GENERAL SYSTEMS
Volume XIX, 1974

ON A THERMODYNAMIC THEORY OF HISTORY*

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INTRODUCTION

The issue of historical particularism versus deterministic necessity has long been the subject of historical debate—by philosophers and by social scientists.[1] There is an assumption, often made or implied, that the physical scientist commands the ruling paradigm of the times, the theoretical models of physics.[2] Yet it is never made clear to the student of the physical or social sciences to what extent physics might be able to distinguish the erratically emergent particular from the deterministically-cast general result.[3]

In this essay, the notions of a systems' physics are developed in a form that may suggest it is possible to deal with certain scientific aspects of the history of evolving systems, e.g., societies of men with evolving institutional forms. The general approach is through the statistical mechanics of similar interacting entities—humans—which leads to an irreversible thermodynamic formulation. The "fill" of details, the kinetics of how men interact socially to produce the local details of history, is left for future development.

PART I

There has been a long historical debate about the difference between the descriptions of science with its apparently deterministic nature, as compared to those for the ongoings, past, present, and future, of the human ensemble. In effect, the question revolves around the nature of "history." But what are the similarities and differences of describing the motion of an electron, say, in the womb of some beta decaying unstable nucleus, as it is exposed to the powerful shaping influences of some strong magnetic field, and a child born in the womb of some servant girl in 18th Century London and exposed then to its forces? The intent here is to identify similarities that make both these problems as well as many other of the more obscure problems of science and man comparably tractable.

Most educated people probably hold the view that the "hard" physical scientist has a perfectly clear path toward attacking and formulating his scientific problems. This is not the case.

To provide a point of departure that may serve all—scientist, engineer, social scientist, poet, thinking person—the following simple scheme is offered. Description clusters with two extremes:

the artistic ⟷ the scientific or technically abstract

In some interesting and fruitful dialogues between artists and "technicians" (out of personal experience), it emerged that both are concerned with common problems of technique, suitability of "languages" and "tools", etc.

*This report is related to work supported by the U.S. Army Manpower Resources and Development Center. Their support is gratefully acknowledged.

1. See, for example, an account of such debate in anthropology in M. Harris, *The Rise of Anthropological Theory* (Crowell, 1968).
2. See, for example, the preface to R. Heilbroner's, *Between Capitalism and Socialism: Essays in Political Economics* (Random House, 1970).
3. A distinguished reviewer asked that I clearly set forth what I mean by causality and determinism. Dictionary definitions are inadequate. For causality, they offer a relation between regularly correlated events or phenomena. For determinism, they offer the theory that natural occurrences are determined by antecedent causes or natural laws. In my (physically oriented) outlook, causality relates to a temporal view. Time is undefined (it is known in our metalanguage or metaphyiscs). Causality deals with an ensemble of isolated transient events, in which the physical antecedent A is invariably found to precede the physical consequence B within a particular time span of reference in which other "causes" have not had the chance to enter in, or it is indifferent whether they entered in or not. Also, in the absence of A, B may or may not occur. Then A is spoken of as causal for B. The concept cannot be used for a single transient event, unless that event can be embedded in an ensemble of "like" events. The burden of proof is then on science to establish why they are then alike. The concept cannot be used for a spatial field phenomenon (e.g., the forces on the edge of a plate are "causal" for the stress reactions within the plate), unless by a series of small increments in time it is shown that each increase in force is antecedent to an increase in stress. The concept cannot be used for a cyclically repetitive field of phenomena unless, again, we can show by incremental increases, this time in frequency, that the independent presence of A is followed by B as we proceed through an extensive frequency domain. Thus, for example, when we have nonlinear processes that "spontaneously" (i.e., for stability reasons) burst into cycles of performance, causality is sometimes hard to trace. When we can conceptually slow the process down (and that means that we can do another real experiment with like materials) and follow the "causal" chain of steps around the cycle of performance, then we may be able to talk about its causality. Otherwise, one gets into the sterility of "Which came first, egg or chicken?" I will avoid the murky issue of causality within the quantum mechanical framework, although my remarks were designed to step as close as I felt permitted within a classical philosophic framework.

