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ACTION CREATES BIOS

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Abstract: Simple mathematical recursions generate phenomena of intrinsic interest, and model the newly found biotic pattern, observed in biological and economic series. They also suggest how physical processes might determine creative evolution without relying on accidental contingency or supernatural intervention.

Sommaire: Simple récursivité mathématique engendre phénomènes intrinsèquement intéressant, et il présente une modèle biotique, une configuration recentement identifié dans les processes physiologiques et èconomiques. D'autrefois, cettes equations suggérent comment les processes physiques pourrait déterminer une évolution créatice sans dépendre de l'hasard ou l'intervention supernaturelle.

Nonlinear dynamics and personal computers provide new tools to explore basic questions. How can one explain evolution from simple physical processes to life and mind? Where does evolution go from here? What originates the universe? Why is there something, rather than nothing? Nozick [1981] proposes that the task of philosophy is to explore how reality is possible at all, even when we cannot say as yet, or ever, how it has become real. The point is well taken, and it does not exclude the opposite truth, that that we are active participants in creating reality. Keeping both in mind, it behooves us to focus on processes of creation. Mechanical determinism cannot account for creation, so random fluctuations and accidental contingency are offered as explanations for the origin and evolution of the universe, and of life. Random models have proven scientifically useful, but cannot account for progression from simple to complex. Further, random "explanations" disarm rather than empower the human actor. Even worse, portraying nature as random encourages disregard for natural patterns, the consequences of which we experience as pollution, iatrogenic illness, and failed social experiments [Berry, 1987]. As an alternative, let us consider the hypothesis that physical processes determine creative evolution, just as biological development generates unique individuals. Creative processes can be recognized in that they generate novelty, complexity, diversity, and time-limited patterns. The crucial feature is novelty, meaning change faster than random events; for instance sexual reproduction accelerates change beyond random mutation. Measuring novelty with the recurrence method has already revealed biotic patterns in physiological and economic processes [Sabelli et al, 1997] presumed to be random or chaotic. Biotic patterns can also be generated by the process equation [Kauffman and Sabelli, 1998], providing a tool to understand how novelty may come forth in nature. This article presents a mathematical strategy, and explores a particular model to account for the creativeness of natural processes. The model offers explanations only in the sense stated by Nozick, but it generates mathematical phenomena that can hold our interest regardless possible interpretations. In this spirit I invite the reader to embark with me in a journey of exploration.

Natural science regards the universe as organized by a small set of simple forms, that through their interaction, generate nature, life and mind. The most fundamental forms are mathematical, because physical processes must obey the laws of mathematics, that are both necessary and certain. The fundamental physical processes are quantifiable, and thus must embody arithmetical operations. Necessary mathematical forms and relations are thus materialized in spatial structures and physical processes, including brain and mind.

Action appears to be the sole constituent of the universe. Planck discovered that radiation can be emitted only in multiples of a quantum that has the dimensions of action = energy * time. Energy and time are inseparable. Einstein showed the equivalence of matter and energy, and further, that energy consists of multiples of Planck's quanta. Hence action A_t is an integer quantity that can be iterated, added and subtracted. Also at macroscopic levels action is made of discrete units (atoms, cells, organisms). That action is discrete also indicates that processes should be modeled by discrete difference equations of the form $A_{t+1} = A_t + \Delta A$, rather than by continuous differential equations. Actions produce interactions; interactions produce change, external (causation) and reflexive (feedback). Change in action ΔA embodies information; Shannon stressed that information is necessarily carried by material or energetic tokens.

