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ON THE GENERAL DYNAMICS OF SYSTEMS*

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This paper pursues the implications and consequences of the following physical hypothesis: To maintain their viability[1], systems must exhibit periodic oscillations in their fundamental process chains. These oscillations are either externally cued or autonomous.

This thesis will be probed first in the biological system.

There is usually an unstated but prevailing assumption about the operation of physiological systems in the complex living organism, namely that most of a system's parameters come to a constant state when outside disturbances cease. A recent article by Morley and Stohlman (1) is symptomatic of a trend to challenge this dogma. To introduce their work on the periodic nature of red cell concentration in the animals they studied, these authors state: "Many body parameters are known to be actively controlled in such a way as to oppose disturbances and result in a more or less steady state. A commonly assumed and expressed corollary to this concept of active regulation is that a perfectly steady state results when no external disturbances are acting. However, clear exceptions to this corollary exist . . ." . The authors go on to suggest that oscillating steady states are rare, and refer to a few instances known to them as introduction to their own work.

My colleagues and I have been actively engaged in attempting to create a scientific revolution around the thesis that the living system, and in fact all systems, can operate in no other way but through epochs of periodic "steady states" and a-periodic switch states. We are well aware that cyclic theories of systems are as old as man's written thought; that investigators like Huntington in the social sciences, van der Pol in the physical sciences, Gjessing and Jenner in psychoses, the Foundation for the Study of Cycles, circadian rhythm investigators, etc., have all actively pursued the importance of particular periodic phenomena. However, other than the investigations of Richter (2), we know of few besides our own which have tried systematically to extract a variety of extensive cyclic data from the biological system, and to put forth, before a technical audience, theories, hypotheses, and fancies about the underlying causes of these cycles. We found such investigations essential, when we realized that in most physiological studies there is a shocking poverty of information about sustained, unperturbed normal operation of living organisms. In short, there has been virtually no systematic observational spectroscopy.

BIOPHYSICAL PRELIMINARIES

The reason for the temporal cycles (or at least for our belief in them) will not be clear without at least some brief introduction to the organization of the biological system.

The following outline is offered for our speculative view of the biological organism. Its apparent tidiness does not wholly represent the paths by which we arrived at our description. Our interests and outlook are those of physical scientists and engineers, newly come to biology. Thus our effort has been directed at constructing a biophysical model of the biosystem, that attempts to be based on as well-founded physiology findings as we could assemble, both from countless other investigators and our own limited added efforts.

1. Understanding of the biosystem may be usefully organized around the following levels:
   a. the biochemistry at the molecular level;
   b. process maintenance and exchange at the cellular level;
   c. process maintenance and exchange at the organized level of the individual organ (kidney, heart, liver, etc.);
   d. internal process organization and logic for the entire system (i.e., systems analysis for the macrosystem);
   e. "factory" operation of the biosystem in its total environment (i.e., both internal and external dynamic systems behavior);
   f. genetic and epigenetic coding for reliable reproduction of biosystems that are operative in their total ecological environments.

We selected the exposition of levels c, d, and e for our first long term task. Our experimental-theoretical program, predominately limited to levels c and d (organs and total system), led us to the need for formulating a position for level e, namely the operation of the factory (3).

2. The preferred tool for systems analysis of a gross system and its major subcomponents, treated at that structural-hierarchical level, is the dynamic systems analysis of its response, both steady state and transient, i.e., the determination

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*This paper summarizes a more extensive development of the subject by the author in Toward a General Sci
of Viable Systems (McGraw-Hill, 1972).

[1] viable—having attained form and development of organs (i.e., internal parts) as to be normally capable of living outside the uterus (i.e., outside of the "laboratory," "crucible," or environment, in which the system had its start-up).

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of the temporal and spatial course of the salient identified fluxes and potentials, and the modes of motor actions (that is, via its actuators, e.g., switches, valves, pumps, motors, vasomotors, constrictors, etc.) that the system exhibits. (We will loosely refer to this process of analysis as "biospectroscopy," since it really relates to physical-chemical spectroscopy.) If these are well identified, then the "chains" of causality, as these fluxes and modes course through the system, may perhaps be identified by physical-chemical phyotheses.