Determinism has to do with the prediction of connectivity between distinguishable physical configurations, whether in space or time. (I will take "B" determined by "A" to be essentially equivalent to A is causal for B; but determinism is not concerned identically with causality.) A and B are deterministically linked when the presence of either A or B assures the presence of the other configuration with an acceptable small configurational source of error in space or time. I seldom mistake my wife for her sister, although Jacob had such trouble. But determinism may relate to connection among temporal or spatial transients as well as periodic configurations. (Namely, if I predict a transient event with sufficiently small error, I may regard the events as deterministically connected. My opponents may deny the causality. Only by repeated predictions will they

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and creative products, but a distinction seems to lie in the character of the end product. The artist's concern is with creating a product or form that is unique; the scientist is concerned with that which is general. They both enjoy a product that is "economical" in execution: the one in which the essence of a unique experience or idea is caught up with an economy of material and method; the other in which the essence of many apparently unrelated exemplars of a being is caught up in its generality with an economy of description. In examining some of the history of thought on these matters, it is clear that this is not the first time that this observation has been made.

But the salient point of relevance here is that the artist is not concerned with the economy of his description. For example, as poet or prose writer or musician, he is concerned with a richness and redundancy of image; he is concerned with finding ways to attune the internal emotional apparatus of his listener or reader to follow the path on which he has set forth. To create this as a unique experience, the "composer" (here, of words) arranges his material with multichannelled (at least in part), ambiguous outlines.

On the other hand, the scientist is not permitted such luxury. He is not supposed to ramble on. He is responsible for a compact, crisp formulation which sets forth what he starts from, identifies the body of observation, and makes a clear and economical explanation or account. Science, it is said, then must become public, demonstrable, reproducible, and communicable.

However, within the technically abstract cluster of describers, "technicians" can be further separated into two classes: scientists and engineers.

The engineer is concerned with techniques of good practice for handling well-defined fields, e.g., safety engineering, applied mechanics, communications engineering, biomedical engineering (as well as engineering's more conventional compartments), and also clinical medicine. To the query, "In what spirit does the engineer formulate his descriptions?", we reply that he does not seek the most economical or general path of explanation or description. He is willing to specialize, or make his problem unique, as quickly as he is able. By a creative act he decides what compartments are "good enough" to contain the fragments of his problem.

The scientist is confronted, ultimately, with a requirement for greatest economy, greatest generality, greatest condensation. He is responsible for finding vantage points that have the greatest degree of abstraction. Still, many educated laymen believe that the scientist has some quickly applicable, beautiful, highly conventional, perhaps even sterile techniques or rules for achieving this result. This point needs exploration. For example, Monod[4] stresses that the selection of science as a path is not devoid of value judgments.

Thus the basic question to be explored is whether there is a path for describing the formulation of science which is any more or less determinate than that for history (e.g., man–his story), and whether there is a comparable path for describing history. The value judgment that will be offered is a choice, the quest for the "most economical and most general description" of these fields associated with their respective phenomena.

It turns out that the scientist has no "most economical" path unless he is willing to adopt one particular point of view. Thus, in general, science initially develops along a path very like engineering. Various practitioners explore a great variety of points of view in a given phenomenological field, then gradually sift and simmer these down and formalize their descriptions and explanations. At some point in time some individual may come along and see a synthesis of various of the pieces and thereby offer a much more compact description.

To the scientist who has lived through many more than one such endeavor, who has explored many more than one field of science, the scene is excruciatingly painful. The scrapings and twitchings and birth pangs make up a whole sociology of science, whose marketplace of ideas is no less niggling, haggling, higgledy-piggleding than any other human activity. The vaunted economy of effort in science is more myth than reality. (Of course, as in many other marketplaces, problems are swept into its sewers and its field is tidied up for the start of each new day, as textbook arrays are neatly arrived at by nightly toil.) Consequently, at this point in the sociology of man's thinking about natural systems and about man's own system, the indeterminate branching, much less certain, nature of science and history becomes evident (to be observed by spending a time in the marketplace).

However, an economical scheme was promised for both. What is the scheme? Before outlining it, we shall find it desirable to characterize an alternative economical scheme first, and discard it.