Lattice, group and topological theory are the three pillars of mathematics (Bourbaki, Piaget, Mac Lane [1986]), suggesting that the most fundamental forms of nature are asymmetric and transitive order (lattice theory), opposition and symmetry (group theory), and continuous and discontinuous transformations (topology). Process theory [Sabelli, 1989; Sabelli et al, 1997; Sabelli and Kauffman, in press] formulates the view that creative evolution is the necessary consequence of mathematical laws embodied in action, information, and formation at all levels of organization in the following hypotheses: (1). **Action**, the change of energy in time, is an asymmetry in the background of uniformity that appears static or void. (The void is full of energy, fluctuating within the limits of Planck's constant.) Time asymmetry organizes actions into a lattice. (2). **Information** is difference or distinction, embodied in changes of action. One value carries no information. Information implies the local separation of opposites that coexist in the process; processes are groups containing opposites defining a variety of symmetries. (3). **Co-creation**: interactions between partial opposites generate (and destroy) form, generating novelty, diversity and complexity (higher dimensions), such as tridimensional matter and multidimensional organisms. Forms transform; they are less rapidly changing, but less durable than action and information. Mutual feedback transforms each interactor. Division and combinations generate new systems. This notion of co-creation through interactions that are both synergic and antagonistic is offered as an alternative to both one-sided idealization of competition and struggle as the motor of evolution, history, and economic progress, and one-sided descriptions of systems as integrated, non-conflictual wholes.

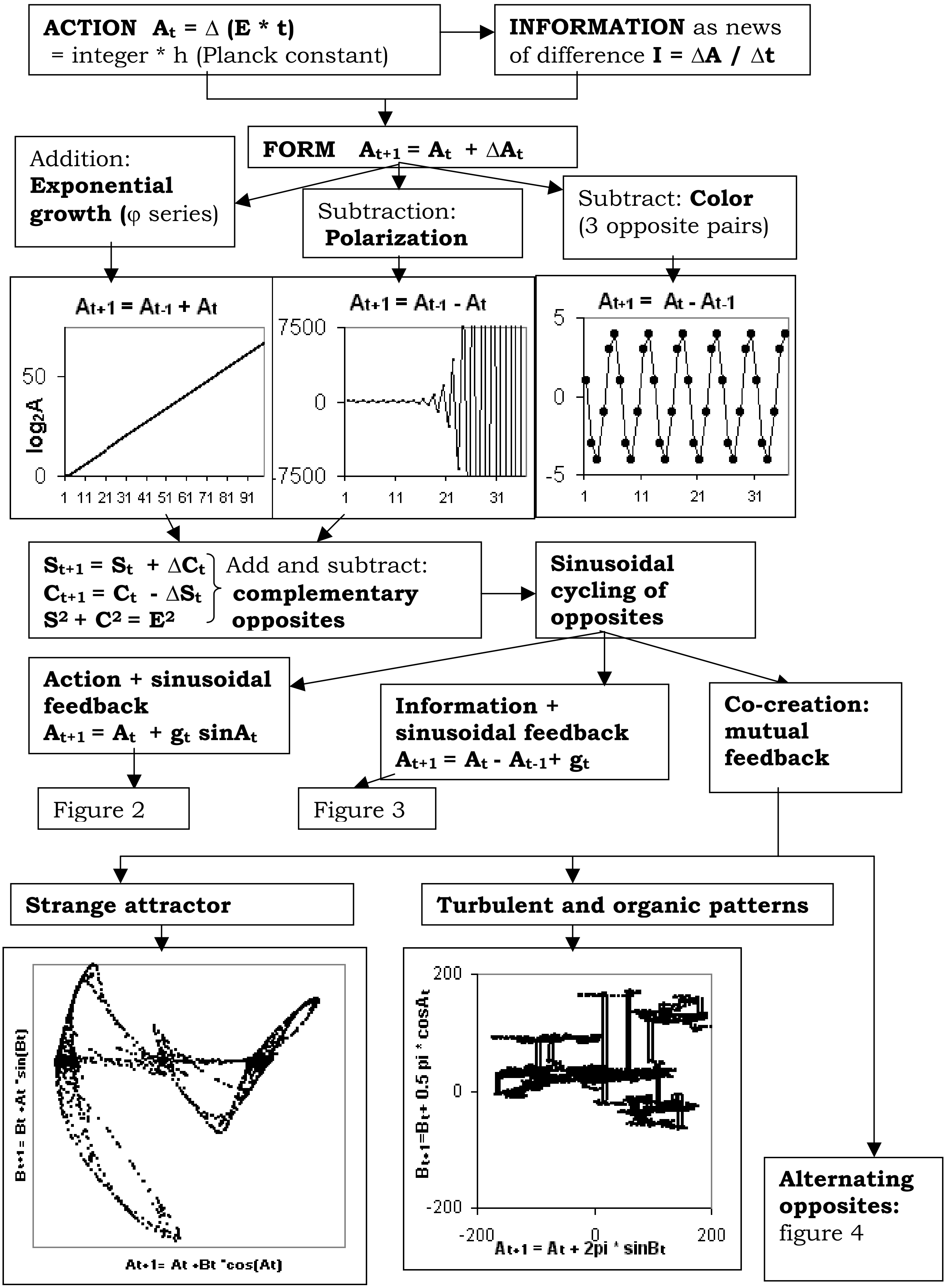
Here these hypotheses are explored with a series of simple mathematical models in which action is represented by A_t, indicating that it changes in time, information is the change ΔA_t, co-creation is modeled by making ΔA a function of A_t, and form is represented by the pattern of the time series. Each model builds upon the preceding ones, forming patterns of increasing dimensionality (complexity). In this manner a "toy universe" is constructed.

