CREATIVE PROCESSES IN NATURAL AND HUMAN SYSTEMS
Methodologies and Applications for Systems Approaches

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Introduction

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The last two decades have witnessed the convergence of physics, biology, and economics, encouraging the development of general methods and theories applicable to the study of a wide variety of systems. This systemic perspective has promoted the study of processes, as contrasted to the predominantly static perspective that had long guided research. Dynamic views lead to a focus on function and evolution beyond composition and structure. An evolutionary approach leads to the study of how complex systems are created and destroyed beyond the study of their operation and maintenance.

Though the creative character of natural processes is becoming widely recognized, there is a paucity of techniques to measure the features of creativity in empirical data. This collection of articles presents time series analyses and mathematical models designed to investigate creative phenomena in empirical data.

We understand creativity as the production of novelty and complexity, a definition that applies to biological, physical, and psychological processes. We do not limit the meaning of creativity to intellectual or artistic creativity. The creativity of natural processes can be demonstrated by pointing to characteristic examples. Cosmological evolution, biological evolution, and chemical synthesis illustrate how many causal processes spontaneously generate novelty and complexity. Individual development is exemplary. While initiated and guided by information and energy contained in DNA and proteins, in conjunction with the morphology of the egg, biological development is co-determined by energetic and informational inputs. Over time, individuals generate complex thoughts, traits, behaviors, and histories unique to them. Science, art, and mathematics demonstrate human creativity at a more abstract level. Physiological rhythms such as respiration or sleep also display novel, unique complexities webbed into the fabric of overall periodicity.

Static views have long dominated the sciences, from physics to psychology and economics. Physics developed a theory of evolution only well after biological evolution had been recognized. Einstein regarded time as an illusion, and many contemporary physicists speculate about time reversibility. In psychological theory, personal traits are attributed in large part to unchangeable genetic factors. In psychological practice, experiences that have obvious temporal characteristics are analyzed with static statistical methods. “Economic laws” disregard historical circumstance. Such static views do not allow for the study of processes, in which time’s arrow has a central role.

The notion that complexity can be generated by simple processes dates from antiquity; it is implicit in Lamarckian and Darwinian evolutionary theories, and it has been given new scientific foundations with the work of Prigogine [(1980)], May [(1976)], Mandelbrot [(1977)], Thom [(1983)], Lorenz [(1993)], Feigenbaum [(1983)], Smale [(1967)], Sarkovskii [(1964)], Ueda [(1992)], the Abrahams {Abraham et al (1990)] and many others. There is currently much interest in the study of simple processes that produce complex phenomena, as contrasted to random processes that produce innovation by mere chance.

Predominant scientific worldviews regard processes as either deterministic or probabilistic and attribute innovation to random change. These theories do not privilege the study of novelty and complexity, but rather highlight equilibrium, competition, struggle, chaos, and disordering ("entropy") when addressing natural processes. The assumptions these theories are predicated on thus fail to provide guidelines to identify and measure creative phenomena, and in fact hinder the development of methods to analyze creative features in time series. No incentives and no guidelines to study creative processes can be derived from mechanistic viewpoints that imply determinism without creativity, or from probabilistic views that regard innovations as aleatory events. Accidents impose significant constraints, but do not constitute an explanation of the origins of biological form or function [Crutchfield (2003)]. A history of accidents also fails to provide a methodology for research. In this issue, we focus on causal processes, in the belief that creative evolution is an autodynamic process rather than the result of the accumulation of accidental events.

Chaos theory is the backbone of current efforts to account for innovative phenomena deterministically. However, chaos research has focused on bounded attractors, which, being stable, cannot account for creative phenomena. Thus Walter J. Freeman, in his award accepting presentation, suggested the need to move away from such models in order to study creative dynamics: "We stumbled badly over correlation dimension and the rigidity of basin-attractor theory. Now these useful excesses are behind us" [Freeman (2003)]. Here, the authors focus on two recently identified phenomena- bios and blown-up, two newly recognized patterns that appear in complex processes and signal creative and/or destructive events.

A blown-up is a combined transitional change in which the mathematical model blows up and the relevant physical structure undergoes a fundamental change into a new structure. Lin and Wu [(1998)] have shown that blown-ups appear in nonlinear evolutions.

Bios is an example of creative processes, because it involves the progressive generation of greater novelty, complexity, and diversity. Biotic patterns are found in biological, cosmological and other natural processes, as well as in mathematical series. The study of biotic process is the focus of *Bios. A Study of Creation* [Sabelli (in press)].