It is common in much science to seek various optimization principles. For example, in mechanics, Hamilton's principle is offered, by which a certain function of the motion of a system of mechanical particles is supposed to be minimized for the dynamic path of that system as compared to all other neighboring geometric paths. This is supposed to lead to the deterministic motion of the system of particles. As another example, in economics,[5] an objective function of value is proposed, and the entire program in modern systematic economics is to play out the consequences of maximizing that function. As one final example, in automatic control theory, the design problem

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believe the causality.) Further, the connection is only of configuration. I do not have to associate a unique trajectory. Namely, a diffusive field (e.g., Einstein's account for Brownian motion) that spreads out in a well accountable fashion by what some may consider to be "purely random" is quite deterministic.

Thus my concepts of causality and determinism in science relate to observable accountability after or for a suitable scale of time or space. Namely, they refer to the relations among phenomena which I can make emerge on a macroscopic scale.

4. See J. Monod, *Chance and Necessity* (Knopf, 1971).
5. See W. Leontief's review of Heilbroner's book in *N. Y. Review of Books*, July 20, 1972.

is how to provide mechanisms and operators that will minimize a certain error of performance function.

But the main point being pursued is that it is surprising how much science is formally or intuitively cast around identifying such minimum or maximum performance criteria as a basic for description of "design" (for example, asking such questions as how the cardiovascular system is "designed").

To provide a concrete image of the problem, one might describe the results of a Hamiltonian program for a mass-spring system as the sum of its kinetic energy and its potential energy.

Such a system goes back and forth endlessly. Displacement, by which the spring stretches, is traded over and over again for velocity, which measures its kinetic energy. Why was it offered as an example? It is one of the simplest illustrations of a systems motion that will go on indefinitely, and this is what we are here concerned with for the social sciences. How can one economically describe systems' motions which may be more or less deterministically played out, but which continue to play out (e.g., man's history)?

The elementary point of criticism, using the mass-spring example as a scapegoat, is that such systems cannot really possess such Hamiltonians. There is, in fact, another law of physics which guarantees that such mechanical systems will be caught up in dissipative phenomena (e.g., through friction) and will lose their energy and decay in their motion. Thus, if systems persist—namely, if systems which dissipate energy persist— they must do so by virtue of some program other than the type of mechanical optimization program that led to this answer for sustained motion.

The answer lies in thermodynamics, and in irreversible thermodynamics, at that. Offered as a mechanical prototype is the example of what is needed to make a clock run, given a steady source of energy, instead of running down. Briefly, the answer is that nonlinear mechanisms convert the energy available from a potential store, intermittently, in accordance with the system's self-timed cycle, in order to continue to run. To state this with even greater brevity, the clock is a thermodynamic engine. It requires an escapement to meter stored energy and to put it into play in the system. But if we are to appreciate the ironic quality of this answer, we should note that, while the clock keeps time deterministically, its motion is not fully determinate.[6] This appears to be paradoxical. But it means that two "similar" clocks (e.g., two boys born in London) do not remain in synchrony indefinitely.[7] In time, their phases drift apart and wander indeterministically relative to each other.[8] Such flavor, of course, is at least one step closer to human history. You may predict the nominal course of a young man growing up in a particular cultural setting within a particular economic class structure, etc., but the phases of his growth remain indeterminate. The process is one of diffusion, not sharply determinate wave propagation (as could be illustrated with the mechanical mass-spring). The causality of a "dissipative" diffusive model, in general, is thus more valid than an energy conserving Hamiltonian model.

Finally we are ready to exemplify what this means for history, or for historical description.

PART II

We are here concerned with history as a temporal process taking place among an interdiffusing ensemble of members of a like species. The issue in description is whether that experience has been unique, or whether it has threads that can be deterministically traced as the causal or descriptive structure of change. In addition, there is concern with "evolutionary" change, in which, in the ensemble itself, changes take place in the individual. How these issues have been dealt with by "non-economical" descriptions is part of the entire science, art, and history of history. What can we suggest that is "new" toward a more compact description? We will make our offer as theses—first enunciated compactly, and then discussed.

1. We offer a compact thermodynamic description for systems in which groups of like individuals pass through time cycles which reliably return those groups to their intitial states or to states very close to the initial ones.

