Quantum Bios and Biotic Complexity in the Distribution of Galaxies

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Bios is a nonstationary chaotic pattern that resembles stochastic noise. New time series analyses identify features of creativity, namely episodic patterns, novelty, increasing variance, and nonrandom complexity. These properties characterize bios and are absent in chaotic attractors. Biotic patterns are found in biological processes. Here we report the demonstration of bios in two fundamental physical processes. Time series generated with the Schrödinger’s equation display biotic features. Quantum bios is consistent with evidence for quantum chaos. The distribution of galaxies recorded in two recent surveys show a biotic pattern along the time-space axis. This is consistent with the demonstration of fractal features. Bipolar feedback recursions generate increasingly complex patterns (equilibrium, periods, chaos, bios), thus offering a model for the causal creation of complexity.


Key Words: bios; chaos; complexity; galaxies; quantum physics

Here we report the demonstration of biotic (life-like) features in two fundamental physical processes: the wave function of an electron described by Schrödinger’s equation, and the distribution of galaxies along the time-space axis. We characterize “biotic” by features of creativity found in biological processes such as heartbeat interval series [1] that we regard as the prototype of bios. Biotic patterns are widespread in natural and human processes (respiration, sequences of bases in DNA, meteorological data, economic series; [2]), but they have been described as noise or chaos.

Considering causal processes as mechanical rather than creative, leads one to regard the emergence of novelty as accidental, and complexity as generated solely by selection among random events (Darwinian model). We here con-
Consider an alternative hypothesis, namely that the interaction of simple processes causally generates diversity, novelty, and complexity. Cosmological, biological and human evolutions may thus be both creative and causal.

Complexity is by definition a high dimensional process. A cause is a simple, low dimensional process, as contrasted to randomness, which has maximal algorithmic complexity [3]. To demonstrate and measure the creation of complexity, one must then measure both simple and complex components of the process under consideration. This can be done by quantifying statistical and dynamic features of the series at low and high embedding dimensions. This is the core strategy used in the Bios Data Analyzer (BDA), a set of computer programs to study causal creative processes in time series data [4]. In this manner, biotic complexity can be differentiated from chaotic turbulence and from stochastic noise. Chaos resembles randomness; bios resembles Brownian noise. Bios differs from stochastic noise in its deterministic origin, which can be demonstrated by partial autocorrelation [5] and consecutive recurrence. Bios resembles chaos in its aperiodic trajectory and sensitivity to initial conditions. Bios differs from chaotic attractors in displaying features of creativity such as diversification, complexes, novelty [6] and arrangement [7].

**MATHEMATICAL MODELS**

Bios can be generated by a number of simple recursions of trigonometric functions [8], which we shall call biotic equations, the simplest of which are the process and the diversifying recursions:

\[
A_{t+1} = A_t + g \cdot \sin(A_t).
\]

\[
A_{t+1} = A_t + \sin(g \cdot A_t).
\]

As a sine (or cosine) function oscillates between +1 and −1, the feedback is at times positive and at times negative. The sine function generates a simple harmonic motion, which is bipolar and diverse. It models the interaction of a process with a wide gamut of synergistic and antagonistic opposites. The complexity of the patterns generated by these simple recursions increases with the magnitude of the feedback gain (Figure 1): (1) convergence to steady state π; (2) bifurcation cascade; (3) period 2 chaos (4) chaos; (5) bios; and (6) infusion.

Visual inspection readily distinguishes biotic from chaotic series (Figure 2); nonstationarity, contiguity, irreversibility, and global sensitivity to initial conditions differentiate them (Figure 3). In chaos there is only local sensitivity to initial conditions (change in trajectory but not in basin of attraction). Chaos is a uniform and bounded pattern, in which successive terms often lie across the midline. Bios is nonstationarity, and successive terms lie close to each other (contiguity, a discrete form of continuity). Thus chaotic series show negative autocorrelation, whereas biotic series are highly self-correlated (Pearson’s correlation coefficients R > 0.99). Biotic series are expansive; chaotic processes converge to an attractor (Figure 4).

**BIOS DATA ANALYSIS**

A number of time series analyses differentiate biotic patterns from other aperiodic patterns in empirical data. In our studies, these series were analyzed using the Chaos Data Analyzer [9], the Bios Data Analyzer [4], and other statistical and recurrence programs [10]. As shown in Table 1, bios differs from chaos in a number of standard statistical and dynamical measures. Partial autocorrelation coefficients demonstrate causality; positive and negative autocorrelation for multiple lags are observed with bios and chaos, differentiating them from 1/f noise and Brownian noise that correlate for only one lag.

