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Introduction to Nonlinear Methodology, Part 1: Challenges We Face and Those That We Offer

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Welcome to the first of two special issues on methodologies for nonlinear dynamics. This collection of papers on methodological problems, and their potential solutions, that face any researcher with an interest in applying nonlinear dynamics to the life sciences, expresses the welcome responses of diverse independent scholars to the editors' open invitation to contribute. It is a symposium on, hopefully, state of the art questions. The gap between what psychologists are taught comprise the relevant repertoire of statistical methods, and what statisticians actually use today, has widened, and nonlinear dynamics has inevitably contributed to this widening. All our contributors draw attention to the special problems of identifying underlying dynamics in real biological data where the simplifying assumptions of the physical sciences do not readily hold. The dangers of false prior assumptions, and over-fitting of data, are emphasized from various viewpoints.

If we follow the approach of Popper to scientific method, then investigating the hypothesis that all swans are white is not addressed by endlessly counting white swans, but by searching until we find a black swan. Some may not know that black swans are in fact white under their wings, so the next step would be to revise the hypothesis to assert more cautiously that all swans have some white feathers. This swan search is in a metaphorical way a description of the attempt to pin down nonlinear dynamics in real data. The truth is not one of choosing simple alternatives, but of studying systems which are endlessly mixed in their behavior, and intermediate states between traditional linear dependencies and Gaussian noise are variably present over time.

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One might think that there already exist a profusion of statistical procedures to identify where and when, in experimental data, we have strong evidence of nonlinearity. For example, Walsh (1962-1968) gave us a total of 1982 pages of statistical tests that will show us when things are not random, without assuming that they are necessarily metric, but simply capable of being ordered. But we continue to need new and more precisely focussed methods to find whether the observed dynamics are indeed nonlinear at least some of the time. Determination of nonlinearity is not enough; practical implications from our research will require knowing *what kinds of dynamics* are involved.

Statistics as a discipline is not static, and new methods evolve to distinguish between variable-free and model-free estimation and identification of structure and dynamics (Li, Cook, & Nachtsheim, 2005). We seek methodologies that are robust with respect to the associated phenomena of nonstationarity, singularities, catastrophes, shifts in dimensionality, varieties of noise, similarity across scales, fractals and the edge-of-chaos, and violations of metric axioms. We challenge the myth that "huge quantities of data are required to test for chaos or other nonlinearities." Indeed the myth already breaks down if we consider the differences of opinion (cataloged by Liebovitch, 1998, p. 211) as to how many data points are required to evaluate a 6-dimensional attractor range from 10 to 5,000,000,000. In contrast, we take the position, that if a statistical procedure cannot discern what we need to discern from sample sizes or time series lengths germane to the social sciences it simply is not good enough.

Each of our contributors describe particular methods they have found useful and warn that unsettled issues about dimensionality and the presence or absence of fractals are not diagnostically sufficient; healthily there are some overlaps, some innovations, and some mutual disagreement of emphasis. All of these issues have their original definitions in pure mathematics, and all have to be matched to real data by some approximations; the very task of such matching has its own mathematical underpinning in theorems about the shadowing of trajectories. False positive or false negative identifications are always with us, but their probabilities may be reduced if data are clean enough and numerous enough.

We need to encourage experiments in methodology itself, as the great British statistician I. J. Good observed "we make no mockery of honest ad hocery," and it can be as valuable to learn from mistakes as from successes.

The dominant paradigm in experimental psychology has been the General Linear Model where almost always the choice is to accept a linear regression of data on theory and partition the failure to fit into trend and residual Gaussian noise. The third (or even more) alternatives of chaotic dynamics, locally predictable but not long-term predictable in their moments, do not feature there. The sciences concerned with memory paradoxically have chosen to filter out anything that can be misidentified as independent and identically distributed (IID) noise. Our contributors examine various ways of stepping outside this tradition, at the same time warning us not credulously to see things that are not likely to be there.

For the benefit of the throngs of newcomers to nonlinear science, it is important to recall briefly a haunting historical episode. Shortly after catastrophe theory (Thom, 1975) first appeared, a plethora of theoretical applications were also introduced to the social sciences (Zeeman, 1977). The new nonlinear theories conflicted with standard thinking on those subjects, resulting in a scathing critique (Sussmann & Zahler, 1978) that chilled developments in the field for many years afterwards. Fortunately, statisticians rallied to the cause and developed methods for explicitly testing new models along with a few classics. As a result we can say that two of the more controversial early catastrophe models – prison riots and stock market behavior – have been empirically verified (Guastello, 1995); economists have since changed their views on the nature of markets as a result of nonlinear dynamics and its associated theorizing (Rosser, 1997).

Fortunately the surge of interest in chaos, fractals, and related dynamics in the early 1990s did not catch statisticians unaware. It is now possible to say that in studies where it was possible to compare proportions of variance accounted for by linear and nonlinear models, and in which the researchers concluded in favor of the nonlinear model, the average advantage for the nonlinear model is 2:1 (Guastello, 1995, 2002). The additional variance accounted for comes from two places. The first is a good theory about the nonlinear deterministic properties of the phenomenon; we cannot expect methodology to compensate for deficits in theory. The second is the ability to reckon with non-IID noise; when it is present in sufficient quantities, nonlinearity *is* present (Brock, Hseih, & LeBaron, 1991).

This symposium has been divided into two parts, this first describes various methods and their applications that workers have found informative. Here one may find analytic traditions that emanate from both the physical and social sciences. The second part of the symposium, to appear in another issue in Volume 10, continues with the emphasis more on content-specific applications in psychology and psychophysiology.

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