Biotic Population Dynamics and the Theory of Evolution

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Abstract: We present a theory of evolution and empirical support from empirical studies and computer models of population dynamics. Analyzing published data, we found that changes in population size of lynx, muskrat, beaver, salmon, and fox display diversification, episodic changes in pattern, novelty, and evidence for nonrandom causation. These features characterize bios, as contrasted to random, periodic, chaotic, or random walk patterns. Biotic patterns are also demonstrated in time series generated with multi-agent predator-prey simulations. These observations suggest that population dynamics may be largely determined by bipolar and feedback processes. Biotic patterns are ubiquitous: heartbeat interval series, Schrodinger's wave function, temporal distribution of galaxies, economic processes, meteorological time series, sequences of bases in DNA, and other data [Sabelli 2005; Thomas et al. 2006]. Bios must then be the expected product of generic natural processes inherent in action (energy flow), information and matter, which embody lattice order, group opposition, and topological connection. Biotic patterns are generated mathematically with bipolar feedback models such as A(t+1) = sin((A(t)*t) + A(t) that combine action (recursion), bipolar opposition (trigonometric function) and connection with previous state (+ A(t) term). In contrast to standard theory (random variation, competition for scarce resources, selection by survival of the fittest, and directionless, meaningless evolution), we propose that biological evolution is a creative development from simple to complex in which (1) causal actions generate biological variation; (2) bipolar feedback (synergy and antagonism, abundance and scarcity) generates information (diversification, novelty and complexity); (3) connections (of molecules, genes, species) construct systems in which simple processes have priority for survival but complex processes acquire supremacy.

1. Introduction

Here we formulate the hypothesis that evolution is a creative development from simple to complex, rather than the product of chance and selection. We propose that evolutionary processes are generated causally but their development is open and generates diversity, novelty and complexity beyond those present in their simpler origin. The development of an organism originates with and is guided by genetic structures and creates unique and more complex organisms. In a similar manner, both physical and evolutionary processes may originate with and be guided by generic mathematical and physical relations. The formation of structures and systems is one such generic process, as demonstrated by endosymbiosis and pluricellularity. Here we explore the role that such feedback processes may play in the evolution of species with mathematical models, analyses of empirical data of population numbers, and a multi-agent simulation model. Population studies provide numerical data for mathematical analysis, and we shall see the results obtained indicate creative patterns of change compatible with evolutionary processes rather than with stationary models. Although evolutionary theory and population dynamics have traditionally been separate scientific fields, evolution can be fast, as illustrated not only by the rapid mutations of viruses but also by observations with birds. Ecological and evolutionary dynamics can occur on similar timescales, so population cycles can be transformed into creative processes [Yoshida et al. 2003].

2. Bipolar feedback: the generation of biotic patterns

Recursions of bipolar (positive and negative) feedback such as **A(t+1) = sin((A(t)*t) + A(t)** generate a pattern characterized by features of creativity that we call bios because we first identified it in biological series [Sabelli et al. 1997; Kauffman and Sabelli 1998]. Mathematical bios is chaotic insofar as it is aperiodic, deterministic, and extremely sensitive to initial conditions. Biotic processes are radically different from chaotic attractors in being contiguous and creative. A discrete time series is contiguous when consecutive terms are similar to each other, while consecutive terms often lie on opposite sides of the median in random and chaotic series. Creativity can be operationally defined by the demonstration of three related characteristics: diversification, complexes and novelty in causal processes. Chaotic attractors do not display these properties. Diversification, complexes and novelty can be measured with the Bios Data Analyzer [Sugerman et al. 2005], which compares the series with copies randomized by shuffling. These methods are described below along with analyses of empirical series. Biotic series are clearly differentiated from similar stochastic series by analyzing the time series of differences between consecutive terms, which is chaotic (figure 1) or biotic in the case of deterministically generated bios, and random in the case of random walks.