One may watch children (and adults) getting on a roller coaster. At each trip, an old batch of riders gets off and a new batch gets on. The significant point is not that each batch is identical with every other batch; as far as the preservation of the system (of roller coaster operation) is concerned, an observer can hardly distinguish any difference. The preservation of form and function represents the system. The near equilibrium of cycles of performance characterizes the system. Such performance cycles lead to the concept of summational invariants, near "constants" that can be extracted from an otherwise seemingly random motion.[9]

In the amusement park, the youngster's cruisings may look random, but the summing average taken at the roller coaster station makes the roller coaster a recognizable isolatable system. From such specific sustaining ongoing processes, the systems' characteristics emerge.

Does that mean that one may consider only processes

6. Eventually, the configuration of the clock will result in an unacceptable error in time, and recourse has to be had back to the universal (undefined, except to say that the stars on the average keep that time).

7. Even if the clocks were driven by lasers! Namely, laser clocks too have errors and uncertainties associated with them. They are better than pendula or crystal clocks, but not perfect.

8. On the other hand, although their timekeeping properties exhibit causal relationships, their relative phases are indeterministically related.

9. To illustrate: We have no trouble recognizing human beings. One must note that certain properties tend to remain invariant and help in this recognition: Humans' size seems invariant, their shape seems invariant, various organismic features seem invariant, their motional and emotional characteristics seem invariant (else how would their psychiatrists recognize them); their reproductive outcome seems invariant. In fact, this invariance further exhibits itself as characteristic action modes of the system. For such a description, see A. Iberall, W. McCulloch, "The Organizing Principle of the Living System," Trans. *ASME, J. Basic Eng., Series D, 91*, pp. 290, 1969. The curious can take one step further in McCulloch's book, *Embodiments of Mind* (MIT Press, 1965) for some neurological details on the question of "How we know Universals."

that are tightly linked step after step, in order to have such a thermodynamic description by summational invariants? The answer is no. The answer is best illustrated by an example seemingly outside the scope of the near equilibrium statistical mechanics which leads to thermodynamics.

Suppose one has the composite aperiodic trajectory of many interacting particles as, for example, when one shakes a handful of sand particles in a box and suddenly stops shaking the box. Can this be described? Yes, by aperiodic equations of change, as follows: If one has a physics of particles, a kinematics and a kinetics, then one can attempt to trace out the various large number of collisional interactions that have taken place. The system apparently has no summational invariants,[10] so it appears that its motion is not to be significantly considered by summational invariants. Namely, it appears that each particle had a unique kinetic history akin to each human's view of his own life.

But let us examine this more closely. At the particulate level, the particles—the "atomisms" of the ensemble—may have collided many times during the highly interacting motion. Their cycles of interaction, their free flight "life-times" make up the performance of the system. If they have collided and shared their internal energetics many, many times, then the performance of the system during its overall relaxational phase could have been described by summational invariants and by irreversible thermodynamics.[11]

In short, provided there is ample time for, and a sufficient number of collisions, there exists a physical thermodynamic description for the macroscopic behavior of a system during a transient relaxation. Thus:

2. The motions of systems that strike one as being macroscopically continuous—that is, those in which the performance cycle and performance space of the individual are small compared to the vast space and time within which the system operates—can be described by deviational states of motion, "equations of change" by which the system attempts to move toward its more final fixed cycles of performance.[12] Those equations of change express the content of irreversible thermodynamics for summational invariants.

Still, we must exclude the description of even such systems in transient periods (e.g., "revolutions", etc.) in which change takes place faster than relaxation time of the cycles of performance. There are techniques in physics for handling such issues (kinetic theory is available), but their application is an inordinately more difficult process. At this moment, it is more suitable to define the methods for treating piece-wise continuous systems. Such systems may be discontinuous at limited regions of time and space. At the discontinuities, the simplest usual technique is to treat the rapid epochs of change by "jumps", namely, by characterizing what remains unchanged before and after the jump. In these regions the field properties are no longer summational invariants; yet the jumps involve the changes that may have to be represented for the summational invariants. (For example, before and after a revolution, one generally has to deal with essentially the same population number.)

We may now approach man, social systems, culture, and history—or, at least, living systems.

3. In a minimal description of living systems, including man, the first "equation of change" must deal with the conservation of number.

