the relevant literature that have had the greatest direct or indirect influence on *NDPLS* content in recent years, but it is not intended to exclude any possible new applications. In contrast with my editorial to Volume 1 (Guastello, 1997), it is now possible to include *NDPLS* contributions themselves in the short lists that follow.

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MATHEMATICS AND METHODS

Those who are encountering NDS for the first time are encouraged to read Abraham and Shaw (1992), Kaplan and Glass (1995) Bar-Yam (1997) and Sprott (2003) to catch up on the basic mathematical concepts and some of their latest uses. Pictorial techniques such as attractor reconstruction (Abraham, 1997) and recurrence plots (Sabelli & Abouzeid, 2003) also continue to inform applied nonlinear science. Some of the new developments in mathematical statistics for the physical sciences address the challenge of determining a sufficient nonlinear model from numerous possibilities (Mees, 2000).

The life and social sciences have profited from the ability to translate the mathematical concepts into testable hypotheses concerning the presence of particular dynamics. Some of the new statistical methods are suited to continuously valued functions in a time series (Guastello, 2002; Heath, 2000), whereas others are suited to finding quantifiable patterns in qualitative data that transpire over time. In the former group, fractal dimensions, Lyapunov exponents, and catastrophe models are valuable for describing and comparing nonlinear systems. The qualitative techniques might be based on symbolic dynamics (Guastello, 2000) or network-reduction procedures that lend themselves to the identification of basic nonlinear dynamics (Dooley, Corman, McPhee, & Kuhn, 2003), and appear to provide analytical strategies where few options existed prior to any NDS contributions.

Cellular automata and agent-based simulations constitute another group of NDS methodologies. Just as chaotic behavior may arise from particular simple equations, complex patterns may arise from simple programmable rules. Cellular automata are, for the most part, descriptive of phenomena that can be characterized as 2-dimensional spatial arrays. Typically, the emerging patterns cannot be inferred from simple information provided about the system's initial states and rules. Wolfram (2002) noted that one must develop an intuition for how real-world problems translate into mathematical models, but that intuition comes from practice with building and manipulating models.

Agent-based simulation models have some affinity with cognitive science. Perception-action sequences are codified into simple rules that are executed by "agents," which represent entities in a population. Large quantities of "agents" execute the rules in response to

each other's actions. Global patterns emerge from the myriad local interactions, and thus represent another class of systems that self-organize from the bottom up. Agent based models have been especially useful in the analysis of networks of communications, terrorism, economic development institutional organization, and transportation. A special issue on Agent Based Models is planned for the April 2004 issue of *NDPLS*.

Simulation studies and applied theories of self-organization that are based on the rugged landscape (Kauffman, 1993, 1995) and sandpile (Bak, 1996) scenarios have also been useful, particularly in organizational studies (Levinthal & Warglien, 1999; McKelvey, 1999). Importantly, all forms of self-organizing processes are explicable as information flows (Haken, 2000). The interrelationships among the concepts of information, entropy, Lyapunov exponents and dimensionality, fractals, phase shifts and catastrophes continue to be explored and exploited (Bak, 1996; Ott, Sauer, & Yorke, 1994; Puu, 2001; West & Deering, 1995; Zhang, 2002).

APPLICATIONS

Psychology

The applications in psychology can be roughly organized into four groups: cognitive science, social and organizational behavior, personality and clinical psychology, and neuroscience and physiological psychology. These categories are obviously arbitrary, but they are useful for focusing a picture of a broad literature base. Again, the objective here is to provide an outline of books and articles that is broad enough in scope to convey the topology of the *NDPLS* purview.

A review of NDS applications in cognitive psychology that was current through February, 2000 (Guastello, 2001) indicated that all the major areas of experimental psychology have been reached: psychophysics, perception, cognition, learning and memory, psycho-motor response, and human development. The field has since been augmented with extensive works by Heath (2000), Gilden (2001), Ward (2002), and numerous *NDPLS* articles, of which Gregson (2004, this issue) is the most recent. NDS concepts are now observed as part of nearly traditional areas such as human factors engineering (Jagachinski & Flach, 2003).

The same review article (Guastello, 2001) cataloged numerous topics in social and organization behavior that included motivation and work performance, social cognition and attitude change, interpersonal attraction, creative problem solving, leadership emergence, work group coordination, and policy strategy. Those topics have been extended by Arrow, McGrath, and Bergdahl (2000), Poole, Van de Ven, Dooley, and Holmes (2000), Guastello (2002), and Yuan and McKelvey (2004, this issue). Social networks have gained attention as well (Barab‹si, 2002; Guastello, 2002, Watts, 2000, 2003).

NDS has led to new theory and experimentation within several classical schools of thought in personality theory and within the more pragmatic studies of clinical treatment and complex pathologies such as schizophrenia and bipolar disorder (Guastello, 2001). Perspectives that are grounded in NDS neuroscience are also promising (Grigsby & Stevens, 2000). Family system dynamics appear to generate many forms of interesting dynamics, including chaos (Gottman, Murray, Swanson, Tyson, & Swanson, 2003; Koopmans, 1998; Pincus, 2001). At the broadest level of analysis, however, NDS appears to have changed the basic concept of the human mind itself, according to Orsucci (2002).