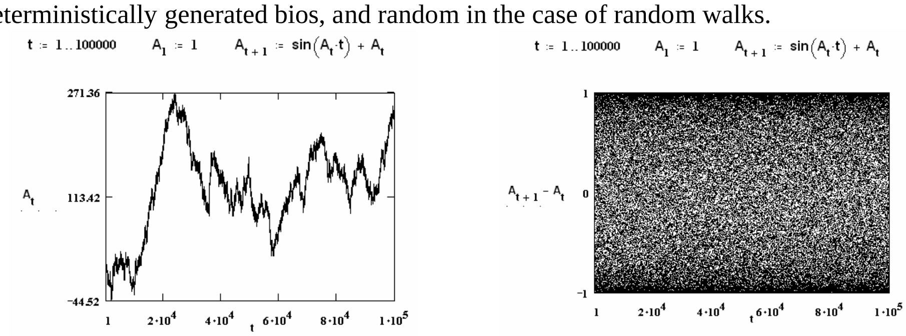

Figure. 1. Biotic series generated by the recursion of a trigonometric function (left), and the chaotic pattern of the series of differences between consecutive terms (right).

These time series analyses show that many processes commonly regarded as chaotic or stochastic actually are biotic. These include Schrödinger wave function [Sabelli and Kovacevic 2006; Thomas et al. 2006] and the temporal distribution of galaxies representing the expansion of the universe [Sabelli and Kovacevic 2006], suggesting that cosmological evolution may be determined by causal physical forces, rather than result from expansion of random non-homogeneities. Biotic patterns are found in heartbeat intervals [Sabelli et al. 1997], respiration, sequences of bases in DNA, the shape of rivers and shorelines, meteorological data, and economic series [Sabelli 2005].

Biotic patterns as well as periods and chaos, are generated by recursions of bipolar feedback which include a conserve term + A(t); recursions without it produce only chaos. Unipolar feedback, such as the logistic equation, produces chaos, but not bios. Bipolar feedback is evident in empirical processes that generate bios. For instance heartbeat intervals are regulated by the antagonistic action of the sympathetic accelerating and parasympathetic decelerating nerves, economic prices are affected in opposite manner by supply and demand, and the Schrödinger equation involves wave functions.

3. Population dynamics

Empirical data were obtained from the Global Population Dynamics Database maintained by the NERC Centre for Population Biology, Imperial College, London. We examined Canadian lynx, Finland voles, North American muskrat, American beaver, American red fox, and Atlantic salmon, species for which there is sufficient data.

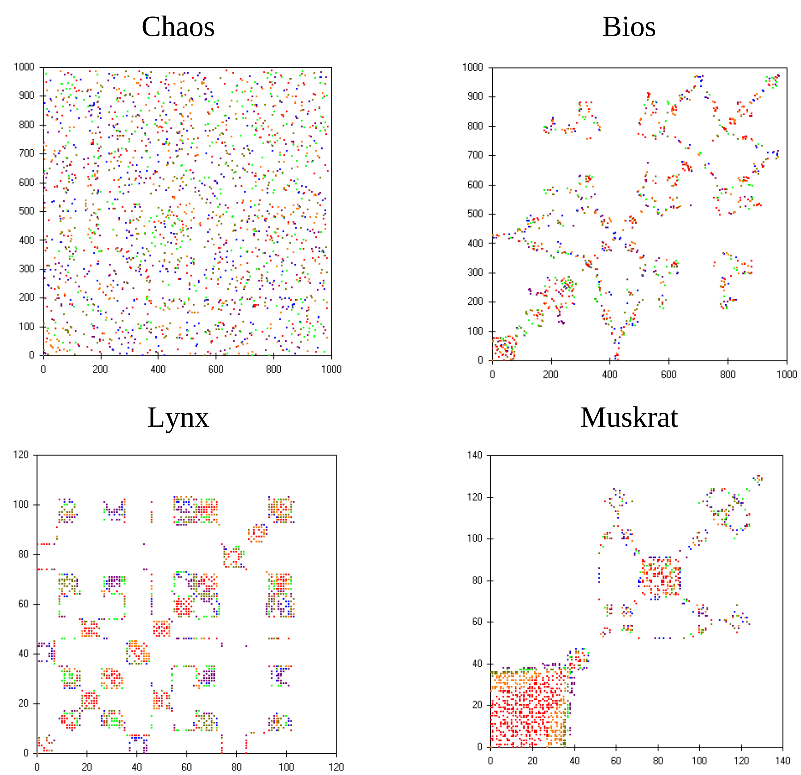

Figure. 2. Recurrent plots of population numbers of two animal species and of mathematically generated biotic series show organized clusters of isometries (complexes) separated by recurrence-free intervals, while chaotic series generate uniform plots such as observed with random data.

