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SOCIAL PROCESSES AS DYNAMICAL PROCESSES: QUALITATIVE DYNAMICAL SYSTEMS THEORY IN SOCIAL PSYCHOLOGY*

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ABSTRACT

We present an alternative view to the dominant discourse in scientific psychology, where researchers are concerned primarily with predictability of phenomena based largely on simple tests of linear relation. Instead, the time-dependent and evolving nature of social experience and interaction can be examined using the methodology of nonlinear dynamical systems theory (NDS). We review relevant concepts from key content areas ("chaos" theory, catastrophe models and self-organising networks) and assess their applicability to the modelling of social psychological phenomena. In addition, we offer a guide to re-analysing existing "between subjects" data for nonlinearity, and "within subjects" data for dynamical change. NDS provides useful metaphors, models and analytical tools for developing qualitative process as opposed to quantitative outcome models.

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INTRODUCTION

Two of the implicit assumptions in many areas of scientific endeavour have been that apparently simple events have simple explanations, and that relatively complex phenomena require description and prediction by large numbers of interacting variables. These assumptions have been challenged in recent years by the development of nonlinear dynamical systems (NDS) theory, the widespread and successful application of which has clearly demonstrated the need for a revision of our ideas concerning causality, determinism, and particularly reductionism in science.

NDS theory is an area of mathematical research that attempts to characterise, predict and provide explanations for phenomena which appear to exhibit complex and often apparently random behaviour. It also seeks to uncover the mechanisms by which this behaviour can be deterministically generated from simple differential equations, requiring few degrees of freedom.

Such systems are of particular interest to social psychology, where analyses using the general linear model have failed to account for large classes of phenomena (see Vallacher & Nowak, 1994, for a review). This is a serious practical problem in studies which employ complex multivariate linear analytical techniques, since each variable and factor level is presumed to have a linear and temporally-stable relationship with all other variables. Clearly, for many systems, linearity is an insufficient basis for a realistic understanding of social phenomena.

Nonlinearity, by definition, refers to the existence of relationships between variables that are not exclusively linear. This does not mean that relationships of interest are always nonlinear - indeed, the cusp catastrophe, a popular nonlinear model, describes relationships which are linear some of the time, but during particular zones, undergo nonlinear qualitative state changes. Coupled with the concept of dynamics, and of systems not at equilibrium, it is possible to explore complex relationships which exhibit spatiotemporal variability. For example, so-called "chaotic" systems generated from deterministic equations display predictable steady-states of activity for certain parameter ranges, after which there is apparently random divergence from states of equilibrium.

NDS offers new paradigms and methodologies which may be of great utility in understanding social behaviour for which analyses using the traditional techniques based on the general linear model, such as the analysis of variance, have not worked. For example, it is difficult to understand attitude-change as a process without either a valid temporal model or related statistics (see Eiser, 1994, for a review). Although the correlation has been used successfully in many fields of endeavour, it can obscure the dynamic and nonlinear relationships between variables which may form the basis of the system's behaviour. It is in this context that NDS theory can enhance some aspects of social psychological theory. In particular, the work of Eiser (1994), Vallacher and Nowak (1994), and Guastello (1995) has pioneered the development of both metaphor and methodology for a dynamical social psychology.

DYNAMICAL SYSTEMS

We would like to briefly outline three areas of nonlinear dynamics which are thematically inter-related, and highlight their salient properties for social psychological explanations of social behaviour. Firstly, the concept of a deterministic dynamical system is linked to what is known as a chaotic system. In traditional terms, according to the Poincare-Bendixson Theorem, there are only two kinds of solutions for dynamical systems - point attractors or limit cycles. Point attractors are characterised by a convergence to a stable point, and cyclic attractors repeat the same path in phase space over a constant number of iterations. Obviously, while these two systems are both potentially dynamic and nonlinear, they are entirely predictable.