Biomedical Sciences and Other Living Systems

This is an area that is as broad as psychology, and one with a longer history. I limit myself, therefore, to the point that NDS has allowed scientists to tackle new questions. *NDPLS* published a special issue on the topic "Fundamental Problems in Biocomplexity" in January 2001.

In the area of cognitive neuroscience, memory is now viewed as a distributed process that involves many relatively small groupings of neurons, and that the temporal patterns of neuron firing contain a substantial amount of information about memory storage processing (Kohonen, 1989). The temporal dynamics of memory experiments can elucidate how the response to one experimental trial would impact on subsequent responses and provide information on the cue encoding, retrieval, and decision processes. One might examine behavioral response times (Clayton & Frey, 1996, 1997) and rates (Metcalf & Allen, 1995), the transfer of local electroencephalogram (EEG) field potentials (Liang, Ding, & Bressler, 2001), similar local transfers in functional magnetic resonance images (fMRI; Guastello, Nielson, & Ross, 2002), or

combinations of response time and EEG data (Popivanov, Janyan, Andonova, & Stamenov, 2003).

Mpitsos (2000) proposed that attractors evolving in a set of neurons are sources of information that can be used not only to model adaptive behavior, but also to effect the neural architecture that generates the attractor. He conjectured that the relaxation dynamic of an attractor may "guide" activity-dependent learning processes in such a way that synaptic strengths, firing thresholds, the physical connections between neurons, and the size of the network are automatically set in an optimal, interrelated fashion. Oscillation patterns and synchronization of neuron firing in various brain areas also require NDS theory and analysis (Balduzzo, Ferro Milone, Minelli, Pittaro-Cadore, & Turiccia, 2003; Basar, 1998, 1999; Kowalik, Steriade, Skinner, & Witte, 2000).

Questions about the temporal dynamics of memory are nestled within a still-broader puzzle known as the "binding problem:" Stimuli arrive at the organism's receptor cells. Neurons fire in complex patterns that represent the elementary sound frequencies or other sensory features. Firing patterns evolve and become connected to memory objects with meanings that the organism recognizes. The nature of the connection between memories as we experience them and the activities of neurons remains a mystery (Sulis, 2001). The mystery extends to top-down memory organization, which occurs when the organism willfully recalls memories while solving a novel problem, and neurons respond accordingly. The general rule appears to be that novel or challenging problems and novel stimuli produce more complex neuronal firing patterns than familiar or mundane tasks or stimuli (Freeman, 2000; Gregson, Campbell, & Gates, 1992; Grigsby & Stevens, 2000; West, Novaes, & Kavcic, 1996). If we consider further that individual humans can show differences as to which neural patterns that become entrained as mundane, something akin to personality can eventually be represented at the neuronal level (Grigsby & Stevens, 2000). In light of the complex relationships that must exist in processes that are driven by both bottom-up and top-down dynamics, the meso-level neuronal circuitry is one new focus of attention from the NDS perspective (Freeman, 2000).

Although conventional science has made great strides in understanding genetic patterns in recent years, there are many DNA nucleotide sequences that are not understood. According to Spinelli (2003), so-called junk DNA may indeed have complex functions that govern mutations and that can only be discerned with NDS concepts.

Nonlinear symbolic dynamics may be required to test Spinelli's genetic theory (Wu, 2000) as they have with heart rate variability associated with a variety of disorders (Berkowitsch, Carlsson, Erdogan, Neuzner, & Pitschner, 2000; Kim et al., 2000; Wessel et al., 2000; Yamada et al., 2000; Yeragani, Nadella, Hinze, Yeragani, & Jampala, 2000), and abnormal versus healthy bone structure (Gowin, Saparin, Kurths, & Felsenberg, 1998). In principle, symbolic dynamics might be applied to any situation where nonlinear behavior or living systems are involved (Arecchi, 2001).

The earliest studies of chaotic behavior in physiological systems relied on computations of the fractal dimension. Studies of cell tissue, EEGs, and electrocardiograms (EKGs) indicate that greater irregularity (turbulence, complexity) appears in the output (or cell morphology) from healthy systems. Unhealthy systems gravitate toward periodic and simplistic output (Goldberger et al., 1996; Hornero, Alonso, Jimeno, Jimeno, & Lopez, 1999; Landini, 1996; Meyer et al., 1998; Sabelli & Kauffman, 1999). This trend has been extrapolated to organizational behavior (Dooley, 1997) and communication dynamics within families (Pincus, 2001). The general principle is that the organism is a complex adaptive system, and that the turbulence or complexity in its behavior allows for the broadest range of adaptive responses.

The presence of $1/f^B$ dynamics, where B is the fractal dimension, has been observed in many self-organizing phenomena in the physical, life and social sciences (Bak, 1996; Gilden, 2001; West & Deering, 1995), including epidemiological phenomena (Philippe, 2000). Other elementary nonlinear dynamics have been identified in the simple mathematical models for epidemic contagion that were published in the early 20th century (Guastello, 1995).