The central goal of this collection of articles is practical. The methods to be described are applicable to a large range of phenomena ranging from blown-ups in the study of the weather and earthquakes to the investigation of bios in physics, medicine and economics. However, this practical objective is pursued in the context of a larger aim: to highlight the crucial role of creativity in the new fields of science dealing with complexity, nonlinearity, qualitative dynamics, self-organization, chaos, catastrophe, nonequilibrium thermodynamics, and fractal geometry. The two goals are connected. A major obstacle to the development of methods for the detection and measurement of creative phenomena is a lack of theory. No methods are developed without theory. Underlying the lack of theory is a lack of motivation stemming from the notion that natural processes are either determined or aleatory.

This issue presents two attempts to develop a theory of creative and destructive processes –bios and blown-up. They were inspired by different philosophies –Greek physiology and Chinese Taoism, and emerged from different disciplines– mathematics and medicine. Yet, both perspectives focus on the creativity of evolution and assign a creative role to the interaction of opposites.

Considering processes as creative posits a different set of questions than those raised by the current focus on nonlinearity, uncertainty, chaos and fractality; in particular, one needs to measure different properties of the time series. Thus, regardless of the relative importance of these various processes –noise, chaos, bios, and blown-up- in any given process, it is useful to consider multiple models in the analysis of empirical data.

In our view, fundamental aspects of process thinking remain to be incorporated into contemporary theories and methods. Mechanism has promoted continuous models, time reversibility, and determinism, as contrasted to discrete units, discontinuous change, temporal unidirectionality and irreversibility, and creative innovation. Many historical and evolutionary views posit increasing complexity while standard thermodynamics postulates decay towards disorder; process thinking implies the coexistence of these opposites. Evolutionism and dialectic materialism stress the conflict of opposites, while systems theorists regard complexity as resulting from the integration of complementary opposites; process thinking implies the coexistence of both integration and conflict. A dichotomous view accrues in current portraits of modern science as opposed to Cartesian and Newtonian worldviews. For instance, according to Capra [1996], chaos theory, fractal geometry, and nonequilibrium thermodynamics have led to a shift in perception from structure to process, from linear to nonlinear, from quantity to quality, from number to pattern, from scale to scale-free complexity, from specialization to wholes, from certainty to uncertainty, from stability to instability, and from order to disorder. In contrast to this dichotomous view, a different strand of process thinking portrays linearity and nonlinearity, quantity and quality, certainty and uncertainty, stability and instability, as coexisting in all processes. Uncertain, unstable, disordered flux coexists and interacts with certain and directed action to generate complex organization. Many purported opposites are simply stages in the development of processes. Change progresses from disorder and order to novelty and diversification. Information evolves from uncertainty and certainty to complexity. Structures evolve from instability and stability to living organisms.

This special issue is unique insofar as it represents a coordinated effort to develop a particular approach to the study of systemic processes. The preparation and editing of these articles has been a collective endeavor of a group of researchers from various fields and institutions.

The first series of articles, **Nonlinearity, Chaos, and Beyond** by Yi Lin, consists of two parts.

Part 1 summarizes some of the most recent work done by the "Blown-Up Research" group. Through mathematical rigor, formal logic reasoning, and numerical experiments, it is shown that blown-ups and "death" of continuity are two very important characteristics of nonlinearity; blown-ups are omens of reversal and transitional changes of evolutions; indeterminacy of a system is simply local reflection of some determinant changes of a larger system.

Part 2 compares the concept of blown-up with Thom's catastrophe and Lorenz's "chaos". The concept of blown-ups is employed to analyze Haken's slaving principle and to reach out to relevant scientific areas beyond nonlinearity, including universal gravitation and Newton's laws of mechanics. A practical application to weather forecasting is presented.

The second series of articles, **Bios Data Analysis: Process Methods to Analyze Creative Processes**, presents a systematic approach to study creative processes through the analysis of time series, and the Bios Data Analyzer (BDA), a collection of computer programs to measure creative phenomena [Sugerman et al, in press)]. This series of articles is organized as following:

Part 1. Empirical Foundation and Medical Application presents an intuitive concept of creative phenomena and introduces the process method through the analysis of a medical application. Heart rate variation, a clinically significant variable, displays novelty, diversity and complexity, the defining features of creativity. This pattern is not appropriately described as either chaos or noise. We call it bios, and regard it as the prototype of creative processes. The methods described distinguish cardiac patterns in healthy persons from those with cardiac or psychiatric illness.

