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SYSTEMS AND SOCIETIES: THE BASIC CYBERNETICS OF EVOLUTION

This study advances two principal propositions. First, that the manifest course of evolution, however chaotic and disordered it may phenomenologically appear to be, is subject to simple and basic general laws that can be discerned with the methods of scientific inquiry. Second, that these laws apply with equal force to physical and physicochemical systems and to biologic -- and possibly also sociocultural -- systems.

Hypotheses of this kind have been advanced periodically throughout the history of Western thought, from Thales of Miletus in the 5th century B.C. to Henri Bergson and Alfred North Whitehead in the 20th century A.D. In the 1980s, however, the above hypotheses have realistic chances of shifting from the realm of philosophical insight to that of scientifically validated theory. There are now experimentally tested and mathematically formulated constructs that provide a factual foundation for a unitary concept of evolution. As there are no empirical matters of fact in the natural and social sciences that could be established once and for all, the 'facts' that undergird the here advanced hypotheses remain subject to change with the further development of scientific theories. The propositions advanced here are hypothetical for the present, and even in the best case would remain a 'likely story' such as Plato named as the status of all theories concerning the nature of reality in the Timaeus. But while all stories are somewhat likely, some are more likely than others, and the story of a unitary law of evolution is getting more 'likely' in our day than it ever was in the past. It merits systematic investigation and debate.

Theories validating the above hypotheses are not emerging from science complete in every detail, like Venus springing from the sea. Empirical sciences investigate special domains and the laws applicable to them. Specialized scientists create the theoretical foundations upon which investigators with a wider scope of interest can construct concept of wider applicable, a more encompassing range of invariance. The scientist is, almost by definition, a specialist: he has to know a great deal to cope with the avalanche of facts and data generated by his colleagues. Consequently he can know but relatively few things, lest he be blessed with a truly encyclopedic knowledge. The generalist, on the other hand, must know many things, and must select what he knows about them with care. He, too, can qualify for being a kind of scientist; a 'scientific generalist' inasmuch as he selects his field of inquiry and constructs his theories with the same care as his specialist colleagues. But he selects the data and the items of knowledge not 'in nature' or the field of first-hand empirical inquiry, but among the reports of such inquiry made by the specialists. The task of the scientific generalist is, then, to fit these data into a coherent whole, discovering pattern and isomorphy, applying criteria of consistency, simplicity as well as inclusiveness and mutual extensibility, and creating higher-level concepts and theories than the specialized scientists. This is not only a valid 'second-order' scientific task (being 'meta-scientific' rather than 'meta-physical' both in virtue of transcending a single discipline such as physics and being more rigorous than the great majority of the metaphysical speculations of the past)--it is also a needed one. In the contemporary world, created by our generation and our immediate predecessors in our biospheric habitat, the main processes of life--the energy and material flows, as well as those of information, communication and of people themselves--have become highly complex and unstable. The human world is evolving fast, but its course is unclear and its future is beset with uncertainty. We do not quite know where we are headed, nor how we can reach our destination. Theories concerning the overall logic or cybernetics of evolutionary processes have a particular 'survival value' under these conditions. They satisfy an intrinsic search for meaning that is as old as the human species itself, as well as a need for practical guidance at a time when this species has the ability to master its own evolution but seems to be tottering blindly on the verge of catastrophe.

There are thus both intrinsic and extrinsic reasons for raising the question of unitary evolution at this particular instant in history. Let us begin, then, to address the issues systematically.

I.

We should start with giving a thumbnail sketch of the historical context in which the evolutionary concepts have emerged in modern science. With the exception of classical physics (mechanics and dynamics), the empirical sciences deal with processes of one-way change over time, i.e., with evolution in some sense of the term. (Classical physics is the exception because of its insistence on time-reversibility, creating a conceptual framework that is based on process but not on evolution.) However, the sciences investigate carefully delimited realms of 'nature' and seldom venture beyond them. Thus astrophysics comes up with laws of the chemical evolution of stars, and astronomy with the evolution of stellar objects and configurations in the cosmic macrospace. The biological sciences produce theories that state laws or regularities in the evolution of macromolecules and cells, and in the development and functioning of ecosystems formed by populations of organisms; while the social and human sciences are at pains to discover comparable laws or regularities in historical, social, cultural, inter-personal, and even psychological processes. Some two-score or more theories of evolution and development coexist uneasily side by side. The task of the scientific generalist is to discover common features among them, and ascertain that they are not accidental similarities in morphology but basic invariances in dynamics. The challenge has been at the doorstep of science for at least a century, ever since it became rent by the split between the early formulations of classical thermodynamics and the Darwinian theory of the origin of species. According to the former, process is basically devolution; the universe is moving from a more organized, more energetic state to one of growing homogeneity and randomness and, ultimately, to the heat-death of thermodynamic equilibrium. According to the latter, life is a continuous process of structuration and organization, moving from states of less complexity toward greater complexity and higher levels of organization, culminating (in our experience) with the human species whose brain is probably the most highly organized collection of particles of matter in the known universe.

Inspired by Darwin, the English philosopher Herbert Spencer described a unitary process of evolution which can only end, in his view, in the establishment of the greatest perfection and the most complete happiness. Darwin's Origin of the Species (1859) and Spencer's First Principles (1862) contrasted with the line of thinking that emerged in classical thermodynamics. Carnot developed the basic principles in 1824, and William Thompson stated them forcefully in his treatise "On the Universal Tendency in Nature to the Dissipation of Mechanical Energy" in 1852. On the continent, Helmholtz published his essay on the preservation of force (Über die Erhaltung der Kraft) in 1847, and Clausius introduced the concept of entropy in 1865. A year later Boltzmann created the formulation which established the concepts of thermodynamics as a major science, linking probability theory with statistical mechanics. In its polished formulation, the main thrust of the new science was that free energy tends to be used up, organization tends to disappear and randomness tends to appear. For any given system (conceived as an isolated system) the arrow of time is given by processes marked by higher probabilities of moving toward equilibrium than remaining in a steady state or moving in the opposite direction, away from equilibrium. Boltzmann himself was sufficiently impressed by Darwin's theories (he once wrote that the century of his lifetime - the 19th century - should be called the 'century of Darwin') that he proposed an interpretation whereby the current state of the universe represents a relatively brief deviation from equilibrium. We should conceive of our world as but one of several regions which are in disequilibrium; and among these worlds the probabilities of their state (i.e. the entropy) increases as often as it decreases. In the universe as a whole the two directions of time are indistinguishable, so that a living organism in one of these regions can always define the direction of time as going from the less probable to the more probable state: the former being the 'past' and the latter the 'future'.