The most evident characteristics of bios are nonstationarity and multimodality. The statistical distribution is asymmetrically distributed above and below the central value; in contrast, random series and chaotic attractors are symmetrically distributed. Asymmetry is an essential feature of fundamental natural processes (Pasteur’s cosmic asymmetry; [11]).

Changes in variance differentiate biotic series from chaotic and stochastic series in empirical data. Random distributions and chaotic attractors maintain a stable variance. Biotic series, as random walks and creative natural processes increase in variance with time, a phenomenon that we call diversification [12]. We measure increase in SD with embedding (local diversification). In a similar manner, we measure diffusion as the increase in mean squared displacement (MSD) with embedding (local diffusion) [2]. Bios and natural creative processes show local diversification beyond local diffusion, that is, an increase in the ratio of diversity (as defined above as the SD) to diffusion (as defined above as the MSD) with an increase in embedding (local).

The pattern of the sequence changes in biotic series, random walks and creative natural processes. The episodic character of biotic series is evident in recurrence plots. The Euclidean norms of vectors of 1, 2, . . . , N consecutive terms are calculated and compared using a program developed by Sugerman et al. [4]. When their difference is less than given radius of tolerance, an isometry is counted and plotted. Clusters of recurrence (complexes) separated by recurrence free intervals indicate time-limited, episodic patterns. Shuffling erases this organization in separate complexes (Figure 5). Random and chaotic series show uniform recurrence plots, without complexes.

**Novelty** is defined as the increase in recurrence isometry produced by shuffling the data [6]. Because a recur-
rence is a repetition of pattern, a lower than random recurrence rate indicates that the process under consideration innovates more than chance events. Random series do not show novelty. Among deterministic series, novelty is the defining feature of bios that differentiates it from chaos.

The proportion of consecutive isometries (as percentage of total isometry) is an indication of causality or determinism [10]. Biotic as well as chaotic series show a high proportion of consecutive isometries at low embedding dimensions, which we interpret as evidence for causality [2], whereas statistical noise shows consecutive recurrence only at high embeddings or not at all.

The ratio of consecutive isometries to total isometry, which we call arrangement, is high in mathematical bios and in biological series, and in particular it is higher than
in their randomized copies. Arrangement is low in random, chaotic, or periodic series [7]. For this reason, we think that arrangement is a measure of nonrandom complexity [2].

**BIOTIC PATTERNS IN THE SCHRODINGER’S EQUATION**

We considered time series generated by the time-dependent Schrödinger equation for a wavepacket representing an electron confined to a region of $L = 1E - 5m$ (approximate...
using a program adapted from Koonin [13]. The time series was constructed as the amplitude of $|\cdot|^2$ at the midpoint between barriers (Figure 6). We also constructed spatial series of $|\cdot|^2$ after a large number of iterations.

The time series show biotic features: aperiodicity (Figure 7), diversification (Figure 8), complexes (Figure 9), novelty, and consecutive recurrence, and nonrandom complexity (arrangement; Figure 10). The spatial series also show biotic features. These experiments show that the fundamental


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atomic dimensions) using a program adapted from Koonin [13]. The time series was constructed as the amplitude of $|\cdot|^2$ at the midpoint between barriers (Figure 6). We also constructed spatial series of $|\cdot|^2$ after a large number of iterations.