The time series of number of organisms shows contiguity and nonperiodic pattern. All the animal populations examined show an increase in standard deviation (SD) with embedding (local diversification), as also observed with biotic series, random walks and many creative natural processes [Sabelli, 2005]. The SD does not increase in shuffled copies of the data. Random distributions and chaotic attractors maintain a stable variance regardless of sample duration or embedding (after the first few embeddings). Our results are consistent with previous observations of increased variance in population abundance with the length of the time series [Pimm 1991; Inchausti and Halley 2001].

Episodic patterns are most evident in recurrence plots (Fig. 2). Distinct clusters of recurrences with different patterns (**complexes**) separated by recurrence-free intervals are evident in the recurrence plots of muskrat, beaver, fox and salmon populations, as well as in biotic series and in brown noise. Shuffling erases these complexes. Lynx and vole populations show more regular clusters, reminiscent of the sequences of identical clusters of recurrences observed with periodic series (e.g. Volterra-Lotka model). Random and chaotic series show uniform recurrence plots, without clustering.

Recurrence quantification measures innovation. Since a recurrence is a repetition of pattern, a lower than random recurrence rate indicates that the process under consideration innovates more than chance events. **Novelty** is thus defined as the increase in recurrence isometry produced by shuffling the data [Sabelli 2001]. Novelty in evident in muskrat, beaver, salmon, lynx, and red-fox populations, but not in voles (Fig. 3). Novelty is an essential feature of bios, which differentiates it from chaos. Novelty initially is a surprising property, but living processes characteristically vary faster than random via specific mechanisms such as sexual reproduction, meiosis, and the induction of mutation by radiation and by stress.

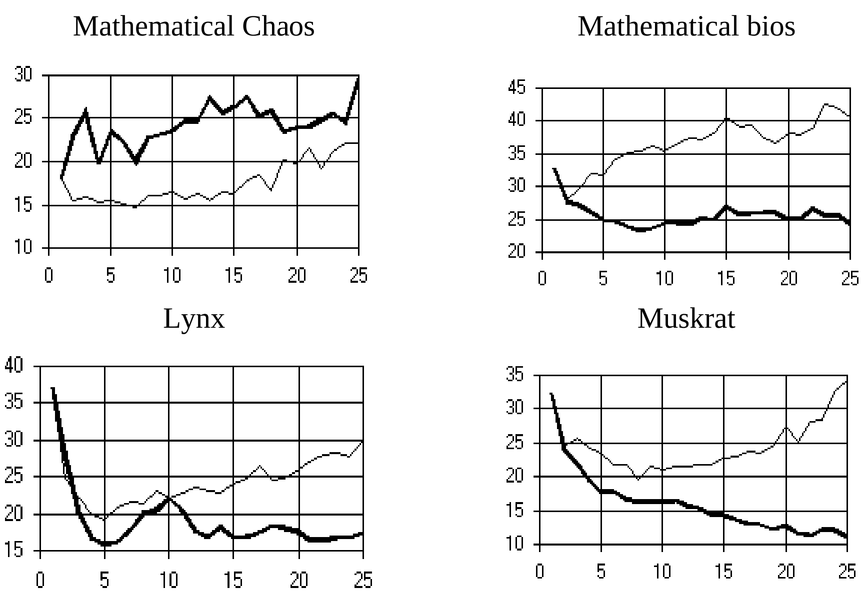

Figure. 3. Embedding plot of the number of isometric recurrences (vertical axis) as a function of the number of embeddings (horizontal axis). Bold line: original series. Thin line: shuffled copy. Randomization increases the number of isometries in animal populations and in biotic series, denoting novelty, and decreases isometries in chaos.

The time series of the **differences between consecutive terms** in population time series showed complexes in all 6 species, and novelty in muskrat, beaver, salmon and red-fox. Thus changes in population number are not random. This conclusion was supported by statistical analysis [Kendall 1973] that showed **partial autocorrelation** for several lags, as observed in causal processes but not in random walks.