Making our world into a brief interval balanced by others tending in the opposite direction, and allowing that all such locally disbalanced regions have arbitrary definitions of the arrow of time makes cosmology speculative; it does nothing to overcome the observed contrast between the universal probability of progressive disorganization and the manifest tendency in biological evolution toward organization. One still proceeds toward thermodynamic equilibrium, and the other in the contrary direction. Western science had to wait for the development of the thermodynamics of irreversible processes (nonequilibrium thermodynamics) in the latter half of the 20th century to perceive that there is no contradiction between the laws of classical thermodynamics and the observed direction of time in our region of the universe. The new insights come from scientists such as Onsager, De Groot, Katchalsky and, most explicitly, Prigogine. Their quantitative theories are interpreted by thinkers such as Erich Jantsch and independent scientists such as Jacob Bronowski. An entire new school of thought is being born today, in various universities in North America, in scientific centers in France, Germany and Italy, among others. It traces its origins to the pioneering work in general system theory of von Bertalanffy, Boulding, Miller and Rapoport, and in cybernetics of Wiener and Ashby. The emerging insight is that the phenomena of interest for evolution are special kinds of systems: open systems, i.e., those which can exchange energy, matter and information with their environment. Evolution occurs when such systems are exposed to massive and enduring energy flows. Even if the universe should be a closed system (a question not answerable on the basis of empirical evidence), it is always true that it includes subsystems that are open to their own environment within the universe as a whole. Thus regardless of whether or not the universe itself is a closed system, there are open systems within it to which the second law of thermodynamics does not apply without qualification: their change of entropy (dS) is not uniquely determined by irreversible processes within the system boundaries, but by the ratio of entropy-import across the boundaries (d_eS) and the entropy production within the system (d_iS), i.e. by the Prigogine equation $dS = d_iS + d_eS$. Whereas for a closed system d_eS is zero, for an open system it can be negative, that is, the system can import negentropy from its surroundings. This does not contradict the second law, since such negentropy import increases by a corresponding amount the entropy of the surroundings. Thus if 'life feeds on negentropy' (Schrödinger), it does so at the expense of entropy production in the sun.

A unitary process of evolution presupposes a unitary universe, one that is capable of generating a single evolutionary sweep. As the sweep originates in the realm of physics, it is noteworthy that contemporary physics is becoming increasingly integrated in the theories it advances of the nature of the physical universe. Unification proceeds in particular with respect to the universal forces which are thought to act upon, and in their confluence determine, the dynamic processes involving the concourse of particles of matter in space-time. Whereas there is a proliferation of elementary particles--without any assurance that any currently known particle is truly 'elementary'--there is a reduction in the number of distinct forces which determine their behavior. Einstein attempted to create a unified field theory by integrating electromagnetism and gravity. However, he left out of account the strong and the weak nuclear forces which appeared in microphysics at about the same time. By mid-century physicists were confronted with four, and not two distinct forces and their unification appeared far-fetched indeed. However, theoretical postulates advanced by Stephen Weinberg and Abdus Salam in 1967, and confirmed by experiments with the Stanford linear accelerator in 1978, permitted the unification of the electromagnetic and the weak nuclear forces. Further confirmation came in the early 1980s, when two of the three particles predicted by the theory (the W plus and W minus intermediate bosons) were identified. The last particle, appropriately called the Z particle, was discovered in May, 1983. Thus today there are but three basic and distinct forces believed to act in the universe: the gravitational, the strong nuclear, and the electroweak. Physicists are currently investigating the mathematics of the theory that could unify the electroweak with the strong nuclear force in a new construct, the electronuclear force. It is no longer far-fetched to believe that one day physics will achieve a complete unification in terms of basic universal forces by showing the fundamental identity of the electronuclear force with that of gravitation. Einstein's vision, of a unitary field universe, though even more complex than he anticipated, could come true: the difficulties appear to be methodological rather than ontological. If 'nature' permits the reduction of four forces to three and then to two, there is no *a priori* reason why it would prevent their reduction to one.

II.

A unitary field universe is a logical basis for an integrated evolutionary process that builds dynamic systems in stepwise progression from the physical, through the chemical and the biological, perhaps all the way to the social realms. But physics, although it is becoming increasingly integrated horizontally in its own domain, is not yet vertically integrated with the domain of the life, not to mention the social, sciences. For a vertical integration we need a basic dynamic of evolutionary transformation that is rooted in physical processes but is applicable, in specific transformations, to the life, and perhaps also the social sciences. In the mid-1980s, the most promising candidate for a theory of this nature is that of nonequilibrium thermodynamics. This is true in virtue of the fact that in the latest conception the physical universe has lost every trace of its mechanistic character: it is now conceived as a potentially integrated multidimensional field that could well have generated all the phenomenal complexity encountered in daily life as well as in science. Evolving between the last 'big bang' and the next 'big crunch' (if it is a cyclic universe) or between the original 'big bang' and a state of final dissipation of matter in the cosmos, processes of structuration and complexification in the universe break the symmetries of time-reversibility and bring forth metastable nonequilibrium systems. Thus a theory of irreversible system-building processes originating in the physical universe would be formulated within the physical sciences but would transcend it in its application to other (i.e. biologic and even social) realms. A vertical integration of the empirical sciences based on the thermodynamics of irreversible processes could be the greatest achievement of the human intellect in our day.

There are several ways we can progress toward such a breakthough. We may review the products of evolution and compare them with regard to uniformities or law-like differentiations or progressions. We may also take the descriptions of various dynamic processes in special fields, and compare the descriptions for isomorphies and structural analogies. Taking first the products of evolution into consideration, we find a remarkable progression. Evolution takes us from natural units that are relatively simple and minute to those that are complex and on a larger scale. It also takes us from units that are weakly and relatively rigidly bound to others that are weakly and more flexibly bonded. The relation between size, complexity and binding energy exhibits a continuum; a logical sequence, in the vast reaches of the observable universe as well as on our own planetary surface. The big bang created particles of an extremely high state of concentration bound by unimaginably strong forces. In the first few milliseconds in the life of the universe - whether these were in the life of the present cycle of the universe between big bang and big crunch or the first and only beginning of it makes no difference in this regard - quarks and electrons formed. Quarks combined into protons and neutrons, and protons and neutrons formed atomic nuclei which were subsequently surrounded by shells of electrons. Here and there, where energetic conditions permitted, atoms became elements in molecular aggregates. On suitable planetary surfaces, where the critical conditions of energy flow, moderate temperature range and a rich soup of elements were present, the molecular aggregates passed from the level of chemical reactions to those which define the phenomenon of life: metabolism and reproduction, with protected nuclei and coded information. The step from prokaryotic to eukaryotic cells opened vast new possibilities for evolution in the form of multicellular organisms. Such organisms formed multiple branching lines, filling available niches and exploiting the potentials of a constant energy flow, cascading through an increasing variety of living forms.