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However, Lorenz (1963) by the use of a numerical simulation of differential equations, uncovered a third possible state, the chaotic state. This discovery had been foreshadowed by the curious topological forms investigated by Poincare in the previous century, which defied contemporary scientific explanation. "Chaos theory" is significant because it provides a deterministic account of interesting behaviour which appears to be random. Thus, it is possible to generate such behaviour from known equations. This gives rise to the possibility of understanding so-called random systems as the solutions to differential equations, and in a sense, makes many statistical analyses redundant if the system can be correctly identified.

Thus, the model of convection currents developed by Lorenz (1963) was able to reproduce many of the qualitative features of weather patterns by simple deterministic equations, and demonstrated the inherent limits of weather prediction. Lorenz's model can thus be used for short-term weather prediction, but its sensitivity to small changes in convection parameters means that the system may exhibit a large number of possible solutions, many of which are simply not estimable over the long-term evolution of the system. However, simulation of many possible solutions to the equations has provided further insight into the generation of particular weather patterns.

The qualitative dynamics of this model have been widely- propagated in the popular press, with the two characteristic attractors becoming an icon for the "new" mathematics of chaos, as well as literally representing the trajectories of solutions to the Lorenz equations.

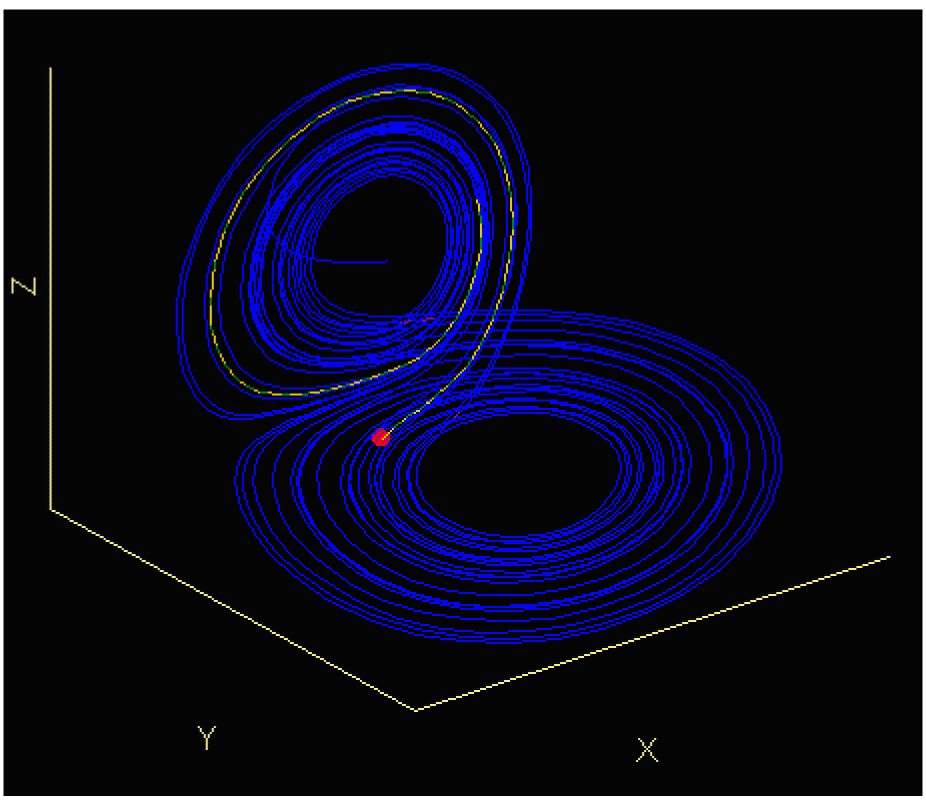

Figure 1

Figure 1 demonstrates the complex phase space of Lorenz's model: note the basically cyclic nature of the trajectories, up to a point where they "cross over," and then diverge slightly from their previous path. It is this divergence which signals the onset of chaos, and is the factor that gives rise to the possibility of generating a large number of qualitatively different weather patterns (in this example). It is technically known as a bifurcation, and represents an abrupt qualitative state change in the relationship between two variables influenced by a "splitting factor", giving rise to the possibility of multiple solutions to qualitatively different states for the system.

