Nonlinear Dynamics, Psychology, and Life Sciences, Vol. 1, No. 1, 1997

Science Evolves: An Introduction to Nonlinear Dynamics, Psychology, and Life Sciences

INTRODUCTION

Welcome to the inaugural issue of *Nonlinear Dynamics, Psychology, and Life Sciences*. This editorial will explain the journal's intentions, how its subject matter has evolved, and its potential near-term future.

Nonlinear dynamical systems (NDS) theory, colloquially known as "chaos theory," is a hybrid of mathematical concepts and developments concerning attractors (some of which are chaotic), bifurcations, structural stabilities and instabilities (some of which involve chaos in the literal sense), fractals, catastrophes, self-organizing processes, cellular automata, genetic algorithms and other evolutionary processes, and neural networks. The scientists whose work will appear in *Nonlinear Dynamics, Psychology, and Life Sciences* will be using the *products* of these mathematical efforts to explain or explore phenomena of widespread interest. The journal is thus dedicated to the advancement of both the theory and experimental knowledge base of NDS in a wide range of disciplines spanning from biology, through psychology, to economics, sociology, and political science. The broad mixture of disciplines represented here is a recognition 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.

Two key words signify what is about to occur: *nonlinear* and *dynamical*. A nonlinear relationship between two variables is one where an incremental change in one is not met with a proportional change in the other. Rather, a small change in one variable, at the right place and time, can produce a large effect elsewhere in the system. Alternatively, a large change in one variable could produce a negligible impact on another. Although nonlinear phenomena abound in nature, they are often treated as quaint curiosities in a relentlessly linear world view. What Ian Stewart writes about the physi-

1090-0578/97/0100-0001$12.50/0 © 1997 Human Sciences Press, Inc.

cal sciences of 50 years ago can be readily applied to much of social science today:

> So ingrained became the linear habit, that by the 1940s and 1950s many scientist[s] and engineers knew little else . . . . [W]e live in a world which for centuries acted as if the only animal in existence was the elephant, which assumed that holes in the skirting-board must be made by tiny elephants, which saw the soaring eagle as a wing-eared Dumbo, [and] the tiger as an elephant with a rather short trunk and stripes. (1989, pp. 83-84)

Dynamical systems are those whose properties, behaviors, or interrelationships change over time or space. Although many dictionaries say that the adjectives "dynamic" and "dynamical" can be used interchangeably, a convention has evolved where "dynamical" refers to changes over time that involve attractors, bifurcations, and related concepts explicitly. That convention is adopted here.

The elementary dynamics do not always appear in isolation. Living systems typically have many interrelated parts. The output, or behavior, of one subsystem, which may itself display interesting dynamics, becomes the input for another subsystem which imposes a second dynamical process. Thus we have *coupled dynamics*, or *synergetic* relationships. With enough synergies, complex adaptive systems in the sense of evolutionary behavior, ecological niches, and ordinary learning emerge.

There is nothing deliberately anti-establishmentarian about nonlinear dynamics or the objectives of the journal, at least not in the sense of anyone having any special ax to grind. There are no enemies of the virtual state. It is against such a placid intellectual background that the basis of a scientific revolution is about to take shape if it has not started to do so already. The following remarks are not intended to touch upon all the great and relevant ideas. They do represent the major tips of what are likely to be substantial icebergs.

SCIENCE EVOLVES

The consensus is that the subject matter of nonlinear dynamics is traced most pivotally to mathematician Henri Poincaré. His study of astrophysical dynamical processes produced the first observation of mathematical chaos, on the one hand, and a highly visual approach to mathematics on the other. Many of the topologies he studied were sufficiently complex that equations could not be written at that time. A major task thus awaited Marston Morse (1934), who combined differential equations with topology. Another generation later, meteorologist Edward Lorenz (1963) discovered the strange attractor (later also known as the chaotic attractor), which eventually led to two important concepts in NDS theory today:

(1) Many seemingly random events are actually determined by simple differential equations.

(2) Small differences in initial conditions at one point in time can evolve into radically different system states later on in time.

Lorenz' work triggered a parade of developments worldwide in mathematics, biology, chemistry, and physics surrounding nonlinear dynamics, and their applications commanded central attention (Abraham & Shaw, 1993; Stewart, 1989). There was virtually no cross-over to psychology and the social sciences until René Thom (1975) introduced catastrophe theory.

