Nonlinear Dynamics and Sequence Effects

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A characteristic assumption of contemporary models of cognition is that trial-to-trial variations are treatment effects plus random "noise", that is, errors that are independently and identically distributed (IID). An alternative view, beginning to receive some attention, is that variations are, at least in part, the product of a nonlinear deterministic system. A nonlinear dynamic (NLD) perspective encourages both the examination of performance on successive trials as a time series and the investigation for trial-to-trial dependencies. A widely observed phenomenon, the sequence effect, has already established that performance on a given trial depends on the order of responses on preceding trials. Sequence effects occur across a number of behavioral paradigms and dependent measures (cf. Luce, 1986).

The present report extends some preliminary research (Clayton & Frey, in press; Frey & Clayton, 1996) in which a battery of NLD analyses is applied to response latencies in two-choice classification tasks. These tests, which include Brock et al.'s (1991) test of IID, spectral analysis, nonlinear forecasting (Sugihara & May, 1990), and two estimates of dimensionality (Grassberger & Procaccia, 1983; Judd, 1994), provided initial support for the feasibility of a NLD perspective. We add here analyses on data from a simple spatial judgment task and new analyses using noise reduction techniques that discriminate various types of noise from noisy NLD data (Kennel & Abarbanel, in press).

Both the observed time series (Obs-TS) and shuffled surrogates are submitted to the tests. The shuffling operation destroys the trial-to-trial structure while maintaining other important characteristics of the time series (e.g., mean & variance) as well as controlling for sample size. The results from the shuffled data are consistent with an IID account.

The expected outcomes for the two accounts of trial-to-trial variability are presented in Table 1. Results from the test of IID, spectral analysis, and forecasting all support a NLD account of the Obs-TS. The dimensionality estimates (i.e., the minimum number of variables needed to model) are less clear. Both estimates of dimensionality suggest that the dimensionality of the Obs-TS is not less than 6 and in many cases the estimates do not differ from the shuffled data.

One problem with estimates of dimensionality is that they are over-estimated when there is noise in the time series. Further work is needed to test if the dimensionalities are over-estimated. Overall, the tests suggest that the trial-to-trial variability is not IID and that the variability has characteristics that are consistent with NLD.

Table 1: Summary of the Expected Outcomes

Statistic	IID Outcome	NLD Outcome
Test for IID	cannot reject hypothesis of IID	*reject* hypothesis of IID
Spectral analysis	broad frequency spectrum, zero slope	broad frequency spectrum, zero or *non-zero slope*
Forecasting	predictability does not change as prediction time increases	predictability *decreases* as prediction time increases
Dim Est.	*infinite* dimensionality	*finite* dimensionality

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`http://www.vanderbilt.edu/~clayton`

References

Brock, W. A. Hseih, D. A., & LeBaron, B. (1991). *Nonlinear dynamics, chaos, and instability: Statistical theory and economic evidence*. Cambridge, MA: MIT Press.

Clayton, K. & Frey, B. (1997). Studies of Mental 'Noise'. *Nonlinear Dynamics, Psychology and Life Sciences, 1(3)*, 173-180.

Frey, B. & Clayton, K. (June, 1996). Examining Sequence Effects using Nonlinear Dynamics. Paper presented to the annual convention of the Society for Chaos Theory in Psychology and the Life Sciences, Berkeley, CA.

Grassberger, P. & Procaccia, I. (1983). Measuring the strangeness of strange attractors, *Physica 9D*, 189-208.

Judd, K. (1994). Estimating dimension from small samples. *Physica D, 71*, 421-29.

Kennel, M. B. & Abarbanel, H. D. I. (in press). False neighbors and false strands: A reliable minimum embedding dimension algorithm. *Physics Review E*

Luce, R. D. (1986). *Response Times: Their Role in Inferring Elementary Mental Organization*. New York, NY: Oxford University Press.

Sugihara, G. & May, R. M. (1990). Nonlinear forecasting as a way of distinguishing chaos from measurement error in time series. *Nature, 344*, 734-741.