\begin{table}[h]
\centering
\begin{tabular}{|l|c|c|c|c|c|}
\hline
 & Random & Chaos ($g = 4.5$) & Bios ($g = 4.65$) & Schrödinger equation & Galaxies ($z$ axis) \\
\hline
Chaos data analysis & & & & & \\
\hline
Statistical distribution & Symmetric & Symmetric & Asymmetric & Asymmetric & Asymmetric \\
Clumping & No & Clumping & X pattern & Almost none & X pattern \\
Power spectrum $\beta$ & $\sim 0$ & $\sim 0$ & $> 2$ & $> 2$ & $> 2$ \\
Hurst exponent & $- 0$ & $- 0$ & $0.3$ & $0.77$ & $0.2$ \\
Lyapunov exponent & $0.9$ & $0.75$ & $0.3$ & $0.18$ & $0.38$ \\
Capacity dimension & $> 3$ & $3$ & $1.7$ & $1.26$ & $1.38$ \\
Correlation dimension & $- 4$ & $1$ & $1.9$ & $1.9$ & $3.5$ \\
Correlation function $\varphi$ & $0.6$ & $0.5$ & $327$ & $14$ & $157$ \\
Prediction error & Baseline & Larger & Smaller & Smaller & Smaller \\
Lempel-Ziv complexity & $1$ & $0.82$ & $0.25$ & $0.21$ & $1.04$ \\
\hline
Bios data analysis & & & & & \\
\hline
Diversification & No & No & Yes & Yes & Yes \\
Recurrence plot & Uniform & Uniform & Complexes & Complexes & Complexes \\
Recurrence isometry compared to random & Baseline & Higher (order) & Lower (novelty) & Lower (novelty) & Lower (novelty) \\
Consecutive recurrence & No & Yes & Yes & Yes & Yes \\
Nonrandom complexity & No & No & Yes & Yes & Yes \\
\hline
\end{tabular}
\caption{Analyses of Random, Chaotic, Biotic, Schrödinger's and Galactic Time Series}
\end{table}
equation for describing the behavior of a quantum dynamic system shows biotic features.

The biotic pattern of time series generated by Schrödinger’s equation has been recently confirmed by physicist Thomas and coworkers [14]. Finding bios in quantum processes is consistent with evidence for chaotic patterns at the quantum level [15,16].

BIOTIC PATTERN IN THE DISTRIBUTION OF GALAXIES
Paradigmatic of creative processes is the formation and distribution of galaxies. The combination of enormous distances among galaxies with the finite velocity of light allows one to observe directly cosmological evolution. Some cosmological models such as the standard cosmological model described by Peebles [17] assume that the universe is homogenous and isotropic. The overall distribution of matter is regarded as a random stationary process [17]. It is proposed that hierarchical structure of the observed universe, in which galaxies form clusters and superclusters has been determined by initial deviations from uniformity such as those detected in studies of the cosmic background radiation. An alternative model pos-
tulates self-similar fractal geometry generated by stationary stochastic processes [18]. We propose instead that the universe is a causal process of creative evolution that continues to generate heterogeneity in the distribution of matter [19].

Recent surveys of the distribution of galaxies offer significant data for testing these hypotheses. The “Las Campanas Redshift Survey” (LCRS; [20]) covers more than 700 square degrees in 6 strips, three each in the North and South galactic caps. After filtering the data (as indicated in [20]), we analyze 25,322 galaxies. The “2° Field Galaxy Redshift Survey” (2dFGRS; [21]) covers more...
than 100,000 galaxies spread over 2000 square degrees in both South and North galactic caps. Because the survey is not complete, there are discontinuities in the data, so we crop them to obtain two continuous strips. From the redshift, we calculate the distance along the z-axis that represents space-time. The series analyzed are: the number of galaxies in one Mpc bins ("galactic distances"). Analyzes were carried out for the entire set as well as separately for the six strips from LCRS and the two strips from 2dFGRS. For each these series of data, we also construct the time series of differences between consecutive terms. These time series are compared with shuffled copies.

Histograms of galactic distances show multimodal and highly asymmetric distribution (Figure 11). The time series of galactic distances shows local diversification, thus indicating creativity.

Recurrence plots demonstrate complexes separated by interruptions of recurrence (Figure 12). Isometry analysis of the distribution of galaxies along the Z (time and space) axis shows the presence of the novelty, consecutive isometries, and arrangement (Figure 13). The results were similar for the set of all galactic distances as well as for all eight individual strips. The differences noted among them witness the heterogeneity of the distribution of matter in the universe. This heterogeneity is well known. The new information added by the current analyses is the characterization of observed pattern as biotic.

Notably, complexes are also found in the series of differences between consecutive galactic distances, and not in shuffled copies. Recurrence analysis of these series also shows consecutive recurrence creative features: complexes, novelty, and arrangement. Finding pattern in the series of differences demonstrates that the series is determined rather than stochastic.

The causal origin of the pattern is also demonstrated by extended partial autocorrelation (Figure 14).

We also studied the distribution of galaxies long the Right Ascension axis at multiple distances. There were biotic features for series along the Right Ascension axis at 200 to 500 megaparsecs, but not at shorter or larger distance. This range of distances corresponds to that at which fractal structure has been demonstrated [22].