CATASTROPHE THEORY

Catastrophe theory (Thom, 1975) utilises the concept of bifurcation in conjunction with a complementary characteristic known as hysteresis. Where there exists a known bimodality, or discontinuity, between two variables, the process of "jumping" from one level of the function to the other is known as hysteresis. This process facilitates rapid qualitative change in the dynamics of a system. A first-order catastrophe model, known as a "fold," describes the relationship between two variables whose relationship is known to contain hysteretic zones. Figure 2 demonstrates the effect of hysteresis on a well known system. When this feature is observed in a system, but only for a particular range of values of another variable, then a second-order catastrophe exists, known as the "cusp" catastrophe. In this case, the splitting factor (as the third variable) moderates the relationship between the first two variables, giving rise to both a stable relationship (for low values) and an unstable relationship (for high values).

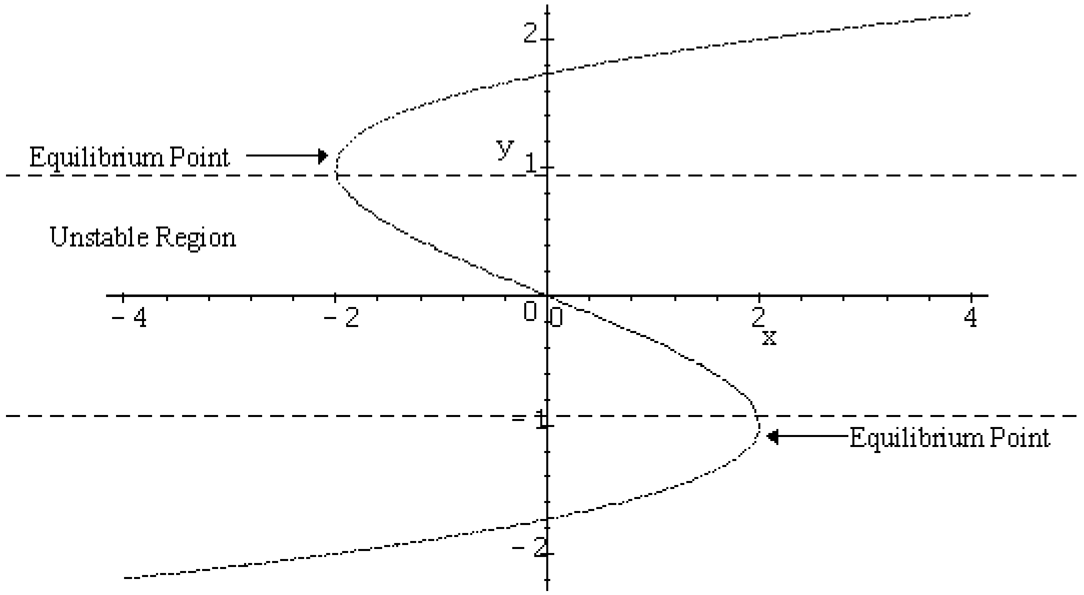

Figure 2

The topology of the cusp catastrophe model is potentially the most useful of the seven elemental catastrophes for analysing existing psychological data for which there does not exist a unique functional relationship between two variables over certain parameter ranges of a third variable. The critical points at which the relationship breaks down become powerful sources of information for both the understanding of the relationship, and evaluating its morphogenetic properties--that is, critical qualitative form changes as a function of time. Using these properties, cusp catastrophe models have been applied to several social psychological problems, in areas as far-ranging as prison disturbances (Zeeman, Hall, Harrison, Marriage, & Shapland, 1976), organisational dynamics (Guastello, 1982), sociolinguistics (Ball, Giles, & Hewstone, 1985) and health- beliefs in Africa (Carr, Watters, & MacLachlan, 1996).