Abstracting for the moment from the dynamics of how these successive forms of organization emerged and concentrating merely on the size-complexity-energy ratio in their sequence, we find that the strongly bound relatively simple particles act as building blocks in the formation of more complex and less strongly bonded units. The latter in turn become the building blocks for still more weakly bonded, larger and still more complex entities. The sequence of evolutionary products resembles a branching Chinese box hierarchy, with systems within systems, built by creating the innermost systems first, and adding further 'boxes' around them, using the existing systems as building material. The hierarchy is built from subatomic particles and the atoms of the elements within molecules; molecules within cells, cells within tissues...within organs, within organisms, within ecologies, and within societies--possibly even of the human kind. At each level, from the bottom to the top, there is an increase in size and in complexity and a decrease in binding energies. The logic of evolution considered in the formal aspects of its products is simple and elegant: it takes the most basic and strongly bound particles, exposes them to each other and creates new aggregates based on the weaker forces that attract or repulse the more strongly bound components. With the exception of the noble gases and some more complex inert chemical substances, the mutual reactivity of the units builds an evolutionary sequence using chance combinations in a constant energy wind. While many combinations are short-lived, some will endure, and the enduring ones become the basis for the next level of mixing, in which the elements are more complex and the binding forces still weaker. (For example, the collision of two helium atoms in the hot interior of a star does not yield a stable aggregate: it disintegrates in a millionth of a microsecond. But if a third helium atom is added to the mix during the collision--a phenomenon with a non-negligible probability in a rapid and long-enduring random mixing process--the aggregate will prove to be relatively stable: it is the nucleus of carbon.) Allow the process to continue in time, and it will climb the ladder of evolution using the principle of the ratchet: with each new level it biases the statistical averages around which the values in the random mixing process fluctuate, moving it from level to level, from the simple, microscopic and energetically bound to the complex, macroscopic and flexibly structured.

We should now consider the dynamics of the process of system-building. Since the process 'takes off' from the level of physical nature but transcends it in a stepwise progression, a theoretical construct capable of describing the process will act as a vertical integrator of physical theory with theory in the natural and the social sciences. This is a tall order and it cannot as yet be entirely filled; but points of departure can be indicated and a first qualitative approximation can be attempted.

The most likely point of departure is, as already indicated, the theory of irreversible processes in nonequilibrium thermodynamics. According to this theory, 'systems' (collections of elements bound together within boundaries that permit a distinction between 'system' and 'environment') can exist in one of three different states. Of these, one state is radically different from the other two, and it is this state that has been ignored in the classical descriptions of thermodynamics. The radically new state is that which is far from equilibrium; the relatively well-understood states are those at thermodynamic equilibrium and near it. In thermodynamic equilibrium energy and matter flows have eliminated differences in temperature and concentration; the elements of the system are unordered in a random mix and the system itself is homogenous and dynamically inert. The second state differs only slightly from the first: in systems near equilibrium there are small differences in temperature and concentration; the internal structure is not random and the system is not inert. Such systems will tend to move toward equilibrium as soon as the constraints which keep them in nonequilibrium are removed. For systems of this kind equilibrium remains the 'attractor' state which it reaches when the forward and reverse reactions compensate one another statistically, so that there is no longer any overall variation in the concentrations (a result known as the 'law of mass action', or Guldberg and Waage's law). The ratio between concentrations determined by this law corresponds to chemical equilibrium just as uniformity of temperature corresponds to thermal equilibrium. While in states near equilibrium the system performs work and is therefore producing entropy, at equilibrium no further work is performed and entropy production ceases. In a condition of equilibrium the production of entropy, and forces and fluxes (the rates of irreversible processes) are all at zero, while in states near equilibrium entropy production is small, the forces are weak and the fluxes are linear functions of the forces. Thus a state near equilibrium is one of linear nonequilibrium, described by linear thermodynamics in terms of statistically predictable behaviors, as the system tends toward the minimum level of entropy production compatible with the existing fluxes. Whatever the initial conditions, the system will ultimately reach a state characterized by the least production of entropy, and the least forces and fluxes compatible with its boundary conditions.

The third possible state of systems is entirely different from the other two. It is a condition far from equilibrium (chemical and thermal), where initial conditions have a critical role and the fluxes are no longer a linear function of the forces. The structure of the system is characterized by nonlinear interactions in the form of feedback loops with auto- or cross-catalytic components. Systems far from equilibrium are typically unstable and unpredictable. They do not tend toward minimum entropy production and equilibrium, but may amplify certain fluctuations, evolving toward a new dynamic regime that is entirely different from stationary states at or near equilibrium.

How is the leap from the first two states to the third performed? This remains one of the most important questions yet to be clarified by contemporary physics. It is the 'bridge' which would enable physics to transcend its own disciplinary boundaries and achieve the first and most crucial step toward its vertical integration with the life, and perhaps also the social, sciences.

We know that under laboratory conditions structures far from equilibrium can be made to appear. For example, when a vertical temperature gradient is created in a liquid by heating its lower surface, a permanent heat flux is set up moving from the bottom to the top. When the gradient reaches a critical value, the stationary state in which heat is conveyed by conduction alone, without convection, becomes unstable. A convection is created, increasing the rate of transfer. It consists of a complex spatial organization of the molecules of the liquid: moving coherently, they form hexagonal cells of a characteristic size (the co-called Bénard cells). These cells are radically different from the products of linear processes tending toward equilibrium, such as crystals. The Bénard cells are maintained in a heat flow, and have a high rate of entropy production. They represent order of the variety encountered in biological systems such as cells, organisms, and ecologies.

Oscillations in states far from equilibrium can likewise be readily induced in the laboratory. In a cross-catalytic chemical reaction system, such as

$$A \dashrightarrow X$$
$$B + X \dashrightarrow Y + D$$
$$2X + Y \dashrightarrow 3X$$
$$X \dashrightarrow E$$

(the so-called Brusselator), the parameters are given by the concentrations of the products A, B, D, and E. When the concentration of B exceeds a critical threshold, with A remaining constant, the system leaves the stationary state and reaches a limit cycle; the concentrations of X and Y begin to oscillate with a well-defined periodicity. The determining factor is the increase in the concentration of B beyond the critical threshold; this externally induced 'perturbation' pushes the system into the oscillatory mode (all other factors being kept equal). The conditions under which periodic oscillations between two or more dynamic states can be induced are well known. These systems have to be fed initial reactants and must be allowed to discharge their final products; i.e. they must be kept open within a controlled energy flow. The system itself must be structured with feedbacks and catalytic cycles and be far from equilibrium: a minimum level of complexity is a basic precondition. Moreover it must have bi- or multi-stability, that is, under the same set of boundary conditions it must be able to exist in two or more steady states. In each of these states it can adjust to small changes in a variable and recover without being transformed. But if the boundary conditions surpass a critical threshold, the system is pushed from one steady state into another. If the second state is disturbed the system is impelled into still another state, which can be the first steady state in bistable systems or a third state in multistable ones.

Chemical oscillators have been designed by following four steps: (a) finding a feedback-connected auto- or cross-catalytic system; (b) running the reactions in a continuous flows reactor with constant inputs and outputs; (c) varying the conditions until a region of bi- or multistability is found; and (d) introducing a substance (or degree of concentration of one) which affects each of the steady states differently and thus induces oscillations from one to another.