(3) Thom's work strongly suggested that all discontinuous changes of events can be explained by one of seven elementary topological forms.

Catastrophe theory formed the basis of a considerable amount of speculative but well-reasoned theory in embryology, linguistics, the social sciences, and elsewhere; many of the early efforts were due to Zeeman (1977). Reality struck the enchanted, however, as the methodology was developed for testing critical features of catastrophes and other interesting dynamics in the social sciences (Guastello, 1995). Yet there is more to be done with techniques for empirical testing of theory as other recent works will testify (Abraham & Gilgen, 1995; Gregson, 1995; Koyama, Yoneyama, Sawada, & Ohtomo, 1994; Robertson & Combs, 1995; Rosser, in press; Sulis & Combs, 1996).

Fractals are geometric structures in fractional dimensions. Fractal geometry started as an independent line of work (Mandelbrot, 1983) that later joined the flow of other developments in dynamics:

(4) Seemingly random shapes, such as those found in living tissue structures, lightning bolts, plant structures, and the shape of islands can actually be generated by relatively simple equations that characterize the fractal structures.

(5) Fractal structures are self-repeating over space, and self-similar over levels of magnification. This principle has widespread implications for the analysis of the time series data taken from complex adaptive systems.

(6) The boundaries of a chaotic attractor are fractal in shape: one of several connections between fractal geometry and nonlinear dynamics.

(7) The complexity of a fractal form is given by its dimension (there are several garden varieties); this role for dimensionality carries over to other dynamical system properties as well.

SCIENCE IGNITES

One scientific paradigm (in the local sense of an experimental paradigm) differs from another in that the same phenomenon or problem is studied from two or more distinct vantage points. The different vantage points are predicated on different assumptions, translate into different approaches to experimentation, anticipate different types of results, and evaluate those results according to new and relevant standards that did not hitherto exist (Goerner, 1994; Kuhn, 1972). Different forms of numerical analysis may be involved.

In the broadest sense, however, a new scientific paradigm would represent a new general approach to a wide range of problems and ask entirely different classes of questions. It would pursue its answers with its own set of essential tools, and often evaluates results according to an evolved set of standards and challenges. Thus the new paradigm unearths and explains phenomena that could not have been approached from pre-paradigmatic means. Alternatively, the new paradigm could be shown to provide better, more compact, and more accurate explanations.

A new scientific paradigm is not an excuse for diminished rigor, untestable hypotheses, or a loss of objectivity. In its early stages of development, however, a new paradigm must begin with some well-reasoned speculations, which are in turn followed by some well-developed theory, before its proponents can provide solid empirical evidence of their claims. The early proponents shoulder a substantial amount of risk. Their work could have dissipated as easily as it could come to fruition. When their efforts do pay off, however, there should be a journal in which to tell the fast-developing story.

It would be tempting at this juncture to revisit ancient history and relive the paradigmatic contributions of Galileo, Darwin, Newton, and their tribulations. Consider it done. We can now scoot to a more germane question: Does NDS show any symptoms of paradigmatic behavior beyond what has been said already about randomness, nonlinear structures, dimensionality hypotheses, and system change? A few more major ideas may be in order.

(8) Systems in a state of chaos, or far-from-equilibrium conditions, self-organize by building feedback loops or other synergetic coupling among the subsystems. These feedback loops serve to control and stabilize the system in a state of lower entropy (Kauffman, 1993; Kelso, 1995; Prigogine & Stengers, 1984).

(9) In Newton's view of a mechanical system, the function of the whole can be understood by understanding the function of each of the parts. In the view of complex adaptive systems, the parts of the system are continually interacting and shaping each other. They change over time with respect to each other. Furthermore, attempts to correct a flaw in the system might not be accomplished by tinkering with one of its parts. One needs to find a dynamical key to the entire set of system interrelationships (Haken, 1984; Hübler, 1992).

(10) In Darwin's view of speciation, the process of evolution and natural selection was slow and gradual. Gaps apparent in the historical chain of species evolution were attributed to missing links that would be found one day. In the new evolutionary paradigm (Laszlo, 1987), the apparent gaps are not gaps at all. Rather, speciation was often sudden and discontinuous. This principle is known as punctuated equilibrium, and is thought to characterize the patterns of sociotechnical development as well (Csányi, 1989; Guastello, 1995).