RECURSIVE EQUATIONS

Arithmetic equations

The entire edifice rests on the fact that action is quantifiable. Hence, information is contained in both the difference between successive actions and in their addition (figure 1).

Adding recursively consecutive members of a series $A_{t+1} = A_{t-1} + A_t$ generates the well known Fibonacci series, that grows exponentially, and also generates spiral forms. Whereas addition is



commutative i.e. symmetric, subtraction displays the asymmetry of order: A - B is not equal to B – A, and hence there are two different recursions. The series generated by the recursion $A_{t+1} = A_{t-1} - A_t$ grows exponentially in both the positive and negative direction --difference generates opposition. This bipolar growth models, exemplifies and perhaps even explains enantiodromia, meaning "race of opposites", postulated by process theorists since Heraclitus, as a fundamental form of nature. The trajectory of the series generated by these two equations in the A_t vs. ΔA_t vs. time space are flat, because the ratio A_{t+1} / A_t converges to a fixed value, $\varphi = 1.618...$(golden ratio) for the recursion of addition, and $-\varphi$ for the recursion of subtraction. In contrast, the trajectory of the series generated by the time-reversed distinction $A_{t+1} = A_t - A_{t-1}$ has a tridimensional form. This recursion generates a "color" structure, meaning three pairs of complementary opposites in which the sum of two complementary opposites produces an identity element, and the sum of two primaries equals the complement of the third. Color organization thus is a complex algebraic structure combining opposition and triad [Sabelli, 1989; Sabelli and Carlson-Sabelli, 1996] with mathematical properties similar to those obtaining in groups and lattices. The importance of this logical structure is highlighted by the fact that classes and combinations of quarks can be described by analogy to colors (quantum chromodynamics). A similar triadic organization also applies to quark's flavor. This self-similarity between processes at different levels of complexity may represent a homology, i.e. the result of a common origin in a natural pattern of organization [Sabelli et al, 1997]. Visual colors arise in the retina as a three-way split of the continuum of light wave frequencies. This trifurcation from physical oneness to biological diversity may in fact reveal a fundamental pattern of creative processes [Sabelli, 1989; Sabelli et al, 1997; Sabelli and Carlson-Sabelli, 1996]. It is already apparent in the existence of three complementary arithmetic recursions.