In these experiments it has become clear that the only stages of the reaction that can move the system out of its stationary state are those which involve its catalytic loops (in which the product of a reaction is involved in its own synthesis). This is a significant finding since it is known that living systems rely on catalytic loops in maintaining their own structure within an energy flux. (For example, nucleic acid molecules carry the information needed to reproduce themselves as well as an enzyme. The latter catalyzes the production of another nucleic acid molecule which in turn reproduces itself plus another enzyme, in a loop that closes in on itself. Within the range of chemical reactions that occur in multicellular organisms there are a large number of catalytic cycles; and in ecological systems catalytic cycles abound, as species reproduce themselves and produce the substances required for the production of other species. Auto-catalysis (where a product is involved in its own synthesis), cross-catalysis (two different products mutually activating each other's synthesis), as well as auto-inhibition (where a product blocks a catalysis required for its own synthesis) are the basic regulatory mechanisms in all metabolic functions.

When the catalytic loops are disturbed by a change in one of the relevant parameters, the system, as we have seen, moves into another steady state, provided that it is bi- or multistable (otherwise it suffers disruption and disorganization). The point at which the system switches from one state to another is known as the point of bifurcation. In general, the further the system is from equilibrium, the greater the number of possible states into which it can settle following a critical perturbation. This renders nonequilibrium systems inherently unpredictable. Confronted with a large number of possible steady states, small and apparently chance variations in the internal systems structure determine the choice among them. For the external observer, even if he controls the critical perturbation, the system remains inherently unpredictable. This is in direct contrast with the overall predictability of the system's behavior while it is in one of the possible steady states.

The fact that systems can exist in states far from equilibrium provides the clue for explaining the manifest course of evolution on our planet. A constant flow of energy acting on systems endowed with a minimum level of complexity creates a constant random mix process which can occasionally destabilize the catalytic loops which maintain the systems in the flow. Cross-catalytic loops are known to be highly error resistent; they introduce the necessary degree of stability to give the evolutionary process continuity and coherence. But even systems endowed with cross-catalytic loops can be destabilized by changes in the critical parameters, and thus evolution, while manifesting long periods of stability, could get underway and can always continue, as long as the sensitive parameters of the catalytic loops are subject to change and new steady states are available to the systems. In the history of life on earth, the constant flow of energy from the sun to the surface of the planet and back into space provided the random mix conditions for occasionally destabilizing existing nonequilibrium systems and creating further 'order out of chaos'--to use an expression of Prigogine's. An increasing diversity of chemical and biochemical systems exposed to the solar energy wind made for the emergence of the prokaryotic cells, and later for the eukaryotes. The latter found steady-state solutions to critically destabilized states in a division of function among increasingly specialized cells. The first metazoa were formed. New niches were filled, and further niches created, by the branching tree of evolution which came to flower some 600 million years ago in the Cambrian explosion.

The path of evolution on this planet encompasses relatively simple systems minute in size and bound by relatively high-energy bonds on the one hand, and complex macrosystems with weak (and often imperfectly understood) binding forces on the other. The question is, whether systems on the late end of the evolutionary spectrum are formed by the same basic dynamic process as systems on the early end. The evidence to decide this question should not be sought by a phenomenological comparison of transformation processes of physico-chemical and organic systems. The phenomenology of the processes is likely to be diverse, since populations of organisms are vastly more complex systems than chemical oscillators or even organic macromolecules. We are dealing with a hierarchical level that is several times higher than those previously considered: species are composed of individual organisms and groups of organisms which themselves are composed of cells and groups of cells which are composed of molecules and aggregates of molecules. Instead of searching for phenomenological similarities, which would reduce to superficial analogies, one should focus on isomorphisms in the dynamics of the evolutionary processes. A general law of evolution is a system of constructs that remains invariant with respect to transformations that represent descriptions of the dynamics of evolution at each of the levels of the evolutionary hierarchy.

Current theory of biologic macroevolution offers significant evidence in regard to the validity of the basic thermodynamic model of nonequilibrium systems as a general evolutionary paradigm applicable _inter alia_ to the evolution of organic species. Recent developments in the theory of macroevolution differ from the classical Darwinian paradigm in two important respects: the theory affirms that natural selection acts on populations of species rather than on individuals; and that the course of evolution is saltatory rather than continuous.

In the theory of 'punctuated equilibrium'* developed by Gould and Eldredge in works published in the 1970s (and accorded widespread recognition as of about 1980), the process of evolution applies to the evolutionary system made up

*'Equilibrium' refers to a balance between species and milieu and not to thermal or chemical equilibrium.

of populations of species in interaction with their milieu rather than to individual reproducers and survivors. Evolution occurs when the dominant population in a species is destabilized in its milieu and mutants, which emerged haphazardly in the periphery, break through the established cycles of dominance. The stasis of the epoch is broken, and there is an evolutionary leap from the old to the new species. The process itself occurs relatively suddenly, with speciation 'punctuating' long periods during which no new species emerge. Stability appears to be the normal condition in the persistence of species; gaps in the fossil record do not necessarily indicate continuous evolution of which we have no record but, more likely, long periods during which evolution just did not occur for a given species. D.V. Ager likens the history of life on earth to the life of a soldier: it consists of long periods of boredom and short periods of terror. What boredom is for the soldier, stability is for populations of species; terror corresponds to the sudden instability that marks the extinction of dominant populations, and the rising to dominance of subspecies and mutants from the periphery.

The Cambrian explosion, when most of the invertebrate animals appeared within the relatively brief span of a few million years, is now explained in terms of critical instabilities and the natural selection of alternative species. About 600 million years ago the dominant community of algae (prokaryotic cells) was destabilized by the chance appearance of single-celled eukaryotes that fed on the algal community. By cropping the algae, they created space for additional species; a larger diversity of prokaryotes in turn permitted the emergence of more specialized cells, their 'predators'. Eukaryotic single-celled organisms could diversify through specialization and a division of labor which ultimately led to cellular colonies and to integrated multicellular species. These could exploit the niches made available in the wake of the destabilization of the algal community which, until then, was the dominant form of life on the planet.

In the intermittent bursts of speciation, 'specialist' species figure more often than 'generalist' species. The reason is obvious: a specialist species is fitted to a narrow environmental niche, a small rut, with other species coexisting in slightly different ruts. Such a species is destabilized by changes in system-environment relations that leave generalist species, with broader niches, undisturbed. Thus a generalist species, such as the Aepyceretini, of which the living member is the impala, survived the last 6 million years with only one or two speciations. The specialist Alcelaphini, on the other hand, which includes the hartebeests and wildebeests, has undergone as many as 26 speciations during the same period, as changing system-environment relations kept knocking out populations of living species and replacing them with populations of mutants that were fitted to more viable neighboring ruts.