Plant life is also relevant to the purview of *NDPLS*. Contributions to date include ecological systems (Medvinsky, Tikhonov, Enderlein, & Malchow, 2000) and the role of fractal structure in the evolution of plant structures (Kocic, 2001).

Economics and Policy Sciences

The relationship between economic concepts and those from physics, nonlinear and otherwise, dates back about as far as the introduction of analogies from physics to psychoanalytic psychology in the early 20th century. The Walrasian equilibrium and the Nash

equilibrium decades later are two notable examples. It is thus no surprise that Mantegna and Stanley (1999) introduced the concept of "econophysics" to characterize the contemporary NDS versions of the associations between physical and economic dynamics.

Finance is one of four broad areas of economics that is replete with nonlinear dynamics (Mantegna & Stanley, 1999; Rosser, 2000). Macroeconomics is another challenging domain. Some schools of economic thought attempt to reduce system-level events to the decisions of individual financial agents. NDS studies in macroeconomics, however, are more consistent with other schools of economic thought that assume that one cannot assume a particular system-level outcomes, such as inflation or unemployment from knowledge of forces acting on individual economic agents. Rosser (1991) laid a good deal of the macroeconomics groundwork. Puu (1993, 2000) has since explored the effects of coupled business cycles (oscillations) on global outcomes. That line of research continues with some emphasis on the control of such systems (Ahmed & Hassan, 2000; Ahmed & Hegazi, 2003; Behrens, Caulkins, & Feichtinger, in press; Puu & Sushko, 2002).

Ecological economics is a third broad area that is replete with potential for NDS analysis. Topics in this group include environmental resource protection and utilization (Rosser, 1991; Guastello, 2002), agricultural management (Sakai, 2001), and land use and the fractal growth of urban areas (Batty & Xie, 1996; Puu, 1997). Cellular automata have been useful tools for studying urban expansion (White & Engelen, 1997; White, Engelen, & Uljee, 1997).

Evolutionary economics is the study of behavior change on the part of microeconomic agents, institutions, or macroeconomic structures. Aruka (2001) identified three basic perspectives within evolutionary economics: chaos and elementary dynamics, game-theoretical experiments with evolutionarily stable states, and multi-agent simulations based on genetic algorithms or related computational strategies. *NDPLS* published a special issue on Evolutionary Economics in April, 2002.

Finally, the temporal dynamics of economic, ecological, and social events are such that the time horizon between a policy decision and an intended effect is often much longer than the professional life expectancy of policy makers. For shorter-cycle events, complicated dynamics that are viewed in too short a time horizon could induce disastrous decisions. Thus policy makers are considering how they can

translate NDS information into successful decisions (Elliott & Kiel, 1999). An important step in that process is the ability to recognize the "time signatures" of various dynamical processes (Koehler, 2003).

PHILOSOPHY AND ART

NDS studies that rely on simulations produce some interesting philosophical issues about the intention and methods of scientific endeavors, which are elaborated by Richardson (2004, this issue). *NDPLS* will consider philosophy of science papers insofar as philosophical ideas can inform nonlinear science so that we can do a better job of what we do. Manuscripts that use NDS ideas or empirical results to solve philosophical problems, however, are not appropriate for *NDPLS* and should be submitted to an appropriate philosophy journal.

Art is not science, for reasons that I do not need to explain to the *NDPLS* readership. Fractal science, however, has produced some legitimate psychological questions about aesthetic preferences and how they might be related to properties of fractal structures. The art feature article in this issue by Sprott (2004) compels us to ask why we are so entertained by fractal graphics, why we like some designs better than others, and what mathematical properties of the fractals produce particular subjective responses. *NDPLS* encourages more works of this type.

Our readers cannot help but notice our new cover design. Fractal designs that are scheduled for this volume year have been selected from Sprott's (http://sprott.physics.wisc.edu/fractals.html) Fractal of the Day web site archives. Our anonymous staff of fractal enthusiasts has identified examples that depict life forms in the abstract. Our graphics department has taken a few liberties to isolate the core features of original fractals that depict the organic content. Feel free to disagree about which cover graphic is really the fern, the catfish, the orchid, or the butterfly.

THE NEW PUBLISHER

NDPLS is now published directly by the Society for Chaos Theory in Psychology & Life Sciences (SCTPLS) which has always been the sponsor behind this journal. After considerable deliberation, the Society has determined that the new publication strategy is best method of producing the greatest amount of high quality scientific products at the

lowest possible costs to all parties involved and to effectively manage the growth of this important area of science for the foreseeable future.

The Society was founded in 1991 as an international forum for the study of nonlinear dynamics and their applications. Its members hail from more than 30 countries and specialize in one or more of the substantive areas covered in this editorial. In additional to *NDPLS*, the Society operates an annual conference that enjoys international attendance, educational workshops devoted to nonlinear dynamics, other regional conferences, a professional newsletter, and a listserver for discussion of any of the foregoing topics (chaopsyc@list.uvm.edu).

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