Complexity theory and nonlinear dynamical models in psychology

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During the last few decades there has been an increase in the number and variety of applications of complexity theory and nonlinear dynamical models in psychology. Some of these applications are quite specialised such as in psychophysics for which such models were designed to explicate long-established psychophysical anomalies. This work, primarily by Gregson, has led to a better understanding of psychophysical phenomena, in particular the processing of multidimensional stimuli.

Perhaps the most significant use of nonlinear methods in cognitive psychology has been the assumption of nonlinear neural processing units in a range of connectionist and neural network models. This work has been complemented by the occasional use of nonlinear system identification procedures, as described by Heath (2000).

A number of papers in experimental psychology have applied the conventional tools of nonlinear dynamics quantification derived directly from physics. These applications include the detection of nonlinearity in sequential response time data (Kelly et al., 2001) as well in the analysis of psychomotor skill as illustrated by Longstaff and Heath's (1999) work on handwriting dynamics. Another interesting application of nonlinear ideas is Heath's (2000) (New Scientist, March 2002; BBC Radio 4, The Material World, April 2002) demonstration that some people are sensitive to chaos in a simulated weather prediction task. This occurs even when the participants have no idea that the data are structured in any way.

There have been several nonlinear analyses of complex psychophysiological data, most particularly scalp-recorded EEG. In these cases, quantitative methods derived from physics, such as fractal dimensionality and the Lyapunov spectrum have been used to characterise various brain states.

Perhaps the most interesting application of complexity and nonlinear ideas have been the mainly qualitative musings of clinical psychologists who notice a great discrepancy between the conventional data analysis methods taught in psychology (mainly linear models including regression, ANOVA and MANOVA) and the more unpredictable and abrupt behaviour changes observed in their clients undergoing psychotherapy.

Recently, quantitative nonlinear methods have been used to understand the differences in mood rating time series between those with a psychiatric condition and those who are healthy. For example, Heiby et al. (2003) noted that the mood series from a chronically depressed person were more regular than those observed from a healthy person. This led to the Maladaptive Determinism Hypothesis which associated illness with regularity or low complexity, and health with high complexity and noise. This idea was further elaborated by Heath (2004), Heath, Heiby and Pagano (2005), and others.

The advent of nonlinear methods, most especially complexity indices such as approximate entropy and sample entropy, has allowed psychologists to examine the behaviour dynamics in

individual cases. This is in stark contrast to the more familiar statistical methods that pool data across individuals and relegate the crucial individual differences to the residual wastebasket. Nonlinear methods allow practitioners to use quantitative methods that have face value and that can be usefully employed to monitor their client's psychotherapeutic progress. This is no better illustrated than by the novel analysis of mood and behaviour ratings provided daily over extended time periods by clients who are being treated for Borderline Personality Disorder. In some cases the increase in complexity with duration of therapy is clearly evident (Heath & Davies, in prep.).

Other important applications of nonlinear dynamics in psychology include those to developmental cognition (e.g. the work of Thalen and van Geert) as well as to higher cognitive functions such as creativity (e.g. Guastello). Although these areas are not among my mainstream interests I can mention them briefly as examples of innovative applications of nonlinear ideas to branches of psychology that previously have been either devoid of an appropriate temporal-evolutionary methodology (developmental cognition), or have been considered too difficult to model using conventional means (creativity).

Perhaps the most significant communicative development in psychology was Guastello's initiation of the journal *Nonlinear Dynamics in Psychology and the Life Sciences*. This journal serves as a publishing outlet for a number of papers that otherwise would be ignored by other psychological journals. The permeation of nonlinear ideas into the mainstream psychological literature is still a problem, due most probably to a lack of graduate training in nonlinear science among psychology students and their mentors.

So the issues that I would like to discuss in the chapter include:

- A brief history of the use of nonlinear models in psychology.
- Initial applications of nonlinear quantification methods derived from engineering and physics, e.g. is the data series chaotic?
- The use of more general methods to discover structure in behaviour time series, e.g. mood ratings, obtained from individuals.
- Technical issues such as the lack of continuous measurement scales in most psychological data, as well as problems resulting from nonstationarity.
- The impact of nonlinear dynamics on the evolution of psychological theory, especially a new emphasis on the individual and his/her transactions with an unpredictable environment.
- Implications of these new tools for relating behavioural phenomena to those occurring at more basic levels of explanation, cf. the analogies between nonlinear processes that occur at the behavioural, physiological and biochemical levels.

The last two issues relate to philosophical ideas such as

- what type of theory and modeling is most appropriate for psychology, especially a reversion to the fundamental idea that behaviour evolves over time and that the more commonly used static models have little explanatory value?
- how can difficult concepts such as behavioural transaction and change be better understood as nonlinear processes, especially in professional work?
- what impact does nonlinear modeling have on our use of appropriate measurement scales

in psychology and how should measurement theory be extended to cater for time-dependent phenomena, especially when the parameters of such processes are subject to change over time as well (the scourge of nonstationarity)?

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