The relative longevity of species such as the shark is due to their ultra-generalist nature: they can survive under an extremely wide range of likely variations in their habitat. Homo himself has embarked on the path of an ultra-generalist. Although his constitution is frail and his diet specialized, his abilities include sophisticated tool-using and communication, enabling him to match his habitats to his requirements. Since Homo left the trees for the plains (possibly in the wake of a cataclysmic event that destabilized the dominant ape-environment relations in the forest) some four to ten million years ago, the species has enlarged and perfected its generalist capacities, increasing the size of his forebrain, evolving a hand with a precise and powerful grip, and adopting an upright posture. Able to use tools, and communicate by means of language, generalist Homo became the ultimate predator in the biosphere; no other species can kill a population of humans, while populations of humans are a potential threat to almost every living species (including, ironically, their own).

III.

The theory of irreversible processes in nonequilibrium thermodynamics, and the current biologic theory of macroevolution, exhibit remarkable isomorphies. 'Critical instability' in the former appears as a particular transform of a general law which appears as 'punctuated equilibrium', another transform, in the latter. 'Bifurcation' in the thermodynamic theory corresponds in a similar fashion to 'species-selection' in the theory of biological macroevolution. Both occurrences intersperse extended periods of stability (or metastability) during which the systems maintain themselves in an energy-flow through catalytic cycles with feedback loops. Evolution is essentially 'saltatory' in both theories, again pointing to a fundamental invariance at the very heart of the dynamics of change in the universe.

To summarize the main features of each theory it is sufficient to recall, first, that in the thermodynamic theory systems may exist in the 'third state' far from equilibrium. In this state they no longer tend predictably toward thermal or chemical equilibrium; the fluxes are not linear functions of the forces, and structure is maintained by nonlinear feedback loops forming auto- and cross-catalytic cycles. Nonequilibrium systems in the third state can exist in two or more steady states. All possible states are inherently unstable, however, as they are maintained by catalytic feedback cycles that have definite upper thresholds of error-tolerance. When such systems are exposed to perturbations which surpass the critical threshold, the self-maintaining cycles are disrupted and the system is destabilized. At that 'point of bifurcation' it either finds another steady state, which can absorb and correct for the perturbation, or it disorganizes to its stable components.

In their stable (more precisely: meta-stable) states nonequilibrium systems are resilient to perturbations within the range of error-tolerance and are dominated by the parametric values of the critical forces and concentrations. Consequently the behavior of the systems is relatively determinate and predictable. At the points of bifurcation determinism vanishes: an external observer is unable to determine in advance which of the fluctuations will be amplified in the system and become dominant. Small modifications may be amplified and can spread rapidly across the entire system; the choice among them is not determined by boundary conditions.

In the theory of biologic macroevolution change does not occur by means of linear adaptations of existing species to their environment, as in the Darwinian theory (such adaptations exist but are relegated to a secondary role in perfecting the fit of the emerging species with their niche); genuine change, i.e. evolution, is species-selection. It involves the destabilization of a dominant population by critical changes in the species-environment relation, and multiple explorations or experimentations by hitherto peripheral isolates as the latter invade the territory of the previously dominant population. Such a process of allopatric speciation is not predeterminate and inherently directional but occurs stochastically. If some of the 'invasions' produce an improved fit of species and environment, reproduction rates are increased and the population may become dominant. This is saltatory evolution through speciation rather than through orthoselection in gradually changing lineages. While gradual adaptations keep fine-tuning organisms to their environment, speciation brings forth new species. The time-span of existing species (i.e. the interval between speciations in a given lineage) varies with changes in environmental conditions and the range of environmental adaptability of the given species: species adapted to a wider range of conditions - the 'generalists' - speciate less often than those that are locked into a relatively narrow niche - the 'specialists'.

While the isomorphies in the dynamics of the evolutionary process are apparent, we should not expect that they appear in phenomenologically analogous transforms. The component subsystems of biologic systems, such as populations of organisms, are far more complex than the elements of the physico-chemical systems investigated in nonequilibrium thermodynamics. Biologic species are further down the scale of evolution also as regards size and the energy-level of bonding. Because we find the systems typically investigated in the two theories at different points in the size-complexity-energy continuum, we should not look for phenomenological similarities but for basic invariances in the transformational dynamics. Such invariances exist, and extend even to the alternation of determination and chance in the periodic alternations between steady states and states of critical instability.

A modification appears, however, in the dynamics of transformation in the biologic as compared with the thermodynamic theory in that in organic evolution entire populations of species become extinct and are replaced by others, whereas in the thermodynamic theory the same system undergoes transformation. The modification proves to be a matter of detail rather than one of basic dynamics if we move, in regard to the biologic theory, to the strategic level of the entire species which undergoes evolution. On that level we find that the species consists of several populations, including a dominant one at the center and additional subspecies or mutants at the periphery. The replacement of the formerly dominant population with another is a change in the internal structure of the species-system, rather than the disappearance of one system and the appearance of another.

There is, then, a significant isomorphy in the description of evolutionary change between the thermodynamic and the biologic theory. The invariant elements of the description function as statements of a general law, or law-like regularity, which remains invariant as we pass from one description to the other. Biologic evolution appears as a specific transform of the thermodynamic process, and vice versa.

IV.

The next, and last, question we must address in this study is perhaps the most difficult of all. Can we stop at the biologic level, or must we press the inquiry further? There do not seem to be valid reasons for drawing a line at the biologic level of organization; after all, empirical evidence indicates that supra-biologic system formations have biologic roots: societies, no matter how complex and autonomous they may be, consist of organic individuals and have evolved from interactions among such individuals. Is it not logical, therefore, to question whether or not societies, including human societies, are likewise the result of the same type of evolutionary process as biologic species? The reductionism inherent in posing the question is avoided by answering it in terms of an invariant set of constructs constituting a general theory. Society could, in this perspective, be a further transform of the basic invariance expressed in the general constructs, and would no more be reduced to biologic individuals as the latter are reduced to their physicochemical components.

Arguments advanced historically for treating human society as an entity *sui generis* have little validity in light of the range of applicability of systems concepts. A society is composed of individual human beings, and groups of individual human beings, in specific relations. The structures formed by them have both structural and dynamic properties that can be measured independently of the uniqueness of their individual members. The social system *per se* evolves, changes, or undergoes transformations. Its individual members pass through it in cycles of birth, maturation and death, and the social structures persist or change according to processes on their own, social level, and not in accordance with the passage of individuals through their life-cycles. Systems and cybernetics concepts are clearly applicable to societies, taken as ensembles of relations, without reference to the identity or quality of the human beings who are the individual relata. The fact that the latter are conscious, language and tool-using persons introduces a good deal of noise and instability into the system, but it can also give rise to the flexible error-correcting negative feedback mechanisms that cybernetically re-stabilize the system in the face of perturbations. Thus the dimension of 'culture' constitutes a qualitative elaboration of system functions, and not a dimension sui generis that blocks the applicability of system concepts.

Human societies can be validly investigated in reference to theories of evolving systems and can be placed, as a working hypothesis, within the context of a unitary evolutionary process. Only a testing of the hypothesis, by matching historical evidence against the postulates of the new theories of evolving systems, can determine the validity of the concept; a priori, there do not appear to be valid objections against it. The dynamics that apply to physico-chemical and to biologic systems may also apply to human social (i.e. sociocultural) systems, at least in principle.