In living systems, as opposed to many physical systems, the population of players that make up the species' (of like individuals) ensemble is not preserved. Put specifically, the preservation of mass does not imply the preservation of number. Thus physical conservation equations split: the first part deals with conservation of number, the second, with mass or size.

This may strike the social scientist as peculiar, for two reasons. First, he will argue that population number is not conserved, so how can it be regarded as an invariant? Second, he will argue that, even if he accepts the first idea, it takes a human male and female to produce progeny, and the number is not determined.

To try to explain both aspects, let us note that population does not explode revolutionarily. As Malthus pointed out, it is rate governed at least by food.[13] It is also rate governed by the physiological mechanisms that make for reproduction (e.g., a nine-month gestation period of prenatal growth). That means roughly, first, that generation begets generation, which process tends to replace each generation of players on the stage of life by another generation; second, that this process *for an ongoing species* is nearly in equilibrium. That is the idea of the summational invariant, not its statistical fluctuations. If then, on top of that, there are "forces," or "pressures," or "stresses," that determine change in population, such change is expressed by the equation of change. However, such an equation of change (by irreversible thermodynamics) would not be possible if the changes were catastrophic or explosive (toward growth or decay). The appropriate descriptive process would then be kinetic theory.

So, our concern in the case of "near equilibrium" processes lies with the determinants of what makes or made population change. Clearly, this is a "history" question for an ensemble of dynamic entities. As such, we

10. This permits us to explain the character of summational invariants with a little more sense of its meaning. Note that, as a result of the many collisions, the character of the motion was not conserved. The motion relaxed; its energy was dissipated.

11. Namely, if we could have seen many many cycles of collisional interaction without the motion decaying. Those major properties that persist over the cycle of interaction represent summational invariants. These include, for example, when atoms collide, the energy, mass, and momentum that are engaged in the cycles of collision. Irreversible thermodynamics is then the description of the slower macroscopic changes that take place over many such collisions.

12. To avoid any suspense, the sand particles generally do not interact sufficiently, unless their motion is augmented, say, by vibrating the walls or shaking the box. On the other hand, atoms, bound by radiation coupling, do interact sufficiently.

13. At a time considerably past the writing of Malthus' essay, one can sense a comparable intensity regarding this problem in Heilbroner's article on "Growth and Survival" in the October 1972 issue of *Foreign Affairs*, p. 139.

must sense anew what a compact "scientific" description of history must lead to. It cannot deal with the individual atomism of the individual's life. Those are stochastic fluctuational issues that concern the kinetics of the individual. The continuum thermodynamic description does not start until one integrates over the generation time. Then the replacement of one atomism by another, although it forms a "grainy" event (i.e., discontinuous totality), can appear in a more macroscopic frame of reference in some kind of diffusive process.

This suggests that the graininess of man does not permit a time scale of "history" with less than thirty years relaxations.[14] Furthermore, those familiar with kinetic theory experience will recognize that "equilibria" are achieved in more nearly 2-10 relaxation times.[15] In round numbers, a thermodynamic historical perspective cannot "see" processes at less than the 100-300 year time scale.

The philosopher of history may very well say "I told you so!" But, of course, this will make the economist of the daily market unhappy (or perhaps happy if he wants to feel that physical theory has nothing to do with his field). On the other hand, it will clarify why a "deterministic" history is not a history of individual molecular actions. That is kinetics. A thermodynamics of history is, instead, the laws of change as man (for example) slowly wends his way through the thickets of time. The forces that change population growth rate at the 100-200-300-year time scale is offered for a first test of adequacy of description, not the intra-generation ripples or fluctuations.

However, it should be clear then that at a time scale of, say, 200 years, we have only 6500 years worth, namely 30-odd relaxation time units of experience for the "modern" urban history of man, or at most (using a Mesolithic transition of, say, 14,000 years ago) 70-odd relaxation time units; stretched to the ultimate of modern genetic man at 40,000 years ago, there are still only about 200 relaxation time units to examine and discuss. Most kineticists, or hydrodynamicists, would tell the social scientist that not a great deal of highly deterministic lawfulness could emerge from such a limited sample.