**DISCUSSION**

The creation of complexity is a central issue in contemporary science. The present studies show diversification, novelty, and nonrandom complexity, the defining features of creative processes, in physical processes at the quantum and cosmological levels. Creative features may be generated by deterministic processes (biors) or stochastically (statistical noise). Consecutive recurrence at low embedding dimensions and partial autocorrelation indicate a deterministic mechanism, i.e., biors.

Finding biors in the Schrödinger’s series suggests that quantum processes may be creative. The potential for creative evolution appears to be already present in causal processes at the quantum level. The demonstration of diversification, novelty, and arrangement (nonrandom complexity) in the distribution of galaxies along the z-axis shows that the physical evolution of the universe may also be a creative process.

Biotic complexity differs from other complex patterns in that it includes within itself simple components that presumably reflect the causal processes that originate it. Biotic complexity is generated by high-amplitude bipolar feedback. This points to a mechanism for the expansion and complexification of the universe, namely the expansion of a chaotic process generated by the interaction of fundamental opposites. In these recursions, periodic order precedes chaos, and biotic complexity emerges at the other end of chaos, rather than between order and chaos. Bios evolves as an expansion of chaos. In many recursions, there is a sharp transition at which the series expands beyond the bounds of the chaotic attractor [23,24]. This phenomenon has been
Embedding plots of time and space series generated with the Schrödinger equation. Isometry recurrence (left), consecutive isometry (center), and arrangement (right) computed after embedding the series 1, 2, 3, ..., 100 times. Circles: original data. Thin line: shuffled copy. Novelty is indicated by the increase in recurrence with shuffling. Determinism is indicated by the decrease in consecutive recurrence with shuffling. Nonrandom complexity is measured by the decrease in arrangement with shuffling.
regarded as a model for physical diffusion [25]. We regard biotic expansion as a model for growth. Deterministic diffusion can be generated by a number of mathematical recursions without generating biotic patterns. Conversely, bios is characterized by features other than diffusion, namely diversification, novelty, nonrandom complexity, complexes, and asymmetry. Biotic series can be bounded, as illustrated by heartbeat series and by homeobiotic equations [2]. In the series of galactic distances, local diversification exceeds local diffusion. What characterizes bios is creativity beyond diffusion. The process of expansion may play a fundamental role in creative processes (bios hypothesis); e.g., quantitative growth is necessary for qualitative maturation in biological organisms; and cosmological evolution is accompanied by an expansion of intergalactic space; ecological spreading of species; and expansion of social systems (tribe, nation, federation, empire), etc. Finding biotic features in the distribution of galaxies for at least 2.5 billion years indicates that biotic expansion must have been operative for a significantly large era of cosmic evolution.

The observation of bios at the quantum and cosmological levels, together with previous observations at the biological and economic levels, indicates that natural processes are both causal and creative at all levels of organization. We propose that fundamental natural processes are deterministically creative in the sense that mathematically deterministic equations generate diversity, novelty, and complexity [2, 26]—rather than being stochastic, indeterministic, chaotic, convergent to equilibrium, or decaying toward entropic disorder. This is not surprising, because as the Schrödinger equation is deterministic, and cosmological studies demonstrate that the universe evolves rather than remaining in a stationary pattern.

The fractal distribution of galaxies [18] is consistent with bios, which has fractal features [27], but biotic processes have a deterministic origin and represent a nonstationary evolution, at variance with Mandelbrot’s notion that stationary and stochastic processes account for the distribution of galaxies.

In summary, biotic patterns appear to be widespread, as they had been now found in physical, physiological, eco-

**FIGURE 11**

![Statistical analysis of the distribution of galaxies along the Z (time and space) axis. Series of galactic distances. LCRS.](image)

**FIGURE 12**

![Recurrence plot of galactic distances. Left: Original data. Few recurrences clustered in separate complexes. Right: Recurrence plot of shuffled copy of galactic distances. Uniform distribution and more recurrence (novelty).](image)
nomic, and meteorological series. These observations suggest to us that bipolar feedback may be one of the generic processes for generating complexity in nature.

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REFERENCES


Partial autocorrelation: Mathematical bios and the distribution of galaxies show extended partial correlation, whereas Brownian noise does not. LCRS stands for Las Cañadas Redshift Survey, and 2dFGRS stands for 2° Field Galaxy Redshift Survey.
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