In order to test the hypothesis for basic conceptual 'fit', we may first review the properties of sociocultural systems with regard to the size-complexity-energy continuum, and then examine them in regard to the dynamics of system transformation.

In size, sociocultural systems are in-between local ecosystems consisting of a multiplicity of species, including the original human tribal communities, and the system formed by the biosphere as a whole. Aside from the latter, human societies are the most extensive systems produced in biologic evolution, not counting large-scale ecologies such as entire continental or subcontinental systems, which are fuzzier in terms of the coherence of their dynamics and the identity of their components. Even more important than sheer size, however, is the hierarchic level which defines complexity. Human societies are composed of populations of human beings in interaction with their natural, and now also their man-made, environment. They introduce a new level of organization on the basic ecosystems formed by Stone Age tribes and their habitat. Social and cultural structures and functions organize these basic components into higher-level systems, and add to them man-made environments and artificial systems. They are not merely ecosystems 'writ large', but qualitatively new systems, with their own dynamic properties (or, if the hypothesis is valid, their own transform of the basic invariances of dynamic evolutionary processes).

While the level of sociocultural systems within the evolutionary branching hierarchy is relatively unproblematic, the third correlate of its level, namely binding energy, is considerably more so. According to the proposed scheme of the evolutionary continuum, sociocultural systems should not only be more extensive in size than organic populations and the ecosystems formed by them, and more complex than they (including as they do all complexities of the organic and ecological levels and adding their own to the mix), they should also be bound by less energetic and more flexible bonds. The question that comes immediately to mind is whether or not society has any 'binding forces' at all? Certainly, no such forces are measurable with instruments presently available to science. Yet there is indirect evidence that indicates the validity of such a concept, even if the 'force' in question may be very different from a physical, chemical or biochemical binding force. First of all, <u>some</u> means of binding individuals is presupposed by the very notion of a social 'system'. A system is an entity in its own right composed of parts which exhibit the required coherence in their collective behavior. If people behaved randomly, or exercised the full freedom which they possess in principle as conscious, unique and individual beings, the system formed by them would be chaotic. And social systems, while they may have periods of anarchy, are not chaotic on the whole but show definite dynamic patterns and recognizable structural features. Hence there must be some constraints on the individual members which introduce the requisite degree of coherent behavior. Just what these constraints may be, is still a matter of conjecture. It is unlikely to be a chemotactic factor such as that which impels slime mold to form a pseudo-plasmodium, or termites to build nests with clearly defined structure. Clues to the nature of social binding may be found in the apparent 'social need' of individuals which expresses itself in the drive to relate to others, to belong, to communicate, to share labor and responsibility. Such factors come clearly to the fore in blood ties: the nuclear family, the extended family, and entire kinship systems exhibit strong and dependable 'binding'. In larger social units mores, customs and accepted behavioral norms ensure coherent behavior. In modern societies the system of laws and regulations takes over this role. Whether or not legal and juridical systems have a base in 'natural law' or merely in custom and utility, they act to preserve social coherence. All these binding factors (whether they are 'forces' in any but an analogous sense remains to be seen) function on the basis of consensual acceptance, rooted in what philosophers have called the 'moral sense'. It may be that the social thinkers, who from Aristotle to Kant perceived man as a basically social being, were right in that there is an element in the human behavior pattern that obeys social regulatory principles. Certainly Kant expressed an understandable sentiment when he said that it is the starry sky above and the moral law within that fills him with wonder.

At least as a first approximation, it appears reasonable to range sociocultural systems along 'natural' systems within the size-complexity-energy continuum, even if the nature of the force or energy underlying the bindings of their components is unclear at present. What is clear, on the other hand, is that sociocultural systems possess <u>some</u> means to impose coherent behavior on their members and thereby to bind social structures and to assure continuity in social functions. Whether or not sociocultural systems are also the product of the same invariant evolutionary dynamics that created the underlying levels of the evolutionary hierarchy is what we shall consider next.

A proper fit between evolutionary theory and history would require that in the course of the latter sociocultural systems, rather than the human population itself, undergo evolution. This is ab ovo concordant with evidence: human populations have not evolved as a biologic species for hundreds of thousands of years, whereas it was only in the last twenty thousand years or so that sociocultural evolution took off with the domestication of plants and animals and the creation of settled communities that permitted a division of labor among their members. But the fact that in the span of recorded history human societies, rather than human populations, were the subjects of evolution does not necessarily mean that the dynamics of sociocultural evolution are an isomorphic transform of general evolutionary processes. Testing this hypothesis requires an in-depth analysis of history, focusing on social structures and functions and their transformations and relating the impact of individuals and ideologies to them. Such an analysis could be readily attempted. It could follow in the footsteps of Spengler's account of the life-cycle of civilizations, Toynbee's interpretation of challenge and response, Lévi-Strauss' formulation of invariant social structures and their transformations, Kroeber's and Kluckhohn's search for cross-cultural universals and Benedict's investigation of universal culture patterns. At the same time it could be even more fruitful than these and analogous attempts in the past, since it would link the development of human societies with evolutionary processes in nature.

Without pretending to undertake such a major task here, a few illustrations of its conceptual foundations can be provided. The first of these concerns the postulates of determinism and indeterminism in systems evolution.

Sociocultural systems have multiple feedback loops which maintain structure and correct for deviations from established norms. During periods of relative stability, the systems are 'governed' by means of a set of rules (or laws) and an established hierarchic structure of power. There is sufficient determinism in such periods to permit predictions within a limited range of events, for example, likely responses to certain types of inputs or perturbations. The social sciences would be impotent without the existence of such regularities; there is no science of a random series of events. Whether in the economy, in politics, in the sphere of the family or in that of the community, the feedback loops operate with sufficient regularity to allow the various disciplines to postulate 'laws' (of market forces, dominance structures, kinship relations, etc.) and deduce consequents from antecedents. However, the situation changes in certain periods of turbulence. While 'revolutions' and other sudden changes and transformations can always be explained retrodictively, they can hardly ever be predicted. Why is it precisely Christianity that became the dominant culture of Europe as of the early Middle Ages? How is it that Communism became the ruling system in Russia in 1917, and Nazism in Germany in the early 1930s? The examples could be multiplied by the dozen: sudden changes abound, especially in contemporary history. However, one common factors needs to be noticed in most, and perhaps all such events. It is the destabilization of a dominant regime, combined with the sudden amplification of a minor social, intellectual, or spiritual current. As the established system falls apart, such minor currents take on social and political force, and 'invade' the centers of power. The parallel with the process of biologic speciation is striking. What better examples of the invasion of a 'peripheral isolate' could we have in the social sphere than the rise of Christianity during the decline and fall of the Roman Empire?; of the Bolshevik take-over in the aftermath of a lost war and internal unrest in Tsarist Russia?; or the coming to power of a Hitler in a country torn by unemployment, debt, and widespread furstration? Each of these developments would have appeared unlikely to a contemporary and would have been unpredictable at the time. There were religious and mystical movements more powerful than the relatively meek Christians in the late phases of the Roman Empire, prior to the reign of Justinian. In 1917 the Bolsheviks were in fact the minority, and not the majority (as the name implies), and Lenin's importation of a 19th century political and economic philosophy as the tool of power was highly improbable: the philosophy did not 'fit' conditions in Tsarist Russia and Lenin himself was a powerless exile until he was permitted to return to his homeland in a sealed train. Hitler would have been dismissed as a fanatic in a sophisticated culture such as the German in any period other than in the economic, social and political crisis that befell that country after the treaty of Trianon.