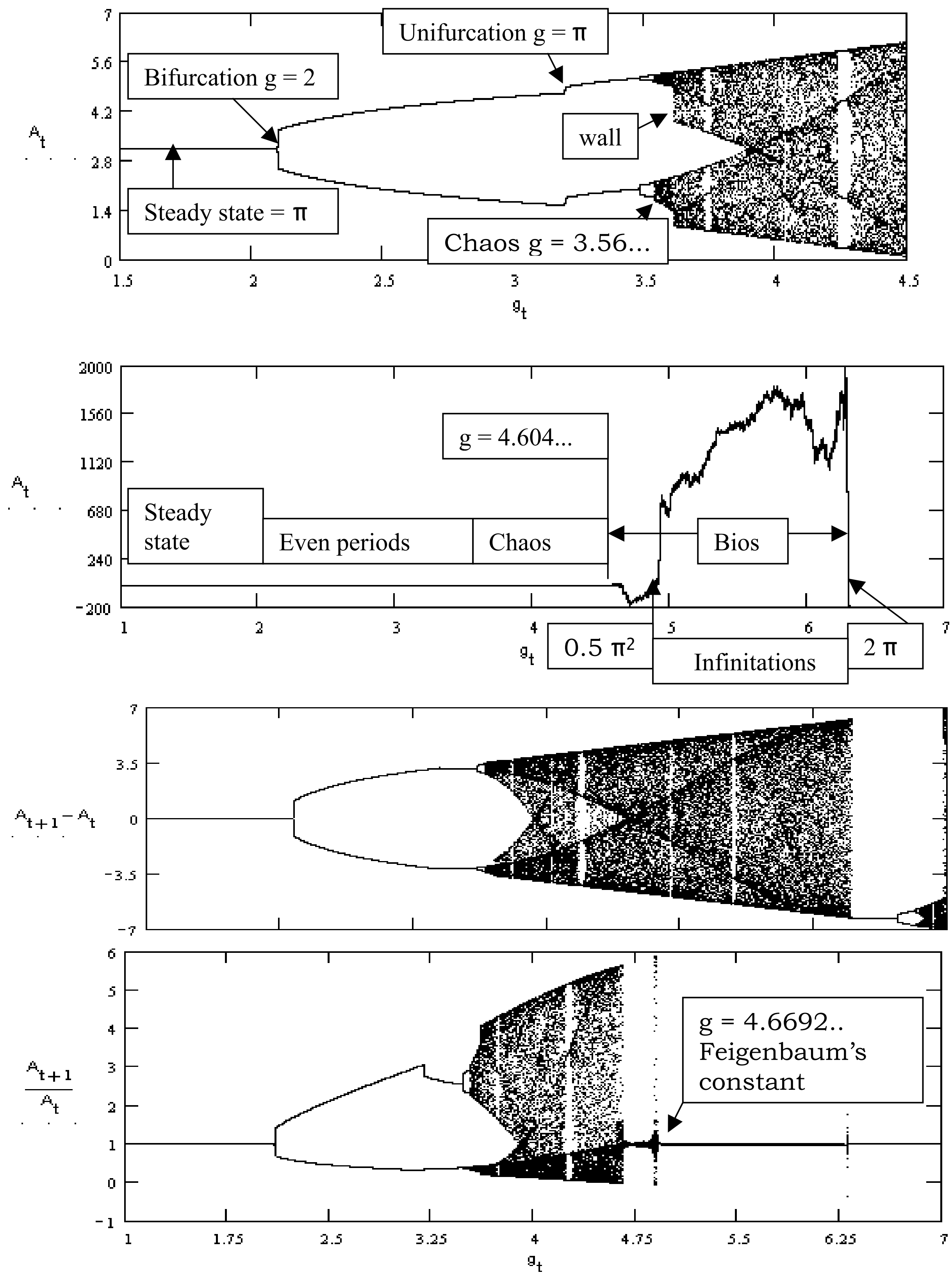
Arithmetic recursions can generate even more complex patterns. The recursion $A_{t+1} = A_t - A_t$ (modulo N) - N generates convergence to a fixed point, period 2, 3, 6, and chaos, depending on the initial value and the modulo. Combining the opposite operations of addition and subtraction in the coupled equations $s_{t+1} = s_t + \Delta c$ and $c_{t+1} = c_t - \Delta s$ produce a number of different patterns, according to the order of operands in the computation of Δs and Δc. Of particular interest is the case in which the total energy of the system of complementary opposites equals a given value, such that $s^2 + c^2 = r^2$. This is Pythagoras theorem, with the sides of the right angle representing the complementary opposites. In this case s and c behave like complementary opposites: they vary together with changes in r, and vary inversely to each other for a given r. This iteration produces an ever expanding polygon that at infinity becomes a circle. Together, circular opposition and linear action generate sinusoidal form. Summarizing: simple arithmetic recursions show how action begets information, and information generates spiraling, opposition, polarization, tridimensional spacing, color organization, chaos, and sinusoidal wave forms. Arithmetic provides a powerful and natural logic [Sabelli and Carlson-Sabelli, 1996], whereas Gödel demonstrated that as a logic, set theory is not sufficient to account for arithmetic.