3. The two great logical divisions regarding the nature of flux (i.e., flow) are the division into power and informational fluxes. While modern electrical engineers may favor the information fluxes (which is indeed evidenced by the attention that those interested in biology have given to the brain and the CNS), a more classically oriented physics and mechanical engineering would tend to start with exhibiting the nature of the power fluxes.

4. We choose to define the human, as our prototype complex biosystem, operationally as a self-actuated motor system ("automobile") that intermittently roams through its physical environment in search of food. Its principle dynamic properties are that it hungers, feeds, and moves about so that it can continue to hunger, feed, and move about. At the right unfolding (aperiodic) time, it couples and reproduces so that the newly formed unit can hunger, feed, and move about. We thereby imply that, by his very fundamental nature, man must involve one or more major internal thermodynamic engines, and thus thermodynamic engine cycles (else he couldn't move). This represents straightforward power engineering. (Fuel food is being taken in, energy is liberated and made available for work.)

5. Our first choice, therefore, was to explore the dynamics of the metabolic processes, and then, as we found the ubiquity of internal biochemical oscillators (or periodic rhythms), to begin to explore some additional variables.

6. Having found a near-stationary spectrum for the many biochemical parameters that we explored (although the cycles varied in frequency, i.e., they warbled and exhibited considerable noise, their power spectra indicated large amounts of energy tied up in these spectral regions), we formally identified the chains in which they were involved as nonlinear limit cycles, ever-beating in the internally lossy system, independent of the starting conditions. Since it seemed clear to us that the mean state of these variables were those regulated parameters identified with homeostasis[2], we were forced to propose a modification of this central biological concept. For regulation of the mean state, by dynamic regulation, we proposed the modified name homeokinesis. It denotes a mediation, mainly by inhibition or release from inhibition, of a manifold of oscillatory (or rhythmic) processes which make up the many biochemical chains in the organism.

7. Having demonstrated thermodynamic consistency in some of the basic metabolic processes, and having postulated causal chains involving hormone interaction for a number of the identified chains, we proceeded to the behavioral logic of the entire system. The biosystem is not an idiot thermodynamic system that sits or moves in a routine path doing its "thing" over and over again. We pointed out that the system has indeterminate gain at zero frequency. The system is essentially marginally unstable.

Roughly speaking, this means that, if the system is put down, it will not stay at rest indefinitely. If in a turbulent disturbed state, it will calm down in time when put into a confined region. We therefore postulated a large number of modalities, its "hungers", into a satisfactory pattern. This we put in our first position paper (3). It represents a proposed extension of physiological to include behavioral homeokinesis.

8. However, this scheme is still not sufficient to stabilize fully the unstable biosystem. We were led to postulate, in addition, a hierarchical nature to the total system's behavioral regulation. Regulation is achieved by overlay of system upon system. A preliminary outline, in the case of thermoregulation, was put forth in a note on thermoregulation (5). A second descriptive model is in progress for cardiovascular system regulation. However, having put together these pieces, we have been better able to formulate an overall scheme (6).

ILLUSTRATING DYNAMIC LIMIT CYCLES IN MAMMALS

The Experimental Foundation for our Belief in Homeokinesis

I bring to the reader's attention the existence of the following kind of spectral data which supports our position, to be assembled in a forthcoming paper; also see Richter (2). A common feature that we find in biological oscillator chains is a relatively slow cycle which suggests that its dynamics are not single rate governing steps at cellular level; yet the cycles are quite fast for the amplitudes exhibited (in that one must visualize that it represents large power that these linearly unstable but nonlinearly stable oscillators put into transit). The amplitude ranges tend to be near-normally (Gaussian) distributed but with finite cut-

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[2] Bernard, Sechenov and Cannon's concept of the constancy of the internal environment independent of external change (e.g., temperature, pH, salt, sugar, other material concentrations, etc.). See (4).

offs. Typically, their cycle to cycle maximum to minimum amplitude ratio range over an observation of many cycles is 5-6 to 1. Thus we are not discussing small changes.

The following is representative of pertinent spectral data (the heartbeat, breathing, and brain rhythms are obvious).

1. Ventilation rate (minute volume) and oxygen consumption.

a. 5 hour segments of quiescent human breathing. Large amplitude cycles of 100 seconds, 7 minutes, 30 minutes, 3 1/2 hours were found.

b. Breath by breath analysis was performed to demonstrate the reality of cycles, the freedom from aliasing errors, and the noise level.

c. Hours segments of quiescent dog breathing. Similar cycles

d. Independent study (by L. Goodman) on human; computer analysis of autocorrelation and spectral density. Similar cycles were found.

e. Independent study (by Lenfant) on human. Shorter test runs; the same 100 seconds, 7 minute cycles were found. The pO_2 and pCO_2 cycles are also shown. Ventilation rate and oxygen consumption are in synchronism.