These kinds of social change are obviously not the only kind; societies also change under the impact of external forces such as military conquests or economic dependence; of external forces such as military coups; of internal social movements; or simply of technological innovations which render the existing structures of power and administration inefficient and ultimately obsolete. However, there are universal factors underlying all such types of change: there is an externally or internally induced perturbation which transcends the dominant system's deviation-correcting feedbacks and introduces a condition of instability; at that point another set of organizational rules takes over which may be an overpowering outside force; or (as in the above examples) a small and until then non-threatening spiritual, ideological or social 'fluctuation' that is suddenly amplified and then spreads with great rapidity across the critically destabilized system, capturing the centers of power. The sociocultural system reaches a point of bifurcation; and in historical instances where a viable peripheral movement was present and could be amplified, it undergoes a process of 'reform' (if fairly gradual) or of 'revolution' (if sudden). 'Evolution' occurs if the new political, economic, social and cultural regime into which the system settles is more adapted to the prevailing conditions than the previous regime has been. Such adaptation is is to be conceived in purely functional, rather than in moral terms: a system is more adapted in a new steady state than it has been in the previous one if it is capable of assimilating the hitherto perturbing condition, or controlling it within its structures of governance.

Except when an external power imposes its own regime on a society, the course of the transformation is due to the interplay of initially minute and unpredictable internal factors, such as the appearance of social, ideological or spiritual movements spreaheaded by charismatic personalities. The prior destabilization of the dominant regime does, however, appear to be a precondition of getting the process underway.

In the examples quoted above the societies that have undergone the changes typical of bifurcation points in destabilized nonequilibrium systems had long histories: that of the Roman Empire stretched for a millenium by the time Christianity became a dominant factor; Tsarist Russia extended back into the Middle Ages, and post-World War I Germany had a century of pre-existence of its own. The reasons for the destabilization of the Roman Empire were complex but, since Gibbons' monumental work, relatively well understood; those that caused instability in Tsarist Russia have been analyzed in every detail, while the causes of Germany's unstable state were evidently due to the aftermath of a lost world war. All three of these societies could be described as 'generalist' societies in that they could, in their stable periods, satisfy all their basic requirements under a wide range of conditions. In its flowering, the Roman Empire ruled the known world and had the military and political power and acumen to bring into line rebellious provinces and squash internal dissent. Its error-correcting feedbacks had a wide range; and its catalytic loops reproduced all the elements needed for the Empire's sustenance: people, wealth, food, institutions, and so on. Tsarist Russia was an empire in its own right and had similarly vast capacities within its own range of power and influence--one which was no longer the entire known world but a good part of it. Bismarck's unified Germany was likewise a great power at the center of Europe, then still the center of the Western world. These were relatively stable sociocultural systems, and the shortening of the timespan as we move from the Romans to the Russians to the Germans is due more than anything else to the accelerating tempo of social and technological change in the world at large. But what about other, more specialized societies?

Specialization in a system is always correlated with interdependence among them. This correlation can be observed already in the simples forms of life: for example, Volvox, a unicellular organism, can live independently and carry out all the functions required for its sustenance on its own; however, when it is aggregated in colonies it exchanges its generalist functions for more specialized ones fitting itself into a division of labor within the colony. The same phenomenon can be observed in all social structures formed by living species, and human societies are no exception. As individuals become more and more dependent on the set of relations that bind them to the whole system, so entire societies, when closely coupled with each other, lose their generalist capabilities and become dependent on the markets, structures of power, distribution of resources and skills, and the labor and consumer pools characterizing the whole, i.e. the international, system. Interdependence in the contemporary world is an undeniable fact, and it has grown spectacularly due to the rapidly intensifying coupling of contemporary societies. Rapid and dependable transport opened up trade routes that criss-cross the globe as well as enable people and armies to move to desired or strategic locations; the new information and communication technologies convey messages almost instantaneously and take up any slack in interrelations that may have been due to delayed and imperfect information flows; the emergence of world markets and of production systems with global outreach impel national economies into mutual competition or mutual alliance, and the technologies of armed destruction create multiple alignments that no nation can any longer escape.

As a result of these factors, 20th century societies have become far more interdependent than the majority of societies in the past. Old established societies have been weakened by catastrophic wars, the detachment of their colonies and by technological innovations undermining time-honored institutions and practices. New societies have been created from the former colonies, and they joined the other, relatively recent societies established in the wake of conquests and explorations by the main European powers. Ancient civilizations, such as those of China and Japan, were opened up to the world and were forced to occupy specific niches within the growing system of interdependence. Today all societies are specialized, but some far more so than others. As a rule of thumb, the newer and smaller the society, the more specialized it is. New and small societies may be rich or poor, technologically advanced or backward; they will be pushed into a specialized niche all the same. Only continental giants can conserve a measure of generalist capacity, such as the United States, the Soviet Union and mainland China. Those like Singapore (among the small and rich countries) and the Gambia (among the small and poor) are forced to specialize, whether by drawing on the skills of their labor force or on the products of their agricultural or mineral resources.

Singapore and the Gambia (and other specialist societies such as Kuwait, Monaco, Brasil, the Seychelles, to mention but a few) are highly vulnerable to changes in their external environment. Singapore is vulnerable to technological changes which determine the existing division of labor in sophisticated technologies, the Gambia is dependent on the world price of groundnuts, its principal export. The point need not be further belabored: specialization entails dependence, and dependence in a changing world spells vulnerability. Although historical experience with highly specialized societies has been limited to Stone Age tribes specialized to the rhythms and endowments of their particular habitats, and we know little of the fate of societies that are specialized within a global context, we may expect that such modern specialists will reach points of critical instability, and therewith points of bifurcation, far sooner than societies that managed to conserve some generalist capabilities. Empirical indications of such processes are not lacking: it will suffice to point to the financial crisis which besets almost all countries of Latin America and Africa and most of Asia, to the food crisis which threatens the majority of African countries and those of South Asia, and to the economic crisis which would erupt in the so-called newly industrialized countries if they do not meet the challenge of technological competitiveness in their respective fields of specialization. We encounter here another basic systemic invariance: the applicability of the principle of frequent speciation for specialists and relatively infrequent speciation for generalists. The crisis of a specialized species in biologic evolution is mirrored in the crisis of specialized societies in history.