Biotic equations

Sine and cosine are complementary opposites, meaning that they are orthogonal to each other, and vary in opposite directions. The orthogonal electrical and magnetic fields in light waves exemplify complementary sinusoidal opposites. The wave form of radiation, the careers of force and information, points to trigonometric functions to model process. The process equation $A_{t+1} = A_t + g_t \sin A_t$ models interactions that produce both positive (augmenting, synergistic) and negative (decreasing, antagonistic) change. Change is a function of the previous action, i.e. a

Figure 2. Process equation: time series of A_t, differences A_t-A_{t-1}, and ratios A_{t+1}/A_t generated by the kinetic form of the equation (g as a function of time). Numerical values at which the various phenomena occur depend on the rate of change of g. The values noted obtain when g is kept constant (dynamic form of the equation).

$A_1 := 1$ $\qquad g_t := 0.000075 \cdot t$ $\qquad A_{t+1} := A_t + g_t \cdot \sin(A_t)$



feedback. The feedback is bipolar and diverse, spanning the range from plus to minus g through the continuity of the trigonometric function. Whereas in standard dynamic equations, the control parameter is kept constant, the process perspective leads to kinetic equations in which the feedback gain is a function of t. The equation $A_{t+1} = A_t + k * t * \sin A_t$ generates a series that progresses from simple to complex patterns (figure 2) in a manner resembling cosmological evolution and embryological development: (1) Convergence to π, a single initial, asymmetric (non-zero), steady state. (2) Cascade of bifurcations generating period 2, 4, 8 ...; within this cascade there is an unifurcation (figure 2). (3) Chaos, that may appear random-like but is highly structured; e.g. it is highly anti-correlated (Pearson's correlation for 1 lag –0.99). (4) Bios, an apparently erratic pattern of much larger magnitude and highly auto-correlated (Pearson's coefficient for 1 lag +0.99), interrupted by bioperiodicities extremely sensitive to initial conditions. (5) Escapes towards positive or negative infinity interrupt bios, whenever $g = 2^n \pi$ and at few other critical values. As g increases further, new biotic series emerge, and further infinitations follow –a mathematical metaphor for death and renewal, essential features of living processes. This series illustrates the greater creativeness of bipolar interactions, both synergic and antagonistic, in comparison to simple positive or negative feedback. Process development is very flexible, allowing any initial value and any value or sign for the g parameter, and generating biotic patterns beyond chaos; logistic development requires initial values between 0 and 1, and flights into infinity after chaos.

Biotic series are aperiodic and highly sensitive to initial conditions, as chaos, but in addition their pattern is punctuated and episodic ("complexes") rather than static and uniform, show novelty, defined as less recurrent than their randomized copies, self-correlation, and multidetermined (numerous but not infinite fixed points). These features are also observed in heartbeat series and economic processes. Note in figure 2 that the time series of differences between successive members is chaotic, so biotic patterns in natural processes are mistakenly identified as chaotic when the data are differenced prior to analysis. Bios is described in greater detail in a companion article at this meeting. There is a wide variety of biotic patterns. A process equation using the cosine rather than the sine function shows noteworthy differences with the sine equation; the fixed point is 0.5 π. Notably, in the sine equation itself there is a significant transition from one type of bios to another when g = 4.66... (Feigenbaum's constant), that can be detected in ratio plots (a technique introduced here), but so far in no other time graphs. Biotic patterns generated with $g < 4.66$ resemble heartbeat series much better than those generated at a larger g.

Pointing to **numerical cosmic forms**, 2^n and π^n repeatedly appear as significant outcomes and gains (see figure 2 legend). π is the initial fixed point for initial values between 0 and 2π; even multiples of π separate basins of initial values that converge to odd multiples of π, and unifurcation occurs when $A_t = 1.5\ \pi$ and 0.5 π. As gain, π produces unifurcation, odd multiples of π produce period 2, and even multiples of π produce infinitation. At $g = 2^3$, there is infinitation; at $g = 2^2$, period 12 develops; at g = 2, the initial single outcomes bifurcates. As the two paths diverge, the lower path reaches the Fibonacci's ratio describing spiral order, when the opposite path achieves the Feigenbaum's number describing chaos-inducing bifurcations --a significant complementarity of opposites. Chaotic patterns start when g approximates Feigenbaum's point 3.56... I am tempted by no lesser men than Pythagoras, Galileo, Gödel and Jung to think that numbers represent form, just as they represent quantity and order.