Therefore, there is an observable spectrum of apparent metabolism as determined from gas uptake.

However, the metabolic oscillations might be due to gas storage lags. We go on to a second proof.

2. Thermal power. While gas constituents may be stored or held as transportation lags without revealing a thermodynamic engine cycle, heat power cannot be hidden.

Source Loss Instantaneous Storage

$$M \qquad -K(T_s - T_o) \qquad = \qquad WC_p \frac{d\bar{T}_B}{dt}$$

M = metabolic power
K = overall heat transfer coefficient
T_s = skin temperature
T_o = ambient temperature
W = body weight
C_p = specific heat
$\bar{T}_B$ = average body temperature
d/dt = time rate of change

The loss is nearly constant if ambient temperature is constant, and near equilibrium arrived at (namely, skin temperature doesn't change its magnitude wildly). Thus

$$M \alpha \frac{d\bar{T}_B}{dt}$$

or a change of 1 unit metabolism $\equiv$ 1.5°C/hr. = 0.03°C/min. Experimentally it was also found that the harmonic content of the average body temperature was not different from the variation in temperature at any one station.

a. Human data on temperature change at 20 body stations.

b. Single station temperature data on man, guinea pig, mouse. Findings: The change in metabolism is comparable in amplitude and frequency to the fluctuations in mean temperature.

If we hypothesize that the engine for both heat and work are the skeletal muscles, they should be warmer than their surrounding tissue.

c. Measurements in muscle temperature relative to tissue above and below the muscle, in guinea pig. The muscle was found to be warmer.

d. Heart rate in dog (i.e., essentially proportional to blood flow, if stroke volume is assumed nearly constant). The blood flow, which supplies the oxygen for metabolism, was found to show similar periodicities.

3. Metabolic balance. A metabolic power balance was tested in a body zone, the hind limb of the guinea pig, used as a calorimeter. Measurements of surface temperature for heat loss; femoral arterial and venous temperature for net heat production; sugar consumption; blood oxygen levels; blood CO_2 levels; blood lactate levels.

a. pO_2, pCO_2 data (low quality data). Spectrum—pO_2; 40 seconds, 210 seconds, 450 seconds. pCO_2: 2 minutes, 7 minutes, 20-40 minutes.

b. Blood sugar data. Oscillations of ± 10-15 vol. % in the guinea pig, with 40 second cycles.

c. Blood suguar data—human (Hansen).

d. Blood sugar and insulin data - human (Anderson).

e. Blood sugar data—human. 40 sec., 100 sec., 400-500 sec. cycle.

4. Metabolic events at the microcirculation level. Since we have postulated mechanistic chains for our various cycles, for example, a chain for the 100 second cycle in the muscle engine, we went searching the microcirculation in muscle to find the energy release.

An oxidative engine can be run by:

(1) metering fuel to the engine;
(2) metering oxygen;
(3) metering a combustion byproduct to regulate the reaction.

Fuel is regulated at a high level in the blood, CO_2 is regulated at a low level; i.e., they have independent regulators. Therefore we expected oxygen to be the potential regulator. We found a 100-second cycle in red cell flow: it was not found in plasma flow, nor in the opening and closing of capillaries, nor in precapillary sphincter action.

a. Red blood cell counts in mice capillaries (2-5μ lumen), and guinea pig capillaries demonstrated these cycles.

5. Water-weight regulation. Not only are there fast cycles, there are cycles longer than the circadian.

a. Weight variation due to water—human—3 1/2 day cycle.

b. Fragment of some data from Newburgh—3 1/2 day water cycle.

6. Sex data. Some privately amassed sexual activity data on humans show a cyclic variation that agrees with data of Michael on human and primate. Humans show strong rhythm keyed to menstrual cycle. Post menopause, it may become free running with a 15-20 day period (i.e., shorter than menstrual period).

7. Circadia. The literature is enormous.

8. Activity.

a. Oxygen consumption and heart rate on start-up of long term tasks. Time constant 2 minutes for oxygen, 7 minutes for heart—human (Brouha).