SELF-ORGANISING SYSTEMS

A third body of work concerns systems which exhibit self- organising behaviour (Haken, 1977), according to some dynamical algorithm which specifies local interactions between simple units. In particular, cellular automata models, pioneered by Von Neumann (1964) may be very relevant for the formal study of dynamics in social interaction. The behaviour of each of the cellular units can generally influence its nearest neighbours, who in turn influence all other units that they are connected to, by several distinct mechanisms: through bistability, or the change from one steady state to another by exceeding some threshold; excitability, or the ability to induce patterns of activity in spatially-related units through irregular pulses; and through oscillation or regular cyclic influence. The emerging patterns can represent many apparently "social" phenomena: co-operation, competition, feedback, social comparison and influence.

The latter topic has received considerable attention from Nowak, Szamrej and Latane (1990), who developed a cellular automata model of attitude change using a network of units which influence other units by support (reinforcing the current attitude of the receptive unit) or persuasion (attempting to change the attitude of the receptive unit). At each discrete time interval, the attitude of each unit is updated in accordance as a sum of the persuasive or supportive behaviour of other local units. By performing such simulations, the authors were formally able to determine the conditions necessary for attitude change to occur, both confirming findings of empirical studies, and generating further empirical hypotheses.

PSYCHOLOGICAL METHODOLOGY AND NONLINEAR DYNAMICS

When confronted with new methodologies, most researchers are keen to understand the advantages with respect to existing techniques. What is it about these new paradigms that gives us more than we already know? We argue that NDS theory offers much that is complementary to the corpus of social psychological knowledge that has already been acquired. In addition, we hope to demonstrate that the data collected from previous studies is extremely useful as a basis for exploring nonlinear dynamical relationships in social psychology.

Whilst not all psychological or social processes are both nonlinear and time-dependent, NDS theory can offer many insights and tools for bridging gaps between description, prediction, and theory. Many techniques in quantitative psychology rely on "snapshots" through time, rather than factoring in time-dependence as a critical variable. Even repeated-measures designs, in general, tend to lock time-divisions to particular events, assuming that the simple passage of time has no effect on the system in question, and that the manipulation of one level of one factor will result in a discriminable mean difference in the criterion variable of interest.

The assumptions of many of these statistical tests, particularly regarding normality and sampling distributions, are often not met in practice (Cohen, 1994), and corrections for observed data which are incompatible with the underlying structural model, such as deleting outliers, are used to "fudge" analyses of the interdependency of variables to significance.

It is inadequate to explain away deviations inconsistent with these models in experimental data as unwanted noise, when the adoption of the tools of nonlinear dynamics can enhance our understanding of how these deviations are sometimes crucial to system function.

We would like to suggest that further investigation into nonlinear dynamics may influence not only our qualitative and quantitative analytical techniques, but also our experimental designs and rationales.

METHODOLOGICAL IMPLICATIONS FOR A DYNAMICAL SOCIAL PSYCHOLOGY

In providing a critique of current methodology in social psychology, we hope to open the way for a more general exploration of alternative models and methods for understanding social behaviour. As noted above, a number of researchers have already embarked upon this mission. For example, Eiser (1994) extended the traditional model of linear attitudinal "states" to a more general nonlinear model of attitudes, which provided qualitative explanations for aspects of attitude research which are inherently dynamic: attitude change, the consistency of certain attitude dimensions embedded in a higher-order space, and balancing the desire for consistency (stability) against the search for alternatives (instability).

The development of complex qualitative metaphors is balanced against the quantitative methodology developed almost entirely by Guastello (1982; 1995) who favours moderator regression as a method for quantifying cusp features in catastrophe models (i.e., demonstrating the nonlinear interaction of operationalised organisational culture variables in order to predict quantifiable changes).