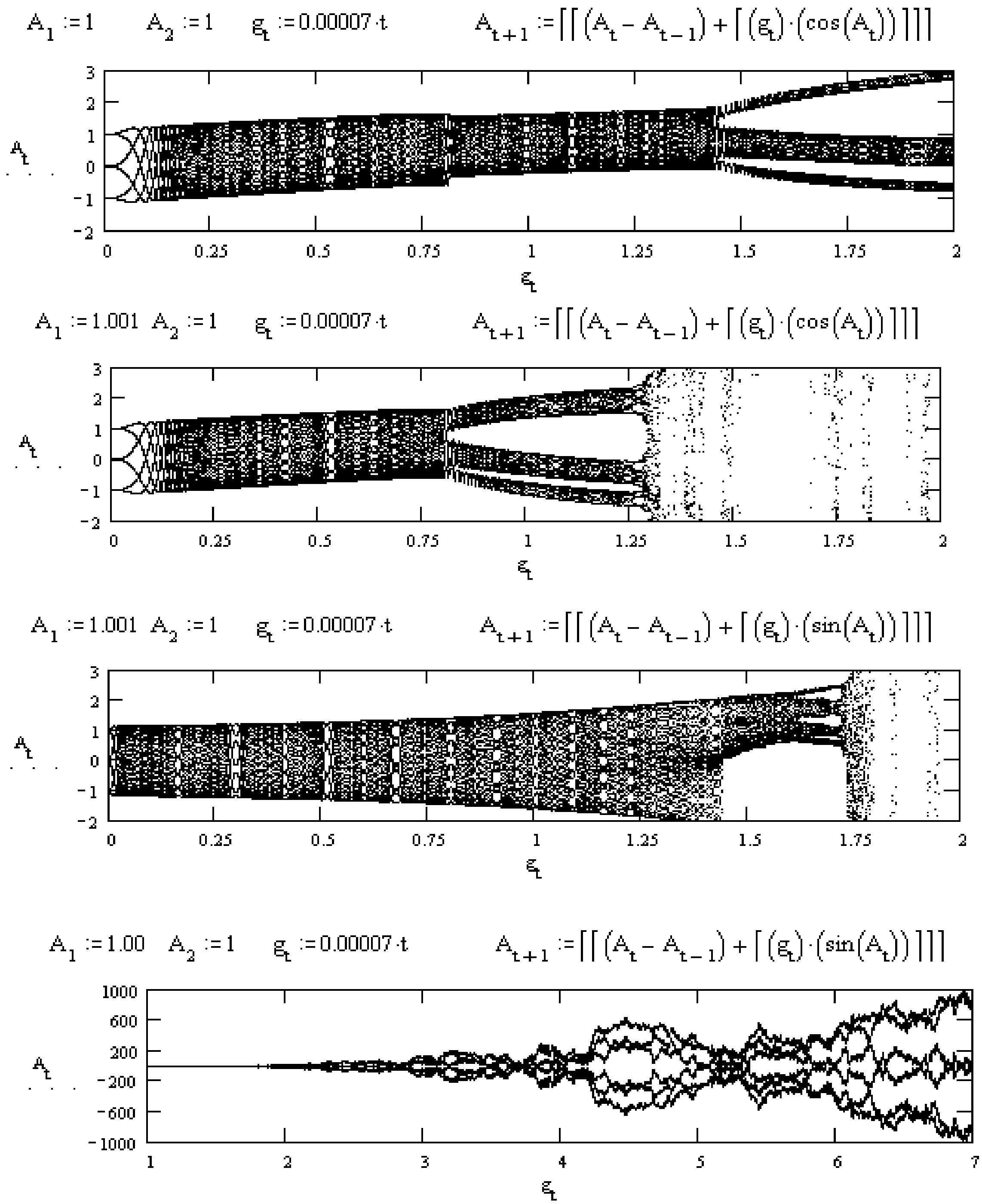
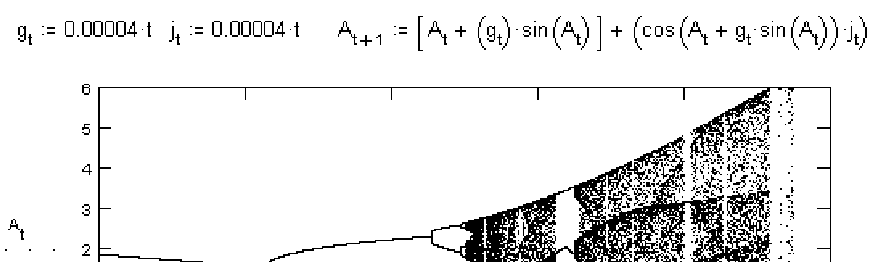