Thus a fairly strong experimental case exists for various relatively slow, large amplitude dynamic processes that are coordinative throughout the entire system.

There is also a more limited amount of circulating hormone data.

Our views on macroscopic spectroscopy in biology are outlined in more detail in (7), and more recently extended in (6).

The sharp issue that lies ahead is not an anecdotal dispute on whether few or many systems are known to vary up and down, but a fundamental point of view of how regulation in the biological system is achieved. The current general belief is that the system reacts to wipe out the cause of disturbances. We propose instead that active non- but near-equilibrium thermodynamic processes are involved in a large spectrum of autonomous oscillators in the living system, and that the regulated average state emerges from parametrically mediating the operating points of these oscillators.

Kuhn, in The Structure of Scientific Revolutions, states that difficulties exist for the investigator in any scientific field whose "paradigm" (we have long preferred "metaphysics") is not of the latest style or fashion. However, a new era is possibly dawning. The 1969 Bowditch lecture of the American Physiological Society presented a comforting introduction to physiological dynamics. A number of participants in the 1969 International Biophysics Congress, such as Prigogine, Katchalsky, Morowitz, Dewan, Landahl, and even students of ganglia in the nervous system (Strumwasser), stressed the possible existence of macroscopic periodic phenomena (in the form of limit cycles), the conditions for their emergence, their ubiquity, even their relevance to the orgins and organization of life.

Having thus briefly introduced our views on biological systems, we can proceed to a broader formulation for all systems.

An Outline for the Dynamics of all Systems

The following is offered as an introductory formalization for a general science of systems. It proposes to view systems within the context of nonlinear mechanics and statistical thermodynamics.

1. There exist A. C. active atomistic systems[3] that are capable of absorbing and emitting energy. They may be regarded as autonomous oscillators.

2. However, such open thermodynamic systems with active properties cannot exist unless they are locally dissipative and inhomogeneous.

3. Their necessary theoretical foundation is linear instability.

4. We postulate that conditions exist under which these systems develop rhythmic alternations in state, which, when long persistent although not necessarily rigid, may be viewed as limit cycles.

5. Internal dissipation "shaves" these systems down to the nearest possible limit cycle, rather than permit their indefinite wandering, which would occur if only conservative collisions existed.

6. We postulate that limit cycles occur, hierarchically, at all levels of organization of physical entities. It is possible that, out of the very hierarchical ordering of systems, time itself emerges pulse by pulse (7).

7. There are illustrations of how the instability that leads to "quantization" comes about.

a. In a hydrodynamic system, for some simple turbulent field spectrum, we can deterministically illustrate the instability.

b. In a meteorological system, one can illustrate with some self-consistency how tidal oscillations come about, and thus how the dynamics of weather may begin.

c. In the cosmological system, one can show semi-theoretically the stellar cycles and the "beginnings" of the current cosmological cycle.

d. In the social system, we can trace man's civilized past to cultural beginnings under Australopithecus, and to civilization in Neolithic times. "Causality" for start-up is not well defined.

e. In the atomic and nuclear case, the quantization is describable, but there is no theory for origins.

8. These atomistic oscillators do not arise in isolation in large space-time vistas, but are found most often bounded and reoccurring within an extended field. It is generally in interaction with the boundaries and each other that the atomistic properties—of limited extension and of quantized fluctuation—arise. Not all regions of the space nor all interactions are freely accessible.

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[3] An A. C. active network or system, using electrical engineering terminology, is a network or system containing a fluctuating source of power, such as a generator. (There may be A. C. active networks containing alternating "current" generators, or D. C. active networks containing direct "current" batteries).

Yet the fact that these entities were formed out of common substance, and common causality roughly makes them alike. When nearly alike and interacting, then their dynamic patterns resemble each other. This is generally described by Gibbs' ergodic hypothesis (preferably in quasi-ergodic form). All portions of accessible phase space are occupied with roughly equal probabilities by members of the ensemble. Averages in space and time approach the same limit upon sufficient sampling.

9. Extensive collections of such active atomistic particles make up a continuum. The conditions for continuum-like properties are that the ratio of the mean free path of an atomistic particle inserted into the collection to the dimensions of the field should be small; and the ratio of the particle relaxation time (both for external relaxations and relaxations of internal degrees of freedom that are not frozen out) to the shortest period of interest should be small.