Thus, in very significant ways, it is likely that the historian has attempted to read too much from the record, hanging, as it were, on the magical story to be derived, by intuition, by poetry, from every rustling or falling (tea) leaf. Is every wisp of wind a hurricane? In the child's poetic image of what he meets on the way home, perhaps!

On the other hand, at the 100-200-300-year time scale, processes are grafted together well enough so that we know the individual's concerns have come to equilibrium. (*He* in fact is dead; we are discussing the cluster of men like himself, his family, his group, his class as these clusters diffuse through society.) Now, the social forces and trends and gradients that stress "him", as a representative member of his cluster, and determine his "choices" (which are not so "free" in cluster), have to emerge.

If the difficulty is that society does not form one homogeneous ground, that issue is well known in the "physics" of ensembles. Its various homogenous phases (e.g., gas, liquid, solid) have to be identified. If society exhibits a class structure as Marx identified, well and good; if some other structure, such as many ethnographic groupings, well and good. There are and must be problems for which the expertise of the social scientist (anthropologist, sociologist) is required. All that this essay is trying to do, in principle, is to provide a minimal scaffold of science.

Why this near equilibrium thermodynamic paradigm, rather than others? Because truly (not as an act of faith, but as an act of examining the physics of interacting ensembles of like entities that affect each other) this provides an image ideal for the greatest of economies of coherent description.[16] So the whole content of forces that govern human procreative structure must enter into this one equation of change to determine why population numbers change.

4. In a minimal description of living systems, the second "equation of change" must deal with the conservation of energy.

The atomistic processes involved in energy exchange in society are much more rapid; "thermodynamic" equilibrium for the individual is achieved more nearly at the level of a day, but we are governed by our slowest relaxational processes, e.g., the lifetime. Thus the individual daily fluctuation is not our scale for social history. At the daily level, we can write (or attempt) the physiological history of the individual.

The equation of change at that time scale would involve the rates of changes from day to day as the person (animal) was driven by existing state variables. But effectively this is uninteresting for history. (Does it matter that Louis XIV over-ate on a certain day?)[17]

14. If generation begets generation, as a summational invariant, and as discussed in my *Toward a General Science of Viable Systems* (McGraw–Hill, 1972), each viable system is marked by a development phase, a life phase, and a degradation phase, the growth phase of the human is not marked by invariance. Each man or woman, or boy or girl, sees his or her experience as unique. It is only when one compares many such experiences or, in technical concepts, integrates over the total growth period and over the entire social ensemble, that one begins to find out what is general and common to all such "histories." The unique, the particularist details lie in a finer grained scale, but the general do not. Reader (particularly if over 30 years of age), what did you do last week, two weeks ago, then years ago on a particular date? Was each day a unique experience? Is every day of your many years unique in your memory? Is every moment? Should one expect more detail for the generality of science than one can expect from one's own memory? At best, your own memories are stereotypes.

15. In the kinetic theory of an ensemble of like atoms in motion, the concept of the mean free path between collisions and the relaxation time, or free flight time, between collisions is used.

16. In the reductionism that we begin here for social science, we do not claim that the social system must immediately be described by the laws of physics. But we do claim that social systems must be in accord with the principles of physics. And we have tried to suggest that the economic structure of thermodynamics must govern ongoing systems that sustain energetic exchanges, regardless of their complex nature.

17. To indicate why we cannot view our social "metabolism" at the level of a day, note, for example, that society depends for its balance on the outcome of yearly crops. But then within the years of his life, a man's needs are different in childhood and youth, over the span of his mature years, and in his declining years. For this first effort, we did not contract to provide that detailed content in social science. Thus any detail less than the metabolic requirements for his mature years, e.g., 15-50, say, was not our concern. That puts the social thermodynamic engine process at or beyond the individual life-time. This does not mean that the social classes of youth and old age are to be disregarded.