In summary, all six species showed deterministic causation, diversification, and contiguity, and five of them met all the criteria for bios including contiguity, aperiodic pattern, complexes, and novelty. Diversification, complexes, and novelty, exclude white noise or chaos. The observation of organization in the time series of differences indicates causal rather than stochastic origin. What are the causal processes that generate life-like (biotic) patterns in nature? The dual, accelerating and decelerating innervation of the heart, the prototype of bios, suggested to us the importance of bipolar, positive and negative, interactions; indeed, bios is generated mathematically by trigonometric functions that model bipolar feedback [Kauffman and Sabelli 1998]. Do similar processes arise in the complex webs formed by individuals of different species?

4. Population Dynamic models

To examine these issues, we constructed a multi-agent simulation model using REPAST (http://repast.sourceforge.net) that includes three types of agents: plants, which grow in a sinusoidal "seasonal" pattern, herbivores that eat the grass, and carnivores who eat the herbivores. Carnivores die when they reach their "natural death" age (randomly set for each agent), or when they lack food. The model is stable within a relatively small range of parameters, within which all three populations show biotic time series with diversification, complexes, novelty, and deterministic causation (partial autocorrelation for several lags, pattern in the series of differences between consecutive terms). Thus using multi-agent instead of differential equations shows that food chains generate creative biotic patterns instead of periodic or chaotic ones. Previous studies have shown that indeed prey-predator relations often generate complex patterns [Dercole et al. 2003; Hudson and Bjornstad 2003; Gilg et al. 2003].

5. Bios Theory of Evolution

The above studies have been guided by a new theory of evolution as a causal and creative process [Sabelli 2005] that applies to physical, biological and human processes. As in the parallel study of quantum processes and cosmological evolution presented at this meeting by Thomas et al, the empirical studies presented here show biotic organization. They do thereby provide support for the notion of causal and creative development. In population data, pattern in the sequence of differences and partial autocorrelation demonstrate deterministic causation, diversification and novelty signify creation, and the succession of different complexes indicates rapid change compatible with fast evolution. Standard evolutionary theory postulates (1) biological variation resulting from accidental events (such as random mutations and giant meteorite crashes); (2) competition for scarce resources; and (3) selection by survival of the fittest. In contrast, the bios model of creation proposes that (1) biological diversification, novelty and complexity largely result from causal processes; (2) synergy and abundance are as important as antagonism and scarcity, and together constitute bipolar feedback processes that generate diversity, greater than random novelty, and complexity; (3) survival has priority but complex processes have supremacy in both variation and selection. Action, bipolarity and connectedness are generic features of natural processes sufficient to generate diverse, novel and complex life-like (biotic) patterns, as illustrated by mathematical recursions. We hypothesize that causal actions, bipolar interactions and connectedness significantly contribute to biological evolution.

Action: Biological actions are physical actions, i.e. changes of energy in time. Time implies unidirectionality, which is imprinted as asymmetry in biomolecules (Pasteur), embodied as sequential order in processes, and more generally manifested as causality. A physical action causes consequences; there are no isolated events. Thus evolution must be causal, not random. Processes are sequences of actions, or more properly lattices, as actions interact, converge, and bifurcate. Causal actions can generate biological variation, as illustrated by the novelty generated by biotic feedback, sexual reproduction, meiosis, the induction of mutation, and the invention and spread of new behaviors by brained organisms that establish new forms of selection. Thus sequences of actions also become imprinted as hierarchies of complexity.

Bipolarity: Just as physical processes are ordered by fundamental symmetries described by mathematical groups, biological processes involve fundamental symmetries. Opposites not only encode information but they also generate it as diversification and novelty. Sexual procreation is exemplary. Notwithstanding, conflict over scarce resources has been regarded as the fundamental motor of change in nineteenth century theories of biological evolution and of economic processes still regarded as current. Correspondingly, the effects of intra and interspecies competition in driving population dynamics have been emphasized. More recently, the importance of positive interactions between species [Bertness and Callaway, 1994; Bruno et al. 2003] as well as the coexistence of positive and negative effects [Jones et al. 1994] have been recognized. Competition of scarce resources generates unipolar feedback, such as the logistic equation, which can generate chaos but not bios, which is the pattern actually observed in population dynamics (see above) as well as in economic processes [Sabelli 2005]. Bipolar opposition can generate bios. Both abundance and scarcity of the multiple biological and non-biological components of life occur in ecological communities. Cooperation among species is as common as competition. Multicellular organisms cannot live and reproduce without the participation of intracellular mitochondria and extracellular microorganisms. We need our intestinal flora, and plants require symbiotic fungi, pollinators, and other birds, mammals or insects that spread their seeds. One quarter of all documented fungi are lichenized; trees need fungi to develop; ants have cultivated fungi for over 50 million years. The importance of synergistic processes for life and its evolution is well known although surprisingly absent from neo-Darwinist discussions. Notably, competition appears to be more important where there is great abundance, such as the tropical areas studied by Darwin, while cooperation among species appears to be more obvious under harsh conditions such as the Siberian plains studied by Kropotkin, the theorist of evolution by mutuality. Ideological differences may have been more important than climatic ones in determining the opposite sign of these two theories of evolution. Incorporating synergy and antagonism, heterotrophy is far more basic than competition in biological dynamics, and it also embodies the incorporation of simpler components to generate complex systems. System formation is exemplary of synergy.