Part 2. Bios and Bipolar Feedback: Mathematical Models of Creative Processes presents models for creative process using recursions of trigonometric functions. The concept of bipolar feedback is contrasted with the standard concepts of positive and negative feedback. Bios is related to and contrasted to chaos.

Part 3. Theoretical Foundations of the Process Method develops the hypothesis that causal interactions between complementary opposite processes create novelty, diversity and complexity. A general theory of processes is developed in which energy, time, information and material structure are regarded as physical embodiments of universal mathematical forms (lattice, group and topology) at all levels of organization. These "primary processes" serve as the generators for creative development.

Part 4. Flux and Action: Process Statistics describes statistical measures of flux and action. Static statistical parameters portray together the undirected and directed flux of energy. Changes in statistical parameters quantify action, the conjoint flow of energy and time. Increase in variance (diversification) is characteristic of creative processes, differentiating them from random or chaotic series. Autocorrelation indicates the continuity of causation: positive in bios and negative in chaos. Partial autocorrelation differentiates causal creative processes from stochastic innovations generated by accidental events.

Part 5. Action and Information: Repetition, Rise and Fall presents simple measures of pattern that encode the information contained and received by a process. Measures of rise and fall detect and differentiate polar, triadic, and quaternary generators in time series. Sequences of repetitions signal large changes in pattern, such as transitions to chaos and bios.

Oppositions generate change and creation. **Part 6. The Phase Space of Opposites in Psychology, Sociology and Economics** presents the use of Cartesian plots as measuring scales. In practice, the diamond of opposites should replace the linear scales that are widely used in psychological and sociological testing which are invalid to measure opposites. Theoretically, the use of these scales leads to the concept of bifurcating personality (intense, introvert and extrovert, harmonious and conflictual), biculturation (cultural individuation of immigrants), and bipolar feedback of supply and demand.

New methods to study coexisting opposites in single time series are described in **Part 7. Opposition: Trigonometric Analysis in Time Series**. The computation of the sine and cosine transform of the time series reveals an archetypal pattern in the apparently erratic sequence of heartbeat intervals, indicating the fundamental character of opposites. Similar transformations demonstrate partial, uncorrelated and asymmetric opposites in all empirical processes, at variance with standard concepts of polar opposites and of complementary opposites.

Part 8. Recurrence Isometry: Measures of Novelty, Causation and Nonrandom Complexity describes recurrence methods to identify the hallmarks of creativity. Recurrence plots show time-limited patterns that replace each other (*complexes*), as contrasted to uniform chaotic patterns and stable dissipative structures. Recurrence quantification of creative processes shows a lower rate of isometry than random copies (*novelty*) and high *arrangement*, a measure of complexity that is largest for biological data and lowest for random series, in contrast to algorithmic complexity. Natural creative processes, bios, and stochastic noise show these features of creativity, while chaos does not.

Part 9. Embedding Plots: A Tool for the Analysis of Simplicity, Complexity and Creativity describes a tool for the simultaneous analysis of simplicity and complexity. Creativity consists in the generation of new dimensions. Practically, the method distinguishes causal creative processes that include both simple and complex components of variation from stochastic processes that include only complex components, and from chaotic processes that decay from order to randomness as the number of dimensions is increased. Theoretically, a focus on both simplicity and complexity integrates reduction and complex systems strategies.

Creative processes necessarily precede and exceed decay. **Part 10. Process Entropy, a Multidimensional Measure of Diversity and Symmetry** introduces methods to study the entropy of processes as contrasted to the entropy of states. To portray both simple and complex levels of organization, process entropy is computed in multiple dimensions. Such measurements distinguish creative from mechanical and random processes, and show that entropy measures symmetry, variety, and organization rather than disorder (a drastic departure from standard presentations of thermodynamics).

Integrating these techniques, **Part 11. Biotic Patterns in Biological, Economic and Physical Processes** describes bios as exemplary of creative processes, distinguishes it from chaos and statistical noise, and demonstrates the presence of biotic features in a wide range of empirical series, including sequences of bases in DNA, air temperature, and commodity prices. A centerpiece of this article is the demonstration of bios in the distribution of galaxies as a function of their redshift –a definitive example of creation.

We hope that this two series of articles can be useful to researchers, practitioners and students who continually encounter the creative phenomena described here in their own work.

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