These relaxational properties, indicating physical degrees of freedom associated with the atomistic elements, create transport coefficients in the continuum-like ensemble. The types of transport may be identified as delays in momentum transport (e.g., viscous relaxation—shear viscosity associated with translational momentum, and bulk viscosity associated with all other forms of internal momentum); delays in energy transport; delays in the transport of mass species. The collection is then described by continuum equations of change.

10. A well-defined formalism, based on Onsager's linear theory, exists for non-equilibrium thermodynamics. It indicates the foundations from which various kinds of interatomistic coupling forces can lead to transport coefficients.

11. One result which comes out of this formulation is the significance to be attached to the bulk viscosity, and to the elastic modulus.

This existence of the property of high bulk viscosity is the gateway toward rigid structure (i.e., to the solid state). At low values, a collection of atomistic elements acts fluid-like, with rapid lively relaxation (through shear viscosity). The ratio of bulk viscosity to bulk elastic modulus defines a time, in this case for internal relaxations.

If now this relaxation time is high, then these internal degrees of freedom are "frozen out".

12. The results of interatomistic association are particularly accentuated by atomistic density itself. Formally, the laws of association of ensembles, groups, populations, civilizations begin to emerge.

13. The basic distinction in characteristics between continuum systems of low and high bulk viscosity is the difference between form and function. When impaired by densification and increased interatomistic forces, function is frozen out and becomes formed structure.

14. The specific nature of the transport properties depends on the inter-element forces. These forces may depend on or may be independent of inter-element distance. The classification of such forces is one of the tasks of physical science. However, one salient force that is apparently fundamental to quantization should be stressed. This is the exchange force. In quantum physics, it is said to have no classical analogue. We propose one. It is a binding force of configuration. In an ensemble arrangement in which elements can hardly be distinguished, an exchange can be imagined by which they interchange position (somewhat independent of their location, if not too far apart). These two arrangements, thereby degenerate, somehow have an energy associated with the exchange, representing an instability within which the system can fluctuate. This binding energy and fluctuation is proposed as the foundation for quantization. What is likely required is coupling of more than one kind of force field.

15. Such ingredients are sufficient to construct statistical mechanics and non-equilibrium thermodynamics for continuum systems. They suggest the behavior of an ensemble placed within a bounded milieu. In time, the system may approach an active statistical mechanical equilibrium. Interactions—"collisions"—will take place until whatever energy is associated with boundary exchange will be distributed among the available degrees of freedom.

16. A system should be examined with a spatial and temporal "box," with a scale extending from a minimum to a maximum time, from a minimum to a maximum size. Unless its relaxation spectrum too extensively overlaps the ranges of this box, a bounded system will be found to "quickly" relax, to where it freely wanders within the phase space available to it. Frozen out degrees of freedom will not be invoked.

17. Characteristically these near-continuum ensembles will display a motion in modalities. These modalities are of two distinct types, diffusive and wavelike.

18. As the continuum-like collection increases in size, it ultimately becomes linearly unstable again at a Reynolds number-like criterion. The characteristic motion is a sustained combination of the modalities permitted by the continuum. A new society appears composed of a space-time motion of larger super-atomistic elements. Each of these is itself made up of a near-continuum of previous atomistic elements.

19. Thus the hierarchy of general systems consists of a line: atomistic element - continuum ensemble - atomistic element - . . .

20. The Reynolds number depends on the ratio of the velocity to the propagation velocity in the medium, and the ratio of dimensions of the field to the mean free path. The propagation ve-

locity measures the rigidity of the system. A continuum thus breaks down if the velocity of any of the dynamic processes in the medium gets too large, if the field becomes too large, if the medium is insufficiently rigidly coupled, or if the mean free path gets too short.

21. There are transitional configurations whose relaxations do not take place rapidly enough to qualify the states as being fully ergodic (e.g., plastically yielding materials, or grainy fields in which some degree of condensation may take place). Such systems tend to relax more slowly and exhibit a much more restrictive kind of equilibrium. This does not prevent, it only complicates, their description.

Their important property, which is difficult to deal with, is that they exhibit emergent evolution. It is difficult to estimate when a new relaxation process may take place from a temporarily frozen out degree of freedom (e.g., when a catalyst may appear for the process).