For the social psychologist who initially and enthusiastically embraces nonlinear dynamical metaphors, the possibilities for generating entirely new areas of research are often overwhelming, particularly when we consider that the linear techniques often used are usually simple instances of more general cases. However, finding a starting point for data analysis, or attempting to design experiments in which variables can potentially provide evidence of substantial nonlinearity, is daunting. There are no encyclopaedic texts for nonlinear dynamics as applied to psychological systems - even to create such a text would be a difficult task because of the many paradigms currently in use, even in subfields of social psychology. In addition, not all social psychology is quantitative or experimental (e.g., symbolic interactionism), but this does not preclude such approaches from utilising the metaphors of nonlinear dynamics.

In this context, we present a brief guide to utilising qualitative nonlinear dynamics in social psychology.

1. Metaphor. Start examining a phenomena that has been explored at a basic level, but that you suspect has interesting features that require a more general explanation. For example, Carr, Watters and MacLachlan (1996) examined an extension to the theory of cognitive dissonance, which incorporates cognitive tolerance as evidence for a "dissonance-tolerance" continuum. This was based on evidence that, in Malawi, individuals successfully combine aspects of traditional and modern health beliefs when seeking modern medical assistance, without the dissonance that might be expected when individuals are confronted with apparently conflicting explanations for illness (MacLachlan & Carr, 1994). The transition from dissonance to tolerance as a function of belief in traditional medicine appeared to fit well with the notion of a splitting factor from catastrophe theory. The use of the cusp catastrophe in this instance permitted a number of specific hypotheses to be generated on the basis of the model's geometry (e.g., what were the critical values of belief in traditional medicine that signalled a move from dissonance to tolerance? If there was a jump between modern medical belief and medical-seeking behaviour, could this be an indication of hysteresis?).

2. Operationalisation. As with many designs in social psychology, it can be difficult to select variables which appropriately reflect the nature of social psychological processes in question. For example, in the study outlined above, principal components analysis was used to provide reduced, composite variables for health beliefs and behaviour which accounted for most of the variability of the original data, gathered from questionnaires. As with traditional multivariate designs, this can be used as a useful technique for determining the utility of particular modes of inquiry. It must be kept in mind that poor variable selection can lead to both unsubstantiated claims of nonlinearity and "chaos," and that there is a large literature on the effects of noise on quantifying dynamical systems, such that irregular fluctuations which may indicate basins of attraction are erroneous (for a comprehensive review, see Provenzale, Smith, Vio, & Murante, 1992).

3. Data collection. In general, to demonstrate nonlinearity, it is sufficient to have variables observed at a single point in time (such as those typically gathered in "between subjects" designs). To demonstrate dynamical activity (limit-cyclic or chaotic), it is necessary to construct a time series of observations over a number of points. This latter method of data collection is more commonly used in the social sciences in econometrics, which perhaps explains the many claims of "chaos" in the stock market (e.g., Sherry, 1994), but data from some "within subjects" and "repeated measures" research designs may also be adequate. The message here is not to "throw away" existing data generated from experiments framed in the traditional null-hypothesis testing rationale: it can be a valuable resource, particularly for determining nonlinearity to justify the search for time-dependent dynamics. Again, in the study outlined above, it was demonstrated that shifts observed in the distribution (as quantified by measures of skewness and dispersion) were related to state transition health behaviours determined by belief in modern medicine alone, rather than to a more complex set of motivations involving traditional beliefs (Carr, Watters & MacLachlan, 1996). This finding has practical relevance for the provision of modern health service in the developing countries of Africa, yet its underlying nature, and the points at which intervention is required, could not have been estimated and understood using a strictly linear model.