Figure 3: Trifurcating equations (kinetic form): Recursions of change (A_{t-1} -A_t) generate trifurcation, and periodic, chaotic and biotic braids. These patterns obtain with both the dynamic (constant g) and the and the kinetic (g is a function of time) forms of the equation. Dramatic changes in pattern result from changes in initial value (top versus next series), and from replacing the sine function by the cosine (second versus third series). The third series shows multifurcation of the braid and a wall (sudden shrinking of chaos). The bottom series illustrates colored bios, with 6 strands, fluctuating symmetrically about 0.



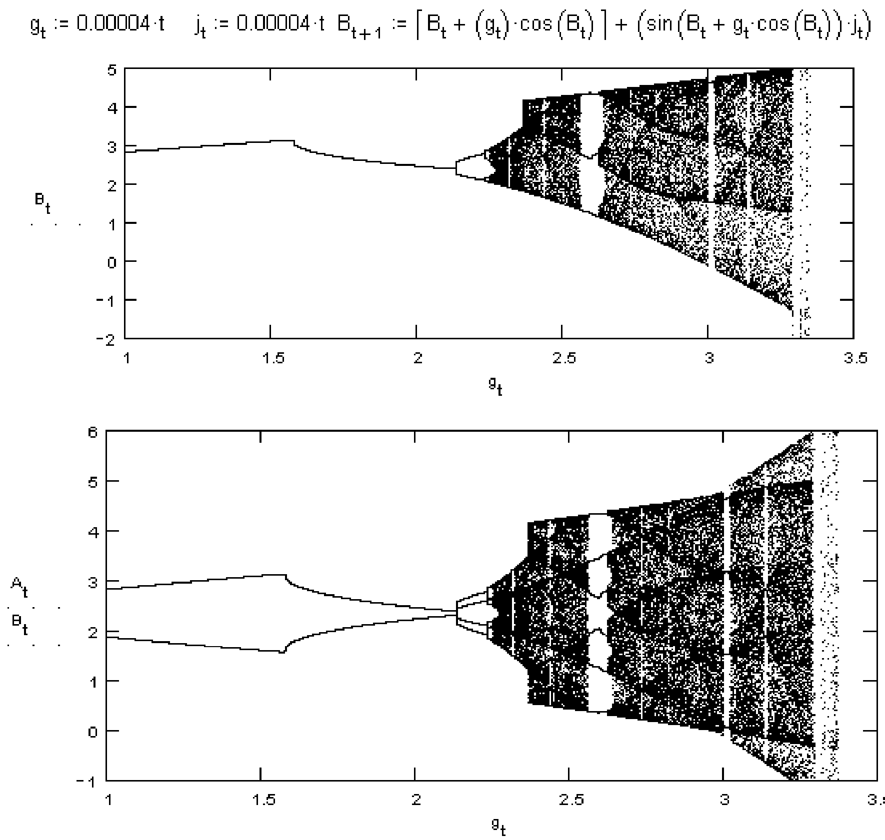


Figure 4. Walking equations modeling the alternation of complementary opposites: The process equation is computed using alternatively the sine and the cosine functions. The order of computation of the sine and cosine generates opposite asymmetric series, partially overlapping mirror images. Each equation generates linear change towards the fixed point corresponding to the second step (π for cosine-sine alternations, 0.5 π for sine-cosine alternations), that obtains at g = 0.5 π at this point there is a sharp unifurcation, followed by even periods, chaos with odd periods and walls (sudden expansion of the chaotic regime), and trended bios.