SCIENCE SELF-ORGANIZES

This is not the place to start a list of major problems in psychology, biology, or society at large. It takes only a small extrapolation to infer that many social problems are the product of multiple interconnected processes, that those processes have evolved in a dynamical fashion, and that they might have taken their contemporary form in part because of cumulative blunderings in policy. Furthermore, the processes are not limited by academic or occupational specialty. We hope that our journal will provide a forum for recognizing the common, nonlinear, dynamical principles which shape the behavior of living systems.

We invite your participation. Please send all manuscript submissions, editorial inquiries, and comments to the Editor-in-Chief: Stephen J. Guastello (see the Instructions to Contributors for details). Please send subscription inquiries and orders directly to the publisher: Subscription Department, Human Sciences Press, Inc., 233 Spring Street, New York, N.Y. 10013.

Nonlinear Dynamics, Psychology, and Life Sciences is an international interdisciplinary forum for the publication of original peer-reviewed papers from all fields that contribute to our understanding of this topic. We trust the journal will prove valuable to scientists, researchers, clinicians, and other professionals. We hope to serve this multidisciplinary field well, and welcome your support—as readers, authors, referees, *and* subscribers—to help achieve that goal.

Stephen J. Guastello
Editor-in-Chief

REFERENCES

Abraham, F. D., & Gilgen, A. (Eds.). (1995). *Chaos theory in psychology*. Westport, CT: Greenwood.

Abraham, R. H., & Shaw, C. D. (1993). *Dynamics, the geometry of behavior* (2nd ed.). Reading, MA: Addison-Wesley.

Csányi, V. (1989). *Evolutionary systems and society: A general theory of life, mind, and culture.* Durham, NC: Duke University Press.

Goerner, S. J. (1994). *Chaos and the evolving ecological universe.* Langhorne, PA: Gordon and Breach.

Gregson, R. A. M. (1995). *Cascades and fields in perceptual psychophysics.* Singapore: World Scientific.

Guastello, S. J. (1995). *Chaos, catastrophe and human affairs: Applications of nonlinear dynamics to work, organizations, and social evolution.* Mahwah, NJ: Lawrence Erlbaum Associates.

Haken, H. (1984). *The science of structure: Synergetics.* New York: Van Nostrand Reinhold.

Hübler, A. (1992). Modeling and control of complex systems. In L. Lam & V. Naroditsky (Eds.), *Modeling complex phenomena* (pp. 5-65). New York: Springer-Verlag.

Kauffman, S. A. (1993). *The origins of order: Self-organization and selection in evolution.* New York: Oxford University Press.

Kelso, J. A. S. (1995). *Dynamics patterns: The self-organization of brain and behavior.* Cambridge, MA: MIT Press.

Koyama, A., Yoneyama, K., Sawada, Y., & Ohtomo, N. (Eds.). (1994). *A recent advance in time series analysis by maximum entropy method: Applications to medical and biological sciences.* Soporro, Japan: Hokkaido University Press.

Kuhn, T. (1972). *The structure of scientific revolutions.* New York: Houghton Mifflin.

Laszlo, E. (1987). *Evolution: The grand synthesis.* Boston: Shambhala.

Lorenz, E. N. (1963). Deterministic nonperiodic flow. *Journal of Atmospheric Sciences, 20,* 130-141.

Mandelbrot, B. B. (1983). *The fractal geometry of nature.* New York: Freeman.

Morse, M. (1934). *Calculus of variations in the large.* New York: American Mathematical Society.

Prigogine, I., & Stengers, I. (1984). *Order out of chaos: Man's new dialog with nature.* New York: Bantam.

Robertson, R., & Combs, A. (Eds.). (1995). *Chaos theory in psychology and the life sciences.* Mahwah, NJ: Lawrence Erlbaum Associates.

Rosser, J. B., Jr. (in press). *From catastrophe to chaos: A general theory of economic discontinuity* (2nd ed.). Boston: Kluwer.

Stewart, I. (1989). *Does God play dice? The mathematics of chaos.* Cambridge, MA: Basil Blackwell.

Sulis, W., & Combs, A. (Eds.). (1996). *Nonlinear dynamics in human behavior.* Singapore: World Scientific.

Thom, R. (1975). *Structural stability and morphegenesis.* New York: Benjamin-Addison-Wesley.

Zeeman, E. C. (1977). *Catastrophe theory: Selected papers 1972–1977.* Reading, MA: Addison-Wesley.