The evolution generally takes place through a number of steps toward more equilibrium configurations. It is as if a very slow motional relaxation process is in progress.

The time scale of relaxation is then set by the bulk viscosity (i.e., internal relaxations), or the time scale of atomistic clustering or diffusive evaporation.

22. The sequence—A - C - A - C—is not a simple one because stability, in a nonlinear sense, is not necessarily sharply defined. For example, the stabilization may not be fully completed in just one particular domain. Thus, there is a hierarchy of efforts at stabilization.

Stabilization begins around a focal center forming space-time orbits. Most often there is an individual element which captures or directs a considerable amount of energy. As such, we shall refer to it as an elite, or key, element.

Thus, for example, the condensation of an ensemble of atomistic particles may take place into an ordered array. At first glance, this array might be thought of as being indefinitely repeated. However, for dynamic reasons, it is unstable. An individual element, a dislocation, "keys" the structure. The dislocation, which may be the site of an "impurity," acts as an elite to fix the level of stability of a rudimentary crystallite. A collection of such elements, locally inhomogenous, but macroscopically more homogeneous, now begins to extend toward continuum size. The border "elites" made the mating configuration possible.

23. Having a universe of space and time to play around in, a discrete density of material, A. C. active elements, and radiative "action-at-a-distance" energy transfer, one can intuitively see that the only potential motional states are a uniform distribution, or singular condensations. Apparently, the uniform distribution is less stable. Thus motion tends toward condensations, i.e., expansion away from one region, condensation around an "elite" focus. Elements tend to cluster.

From a more general point of view, the grand scheme of things appears to be cosmic "dust" condensing to form new stars, the stars clustering in galaxies which also go through a birth and life process, the galaxies tending to form clusters, these galactic clusters then "filling" up space, and thereby closing space. Thus, under the action of interatomistic forces, in this case gravitational, a sequence of levels is required to stabilize the structure.

In any local domain (the argument repeats) the only potential motional states are a uniform distribution or condensations. The uniform distribution appears to be less stable. Thus motion tends toward the condensations. The dynamic stellar processes continue—main sequence to red giant to white dwarf. Condensed material, such as planetary objects, may go through a life phase, as on earth. "Unstable" dynamic processes lead to a geophysical solid, liquid, and gas state, and a fourth category of chemically reactive change. The argument repeats again. Apparently some chemistry is self-replicating, i.e., unstable in the same sense, so that it creates dynamic limit cycle processes—'life'. Life evolves, becomes unstable, forms new patterned structure, etc. This appears to be the continuing chain of thought in the science of general systems.

24. Summarizing, a system has three phases: First is a start-up from the local milieu, arising by design or by incidental assembly. It does not represent a contradiction of thermodynamics, just the development or a local inhomogeneity which is locally unstable. The second phase is the normal life phase. The common negentropic pump is "convection," whether the convection of a turbulent hydrodynamic field in which organization is propagated into the field by unstable eddy formation (the eddies are discrete local elements that draw energy from the constant potential field) or an algorithmic "convection" in which the living system stuffs "energy" into its gut. The third phase is the deterioration phase.

To understand the birth, life, and death of limit cycle systems emerging from the large scale degradation promised by thermodynamics, regard the matter-energy-space-time cosmos as a giant pinball machine. In the current cosmological phase of natural processes, the thermally ordered processes are running down. However, the cosmological matter-space-time-milieu is not homogeneous. There may always occur local pockets in which a relatively long term "life" process will form and lock up. Galaxies, stars, elements, solar systems, geophysical and geochemical processes, life, social organization—all have formed.

Are these foreordained? This is not clear.

If we could see the entire inhomogeneous continuum, we might guess at the density of pockets, or if we had experience with many such cosmologically expansive, thermodynamically degradative process phases, we might see a more general answer. But we lack experience. Thus we only note the processes as essentially stochastic. Whatever grand design exists is not apparent to us. Nevertheless, we can be certain that pockets exist, and systems form—for a time! These are not in a strict sense "evolutionary" as much as they are temporary "stases" of a dynamic sort.

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Page 8 item 7, paragraph 2, beginning with line 5 should read...

We therefore postulated a large number of modalities of performance in the biosystem. Because of its inherent instabilities, the biosystem threads these modalities, its "hungers," into a satisfactory pattern. This...

Page 9 item 2b, line 2 (new paragraph) Findings: The change...