The application of a general evolutionary theory to the field of sociocultural change and development is a new field, rich in promise. Having in hand a systematic theory enables the investigator to focus on key events and match them against the requirements of the theory. With suitable adaptations and modifications, the general theory of evolution could become a valid theory of social change, with significant predictive power. As all theories in social science, it could also become an active force impacting on its field of study. Such a role, abhorred by classical scientists who sought to preserve the myth of the impartial and uninvolved observer, is more than ever needed today, as society after society appears to be headed toward critical instability and a point of bifurcation. We must recall that bifurcation processes are random and indeterminate for the external observer, but they need not be that for the inside participant. Foreknowledge of the potential of a social system to amplify small and hitherto peripheral movements or ideations at times of crisis could enable groups of people to chose a strategic movement or set of ideas, and promulgate them at the proper time. The behavior of the society would then be biased in favor of the consciously promoted 'fluctuation', reducing randomness and introducing determinate directionality. Humanity could gain a significant degree of control over the evolution of its societies precisely at the time when such control is the most needed.

These, however, are perspectives which need yet to be opened by careful and sustained inquiry. We can conclude this concise overview of the wide and varied terrain of general evolutionary theory with a few statements of principle.

V.

The universe, at least in its present phase, is in a state of nonequilibrium. The confluence of gravitation, electromagnetism, and the strong and weak nuclear forces (or of the integrated electronuclear force and graviation or, hypothetically, of a yet-to-be-discovered unified force) in the space-time field creates what Einstein called 'critical condensations' that appear phenomenologically as matter. Matter is no more inert than it is solid; it is an expression of the intrinsic dynamism of the nonequilibrium field. While any isolated system formed of matter would inevitably tend toward chemical and thermal equilibrium, isolated material systems are an idealization. In the field universe all systems are to some extent open. Open systems of sufficient complexity within a constant energy flow can further aggregate in increasingly energetic, large and complex units. These are the systems that are in the 'third state' far from equilibrium (as opposed to the first state of equilibrium and the second of linear nonequilibrium). Within a constant energy flow, populations of open systems are subject to a random mix process in the course of which they are occasionally exposed to perturbations of various kinds. When the perturbations affect the catalytic cycles which maintain system structure, and are above the threshold of error-correction, the systems are destabilized. They encounter a point of bifurcation in which they either settle into one of their other possible steady states (for bi- or multistable systems) or disorganize to their stable components. For systems beyond a minimum level of complexity there are several, and for highly complex system a large number of, possible steady states, and the choice among them is not determined by any process identifiable by an outside observer.

The universe, then, can be characterized as a complex field of processes some of which are nonlinear and are contrary to (in terms of their distribution of probabilities) the tendency of dissipation of energy described in classical thermodynamics. The emergence of life and of society (and in the context of the latter, of culture) is not an accidental process but which is one/integral to the evolution of 'matter' in the cosmos. That it may be statistically rare is due, in this perspective, to the specificity of the conditions required for the unfolding of the higher levels of evolution and not to its inherently accidental character. The general law of evolution would require that, wherever and whenever the energetic and physicochemical conditions for the formation of nonequilibrium systems are given, such systems would eventually form. Given a persistence of favorable conditions (such as that which occurred on the surface of this planet for the last 5 to 10 billion years) nonequilibrium systems will exploit a large variety of the many possible steady state solutions available to them. As there are many more possible steady state solutions for any particular kind of system far from equilibrium than can be chosen by any real-world system of that kind, evolution is likely to be highly selective wherever it occurs. While the manifest forms of evolution in the far reaches of the cosmos are likely to be different, the basic dynamics of the processes could well be the same. Since human types of consciousness and mentality constitute highly specific choices in response to the challenges of evolution in the context of a complex, socially structured organic population, intelligence of the human variety is likely to be statistically rare in the universe, despite the fact that its occurrence on earth is not the product of blind chance but constitutes a possible solution to the sequence of destabilizations faced by Homo in its species history.

These general principles must - because they can and because it is urgent and important that they do - move from the domain of metaphysics, where they have traditionally been in the past, to the realm of physics and biology, as well as the social sciences. They call for a new orientation in the methods and presuppositions of research. The universe can no longer be conceived as a dualistic or pluralistic 'layer-cake' where each level is superimposed on the other without interpenetrating. Levels emerge in successive saltatory transformation, as systems far from equilibrium encounter periods of critical instability and move toward alternative steady states, often involving higher evolutionary levels than the previous (destabilized) state. Time must enter into the calculations of physics, as it enters into those of the 'sciences of complexity': overall irreversibility means evolution, and evolution means change with directionality (despite local and temporal reversals): this provides the necessary and the sufficient condition for defining the 'arrow of time'. General laws must be reconceptualized: they are not in the form of invariances applied to single types of phenomena as constancies or regularities in the behavior of certain specific types of entities; rather, general laws are invariances underlying a large degree of phenomenal diversity which appear as specific, level- and type-bound transforms of invariant laws. The latter map dynamic sequences which repeat in phenomenologically divergent forms and variations corresponding to levels of evolution within the size-complexity-energy continuum. The sequences are not always and exclusively deterministic: some laws allow for indeterminism and the interplay of random events. Chance and random behavior are law-like in their very indeterminateness; they contradict merely deterministic, but not stochastic laws. General evolutionary laws include both, in the form of invariants manifested in divergent transforms.

The invariant general laws of evolution apply to the scientist as a member of the human species, more exactly, of human populations forming variously structured sociocultural systems. The investigator is not a mere spectator of the evolutionary process but a participant in it. Participation is of particular relevance when the general laws allow indeterminacy in the behavior of sociocultural systems, i.e. in epochs if instability. In these epochs conscious action can select and amplify certain 'fluctuations' which bias the statistics of system transformation. The scientist, and all persons in possession of the basic laws of evolutionary transformation, can exercise a higher degree of freedom and autonomy in periods of societal crisis then in periods of relative normalcy. This fact makes the investigation of social transformation dynamics particular urgent and important in our day, when an increasing number of societies are heading toward conditions of crisis.

We should point out, however, that the propositions put forth in this study constitute working hypotheses which define programs of inquiry rather than theories stating validated facts. The programs of inquiry defined by the propositions are substantive intellectually and valuable in practice. If pursued systematically by interdisciplinary teams, they could reinforce current explorations toward the vertical integration of the different branches of the empirical sciences, creating a new, non-reductionist linkage between physics on the one hand and the life and the social sciences on the other. The results would convey fresh and more dependable insight into the dynamics of transformation of systems at all levels of the evolutionary hierarchy. For the social sciences, the results would obtain the added dimension of guidance value in contemporary societal affairs. They would reduce the uncertainty surrounding epochs of rapid change and map out feasible policy alternatives for channeling the course of transformation toward desirable outcomes.

Research programs capable of coming up with such results call for interdisciplinary work by teams of specialists sharing the same systemic and evolutionary orientation. Their implementation constitutes one of the most important challenges facing the contemporary scientific community.

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