Thus, as before, the energy equation has to be integrated over one or more lifetimes. What remains after such integration? Precious little except what that class in that social grouping (e.g., clan-tribe-settlement-village-city-state-nation) both expected and was required to expect from the social and physical ecology in order to live.[18] A conclusion, which may be surprising to most (social scientists as well as others) is that the society is always not far removed from subsistence levels for the species. The total range is give or take 10-20% variations from the average (over the years) daily metabolism. Is this biological? Cultural? That is one of the real new questions facing an economical scientific structure for history.[19]

One of the main difficulties for many is with circular chains of causality. It is useful that the concept is not unknown in economics.[20] However, it is doubtful that its full dynamic impact will be clear to most. One might characterize this problem in the following paradoxical fashion:

It is likely that an equation of change for any given summational invariant should be expressed by a rate equation, a first order differential equation

$$\frac{dy}{dt} = \ldots,$$

where y is the variable (e.g., population) which embodies a summationally invariant process (e.g., in mechanics dp/dt, the time rate change in momentum). The right hand side identifies the "causal" terms that brings about the left hand change.[21]

This somehow doesn't look circular. But when coupled with some other variable, which is likely to be found on the right hand side as a state variable, one or more of these will also likely be caught up in other equations of change. Such y dependence on x[22] (specifically, more likely on $x - x_o$, where x_o is an equilibrium value) and x dependence on y raises the order of the combined differential equation set.

5. In a minimal description of living systems, a third "equation of change" must deal with the momentum or motor aspects of the system.

In a simple physical system, one can identify the mechanical modes of motion and show how the momentum of the system changes as it is pressed on by external forces. In a continuum system, these modes of action in general tend to fall into two classes–wave modes and diffusive modes.[23]

The living system in continuum, namely society, no less falls into such modes. It is just that more difficult to identify these modes, particularly to identify them as wave-like and diffusive. Nevertheless, there is reason to believe from topological considerations that the two underlying processes of wave propagation and diffusion are the essential processes by which the kinetics of interaction in persistent systems takes place.[24] This holds even for the most difficult process to describe–the long-term evolution of the species itself.

If we drop the latter problem–remembering that we proposed to consider here the unfolding history of a particular species–modern man, not of all biological

18. In *Toward a General Science of Viable Systems* (n. 14), the process time scales for the organized constellations of society were outlined in a gross fashion. First of all, we only have modern genetic man for the past 40,000 years. His full cultural background and transmittable heritage were not possible–as homo sapiens sapiens–for a longer historical period. Second, his modern forms of social organization do not emerge until after the last glacial period of perhaps 14,000 years ago. His evolution from wandering hunter to settled agriculturist then took another 8000 years. The time delayed processes emerging from kinetic fluctuations do not arise "instantaneously." We are thus limited to the "story" of many parallel emergences of cultural ethnographic forms in the past 6500 years. What seems to be characteristic are major "moral" conceptual gains in epochs of 2000 years (e.g., a code of law, order, and value; a code of justice; a code of love); while periods of the order of 500 years seem representative of major coherent social experiments–the ethos or ideology of a nation or its equivalent. Faster time scales seem to be about 200 years for a major "idea", e.g., technological, to emerge, from its first sounding within the social-intellectual noise level. The aggressions or major intergroup mismatches of war thrust forward at near 20 years, in time to involve most generations. And so we have moved down to the "moment" of the individual.

19. Data are presented on that point, almost in passing, in Meadows, et al., *Limits of Growth* (Washington: Potomac Assoc., 1972) Figure 8. The thesis, which will not be presented here in great detail, seems so strange that it warrants some exposition. In simple thermostatic equilibrium, physicists are accustomed to think of the symmetric and well defined unimodal Gaussian curve as representative of dynamic equilibrium, e.g., the Maxwellian ensemble distribution among like atoms. But not all distribution functions have that character. First, consider physiological equilibrium among humans. While a quiescent equilibrium may involve the expenditure of energy at a rate of about 1500 Kcal/day, humans can maintain thermodynamic equilibrium rates (for hours) of the order of 20,000 Kcal/day, and athletes can reach peak rates of the order of 35,000 Kcal/day. But note that the human operates with a daily equilibrium of about 2000 to 2500 Kcal/day, far removed from daily peak performances. Namely, one might say that the human operates energetically with a low profile. Examining Meadows' figure should provoke some thought that on an overall social basis, total human machinery is operated at a low 'near subsistence' level. But this is just the physical energetic face of the equilibrium distribution problem. We offer the following conjecture, to be developed elsewhere. The social-ecological organization of any viable species, including the human, is based on a saturation population level that exists at near subsistence levels and equipartitions the power levels available by convenient and well practised technology. At this point, we avoid the next logical issue of how "technology" and practise evolves.