4. Analysis. Measures of dispersion and skewness are a necessary first step to examining the statistical features of a dataset. Nonlinearity in data is easily assessed by using any of the statistical packages which psychologists typically use, and selecting an appropriate nonlinear regression model. These techniques yield correlations ("R" values) and regression coefficients, so that their "fit" can be assessed with respect to existing linear models. Any increase in variability accounted for may indicate a nonlinearity in the dataset. Dynamical activity is generally assessed in one of two ways: by using a measure of divergence in the time series (such as the Lyapunov Exponent; Wolf, Swift, Swinney, & Vastano, 1985), or a measure of dimension, which quantifies the degree of differential equation which would be required to simulate the complexity of behaviour observed in the series (Grassberger & Procaccia, 1983). A positive Lyapunov Exponent of a series indicates that there is a level of divergence of values in the series which cannot be accounted for by regular cyclic activity, and is commonly accepted as an indication of the presence of "chaos". Changes in dimension indicating that the behaviour of a time series can be accounted for by a simpler model (decrease in dimension) or required description by a more complex model (increase in dimension can also quantify state changes.

5. Simulation. Optimistically, the goal of data analysis in search of nonlinearity (and potentially chaos) yields information which permits the simulation of the phenomena in question, that is, the derivation of differential equations which totally describe the phenomena in question. This approach has been particularly successful in ecology, where the basic equations for predator-prey relationships (known as the "Lotka-Volterra" equations after their originators) have been well-known for many years and the methodology for relating nonlinear model to experimental data is well developed (for a comprehensive review, see Rosenzweig & MacArthur, 1963). The social interaction between predator and prey species is described by this model in terms of several individual parameters (e.g., growth rate of the prey in the absence of predator), and their relationship (e.g., attack rate of the predator). The points at which their relationship becomes equilibrious (e.g., cyclic) or moves away from equilibrium, either into a "point attractor", (e.g., when all predators die because of a lack of prey), or into a state of chaos (e.g., the point at which the abundance of prey exceeds all possibility of the predators controlling their population). Although social psychology has utilised simulated events in probabilistic decision making (e.g., the prisoner's dilemma), the relationship between formal modelling and data analysis has not been explored. Simulation of social interactions using zero equilibrium criteria, as in the predator- prey, could be a potentially beneficial way of exploring the dynamics of social interaction prior to experimentation.

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FURTHER READING

Many general reference books have been published in recent years on the topics outlined above. For a comprehensive introduction to chaos theory and dynamical systems, we recommend Ott (1993) for technical clarity and Tsonis (1992) for applications. A popular account of the development of some key concepts in dynamical systems is given by Gleick (1987). For applications of dynamical systems to psychology, the volume by Abraham and Gilgen (1995) provides a wide array of examples. The definitive volume for social psychology is Vallacher and Novak (1994), which contains contributed papers applying dynamical principles (generally as metaphors) to a wide array of topics, including attitudes, organisational dynamics and social judgement. This may be an appropriate starting place for social psychologists interested in extending their work in this area. In addition, Guastello (1995) provides a broad introduction to catastrophe theory, and examines at length the practical issues associated with transitioning current psychological models into appropriate dynamical systems models. A recent text for nonlinear regression is Seber (1989), particularly useful for explanations of parameter estimation.

CONCLUSION

We hope that, in providing a critique of current methodology, and suggestions for a new methodology in the context of the possibilities provided by dynamical system theory, we have highlighted those aspects of the theory which are relevant and useful to social psychologists. It should also be noted that we do not seek to discourage other researchers from pursuing predictability rather than determinism in their research, as the two issues are ultimately closely related. Many simple phenomena do have simple explanations, and perhaps the most elusive, intractable, but fascinating phenomena, will be open to analysis using the new methodologies.

Obviously, the deficits in experimental methodology cannot be solved by the introduction of one or two new techniques, or by a reliance on qualitative research alone to generate new ideas. An integrative approach to theory development is required, which utilises the hypothesis-generation approach to social behaviour as a deterministic, causal activity, as well as the attempt to quantify changes in behaviour as a function of "independent" variables.

ENDNOTE

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