Connectedness: Life evolves as a narrow layer of matter in which atoms nucleate to form systems: molecules, cells, organisms, communities. The formation of materials by other organisms allows the emergence of new and often more complex organisms, a fact that is obvious but not trivial [Sabelli, 1989]. In genome transfers pre-formed materials drive and direct change. Genetic exchange is co-creation. Organisms can supply each other with genes and even complete genomes [Syvaken and Kado, 2002].

Aggregation, endosymbiosis, pluricellularity, multispecies communities, and sociality are essential for evolution. The intracellular incorporation of microorganisms as mitochondria and chloroplasts are necessary for higher form of life, and in fact the very origin of eukaryotes may have been a cellular fusion between bacteria and archea [Gupta and Golding 1996]. Far from leaving microorganisms behind on an evolutionary ladder, we more complex creatures are both surrounded by them and composed of them. Endosymbiosis allows pluricellularity: there are no multicellular organisms composed of prokaryotic cells. Symbiogenesis theory states that species arise from the merger of independent organisms through symbiosis [Margulis and Sagan 2002].

Evolution occurs in the context of biological communities in which continual interactions exclude the occurrence of isolated events. Individuals and species do not interact at random as gas molecules but co-evolve within a web with rich topological structure. The biotic web involves hierarchical lattice structures (e.g. food chains) and processes (e.g. evolution from simple to complex organisms) and group properties at multiple levels, such as the circulation of energy and matter within and among organisms. Thus lattice, group and topological properties are intrinsic to the evolving biosphere. Connectedness provides a multidimensional form of causation capable of generating biotic patterns of population dynamics, as illustrated by simple multi-agent simulation models. It departs from simple causality that determines the outcome instead of creating complexity) as well as from stochasticity, which makes the unlikely assumption that events are independent from each other. The circulation of energy, information and matter are cyclic engines that can generate complexity, as illustrated by mathematical recursions. Species do not evolve in isolation while the biosphere remains stable as a homeostatic superorganism (Gaia). The biosphere evolves as a totality, creating multiple levels of complexity.

These multiple levels of complexity are connected in feedback processes. We thus proposed to split the concept of primacy into the complementary categories of priority and supremacy taking as a model the mammalian central nervous system, in which the lower and simpler bulbo-spinal levels have evolutionary and functional priority and the more recent and more complex brain cortex has functional supremacy [Sabelli and Carlson-Sabelli 1989]. Simple processes and structures have priority in time and in urgency: respiration precedes and is indispensable for thinking; simple processes also are more global and hence involve greater changes in energy. Complex processes and structures emerge later in evolution but acquire local supremacy because of their greater informational content. The physical and chemical processes and products of abiotic evolution initiate and modulate biological evolution. Simple molecules constitute the biomolecules that form cells. The production of materials by simple organisms propels the creation of higher species. The complex biological processes generated by evolution alter drastically the physically composition of the planet, and thereby feedback upon biological evolution. The generation of materials such as oxygen by simpler organisms propels the creation of higher species by providing necessary materials (material hypothesis of evolution, [Sabelli 1989]) and by generating conditions that allow for respiratory processes and are incompatible with many preexisting lifeforms. This illustrates the priority of simple organisms and the supremacy of more developed ones as a cyclic engine of evolution [Sabelli 2005]. Photosynthesis, sexual reproduction, and brain function redirect natural selection. Darwin highlighted the roles of sexual selection and of cooperation; he did not reduce evolution to survival, much less to struggle. The evolution of complex behavior and brains add complex selection factors that frequently are more operative that survival.