20. See for example, J. Schumpeter, *History of Economic Analysis* (Oxford Press, 1954, pp. 967-71.)

21. At a dynamic equilibrium, the summational invariants would be constant throughout the field. But because of process change brought in from the "outside," the summational invariant will change locally at some slow rate. The "causes" for that change are grouped on the right hand side.

22. The variable x is likely another summational variable, or one which is related to summational variables by constitutive relations.

23. Though it is outside of the scope of this article, we have been able to show that the fundamental linear modes of systems of mobile molecules (i.e., system described as the irreversible thermodynamics of fluids) very nearly factors into wave and diffusive modes. For example, there is thermal, viscous, mass, and vorticity diffusion. When the equations are completed with nonlinear terms, e.g., convection and dissipation, then we find that the linear modes drive and couple to the nonlinear terms. We have attempted to model this for turbulence.

24. The detailed justification for this assertion is developed in a monograph *On the Physics of Membrane Transport* by A. Iberall and A. Schindler, published by General Technical Services, Inc., Upper Darby, Pa., September 1973. As far as the content of human modes is

(footnote continued on following page)

species—then again we can detect that our equation of change will have to deal with the changes in modal performance over a few generations.

6. We may add an equation of change for genetic evolution, although this is beyond the short-range concern of history. As Monod would have it, while chance dictates genetic change, the necessity of adaptive conformation to the solvent character of the ecological milieu selects the direction of change. Borrowing from Eigen, as a summational invariant in the genetically coded life process, it is catalyst that begets catalyst; i.e., gene begets gene.

7. Not only does gene beget gene at a slow biological "historical" scale (namely, that there exists an equation of change for all biological species), there is also a cultural historical scale. To offer a neologism, one might say that epigene begets epigene. More transparently, there is the equation of change for man's extensions, for the content of his learned and transmitted heritage. For this there is an equation of change covering technological-aesthetic practices. One may recognize that tools beget tools; or, preferably put, that the extensions of man beget the extensions of man wherein his internal visions of mind are turned into the real practise of customs.

8. As a final companion-piece, there is one so far still unique facet that has emerged from genetic evolution. This is the summational invariant of human value, and a corresponding equation of change. The last two equations of epigenetic change form a dual. They are the only two equations unique for humans, among other biological species. They represent the thrust for change in human culture.

At this point in our exposition we are reluctant to say more. We have furnished some basic clues. Of course, some will say that we have simply provided an empty formalism. Others may be provoked to think about these remarks. Still others will say that they can see little distinction between the thrust of this outline and, say, Forrester, Meadows, Guyton, and other large-scale system modellings, developed as computable equation relations. And some physicists will say that this is a nonsense perversion of the concepts of physics.

The deep, underlying issue which we believe is forced by such concern is, why is it that the living cultural system maintains its existence? Why does it preserve form and function, making up for what should, very quickly, be recognized as degradative thermodynamic processes (rather than catastrophic)? Why does a social system persist? How does it make up dissipative losses in order to continue? And, of course, the reason that the question is important now is because now (as in certain other historical periods) we tend to feel the social fabric tearing itself apart.

But, you see, we propose what in the end is a stability picture of history, a picture of its viability under changing force structure. This is most importantly the picture, the paradigm, that physics can offer, in contrast to the detailed story of storm and strife of *The Hollow Crown.*

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concerned—the discernible content of its motor actions—these have been identified in the Iberall, McCulloch article (n. 9) or E. Block, et al., *Introduction to a Biological Systems Science,* NASA CR-1970 (National Tech. Information Service, 1971). They consist of the organ constellations organized around such focal activities as sleep, eat, void, sex, etc. They include constellations organized around emotional states as well—interpersonally attend, anger, be anxious, etc. Twenty modes in all are proposed. This exceeds the distinct four states—fear, fight, flight, copulate—associated with the autonomic nervous system by physiologists, or, typically, nine states proposed by some ethologists. See for example, J. Scott, "The Emotional Basis of Social Behavior," *Annals N.Y. Acad. Sci.,* 159, 77, 1969.