Trifurcating equations

Recursions such as $A_{t+1} = A_t - A_{t-1} + k * \sin A_t$, and $A_{t+1} = A_t - A_{t-1} + [g_t * \sin(A_t]$ explore processes in which the significant factor is change in action $A_{t+1} - A_t$ (information) rather than the action A_t itself. For instance, sensation (psychobiological information) is a function of a change in the stimulus rather than of its intensity. In these equations the two initial values generate three strands (**trifurcation**) that form a beautiful **braid** (figure 3). At higher gain, the braid expands into 6 biotic strands symmetrically distributed around 0, that approach and separate in a rhythmic fashion (**colored bios**); its trajectory in the At vs. ΔAt vs. time space generates a tridimensional form. In contrast, simple bios is highly asymmetric, and its space portrait is narrow, almost flat. (Note the similarity with the symmetric and tridimensional series generated by subtraction and the asymmetric and two dimensional series generated by addition.) At certain gains, there is a striking growth of new patterns without change in the gain g, a phenomenon that, indulging on biological analogies, we shall call **maturation**. In kinetic forms of the trifurcating equations, the initial braid shows many complexities, including multifurcations, and walls abruptly terminating part of it.

Co-creating equations

Modeling the alternation of opposites, the **walking equation** (figure 4) calculates at one step the change induced by a sinusoidal feedback and at the next step the change induced by a co-sinusoidal feedback. The walks so generated display both similar and complementary features according to the order of the feedback (sine + cosine versus cosine + sine) highlighting the unidirectionality of time. Further, there is no steady state; when the "fixed point" is reached, unifurcation occurs. Combinations of two or more process and/or trifurcating equations produce a variety of intriguing phenomena, including a strange (chaotic) attractor (figure 1), and fractal patterns including with turbulent and organic forms (figure 1). Cascades of process equations, in which the output of one serves as the variable gain of the next one, generate complex forms starting from very simple ones.

CO-CREATION AS A THEORY OF NATURAL CREATION

Far from tending to equilibrium or disorder, successive co-creations generate complex systems. Simple constituents precede, coexist and outlast the complex systems they generate (**priority of the simple**), but informationally richer levels embody the attractor of evolution (**supremacy of the complex**) [Sabelli and Carlson-Sabelli, 1989]. This concept is modeled on the evolutionary, developmental and functional priority of the spinal chord, and the corresponding supremacy of the cerebral cortex. It offers a model for the bidirectional hierarchy of levels of organization in nature based on both complexity of organization and evolutionary temporal sequence: **mathematical < physical < chemical < biological < social < psychological < infinite attractor of evolution**.

Mathematical order is a level of organization of nature, more fundamental than the physical, because mathematical truth is everywhere certain, even in the void, while physical processes must obey mathematical law. The computer experiments presented here show that complex patterns observed in natural processes can be generated by the necessary mathematical properties of action, the simplest and most universal physical form. Does this toy mathematical universe relate to the real one? The gap between mathematical constructs and physical reality appears wider than the gaps between physics and life, life and mind. Notwithstanding, there is a bridge. Two plus two makes four in both natural processes and human reasoning, with equal certainty. Human reason can formulate mathematics, demonstrating a wonderful homology between simple and complex levels of organization. Yet it is also capable of error. Between the extremes of certainty and error lies fantasy and metaphor. Bios, meaning life, is a better metaphor than chaos to describe the universe. Whereas the essence of chaos is unpredictability, the essence of bios is creativity (novelty, complexity, diversity, time-limited patterns). The generation of novel patterns results from the interaction of complementary opposites, as in the process equation. Likewise, in nature, evolution appears to be a process of co-creation, rather than of self-organization. The implications for human behavior are evident.

A philosopher, said Machado, is a poet who believes in the reality of his own images. In our computer age, a philosopher is a mathematician who believes in the reality of his own equations. Fully aware of the difference between preliminary explorations and scientific discourse, let me state the conclusion I would like to draw from these experiments, namely that the necessary mathematical properties of action sustain a development that, albeit determined, is creative. The uni-verse is, as its name states, a unidirectional flow. Such universe does not emerge from, or head towards chaos and entropic disorder. It emerges from action, and heads towards an emergent attractor of infinite complexity. We are part of this evolution, weak but conscious participants. The future is not fully determined, or unpredictable, but co-created. "Caminante, no hay caminos, los caminos se hacen al andar" (Antonio Machado).

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