Hierarchical relations among species are more significant than intrinsic “fitness”. Cows multiply and elephant populations dwindle because of their relation to the dominant mammalian species, and AIDS viruses burgeon because they have made us their host, although through commitment to science we have become able to eradicate smallpox. Topological connectedness is a generic property of natural processes; positing independent random events and single genes or individuals as the units of evolution represent unlikely speculations. The conservation of genes in biology (e.g. the pervasive role of hox genes) is as fundamental as the conservation of matter in physics.

6. Evolution is Creation

Unbiased consideration of evolution from protokaryotic cells to mammals indicates an overall increase in complexity as proposed by Lamarck. Pointing to extinction and involution (e.g. parasites), Neo-Darwinian theorists assert that evolution is directionless. Gould [2002] argues that the fact that most forms of life increase in size and complexity is an “artifact” resulting from the circumstance that life begun at the extreme of smallness and simplicity. However, a simple origin is not an artifact. How else could life have started? Since life could not have started large and complex, doesn’t this fact reflect the basic logic of the universe? Evolutionary progress may be explained as an obligatory sequence: **creation must necessarily precede (and exceed) destruction**, and simplicity must necessarily precede complexity. Constructive processes create higher levels of complexity. Complexity is the necessary result of the fact that creative processes are inherently self-conserving while destructive processes are limited to what has been constructed before. This asymmetry between construction and destruction is a necessary logical relation (tautology) which is a creative. Thus evolution has a direction towards greater complexity, including the formation of minds that create meaning, and in this sense evolution is meaningful.

Evolution is creation, and creation is evolutionary, not a single event in the distant past. Creation is necessarily accompanied by destruction: evolution includes and requires the death of individuals and the extinction of species. Involution occurs. Progress is not unavoidable. Evolution is a creative process, not a deterministic one. It is thus crucial to consider responsibly our role as dominant species. Given the human implications of evolutionary ideas, it behooves us to evaluate our assumptions in the light of all scientific disciplines, from mathematics to psychology, and to be critical of ideology. Making “selfish genes” the units of evolution is unscientific. Genes do not have self because they do not have brains and therefore cannot be selfish. What is absurd from the perspective of one science cannot be useful as a metaphor in another discipline, much less true in reality. We in fact now know that genes only function in context: the same set of genes is present in very different tissues, and different species share many genes, and differ only on their expression. Likewise the portrait of evolution as a chronic, bloody competition among individuals and species is at variance with growing knowledge that shows that forms multiply and grow more complex by incorporating others. Life does not take over the planet by combat, but by networking [De Duve 2002]. The notion of scarcity and struggle as the motor of change was born in political economics (Malthus) where it led to predictions that have been refuted empirically. Mathematical, physical and psychological sciences offer biology a different, richer and more solid set of assumptions.

Lattice, group, and topology, the mother structures of mathematics (Bourbaki), describe generic properties of natural processes embodied at multiple levels of organization [Sabelli 2003], from quantum physics up to and including psychological structures [Beth and Piaget, 1968]. Evolutionary processes, as all other physical processes, are by necessity shaped by these logically necessary mathematical relations, and indeed biotic webs display lattice, group and topological properties. The asymmetry of time, informational oppositions, and tridimensional matter embody lattice order, group symmetry and topological connectedness [Sabelli 2003]. Recursions abstracting these features are sufficient to generate steady states, cycles, chaos and bios; these patterns are found in many processes from physics to psychobiology, and are therefore likely to be the product of causal and generic processes rather than the product of chance or of specific mechanisms. We thus propose that evolution is the necessary consequence of causal action, bipolar feedback (synergy and antagonism), and the combination and conservation of material structures in topological webs with lattice and group organization. Just as physical processes are articulated in terms of causal equations that reflect these generic mathematical structures, we conjecture that biological processes will be similarly described. Causal action, bipolar opposition (positive and negative, synergy and antagonism), connectedness, and systematic creation of complexity oppose the concepts of random change, scarcity, struggle for survival, independent events, genes or individuals, and directionless evolution advanced by standard evolutionary theory. More generally, we put forward the notion of **organization out of order** to replace Nietzsche's "order out of chaos". Recognizing that evolution has direction points to the existence of meaning, and its sensitivity to human intervention extends it to us.

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