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Contributions to a physical science for the study of civilization†

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This paper attempts to apply a physics of systems, e.g., statistical mechanics, thermodynamics, to civilizations. It is offered as a supplement to the thinking of social scientists to provide their constructs with a primitive scientific base. Society is viewed as a collection (an ensemble) of interacting individuals; their interactions are tracked by identifying those basic conservations which are involved in interaction. The claim is made that these variables are the only ones that can be causally related within a scientific construct. The effort assumes the philosophic view known as epistemological reductionism‡ (explanation in terms of a physical construct), and has been pursued, previously, along the line from complex physical systems (e.g., hydrodynamic fields, in laminar and turbulent flow; plastic–elastic deformation including stability), to living systems (e.g. physiological and psychophysiological responses of organs and organisms), and, more recently, to the social system as a social physics.§ In this present essay, the effort is made to offer such a theory for the startup of civilizations. An introductory note is included on their termination.

As a layman not trained in these other-than-physical subjects, I have always made the effort to 'capitulate' to the thoughts and findings of experts in these other fields, that is to the historical and logical development of the field's discipline. The following difficulty is found.

Since the general task under study is the physics of complex systems, including their history and evolution, such study must be grounded parsimoniously on general physical principles and pursue only a physical logic. That effort is found to be philosophically at odds with (offensive to) the current belief structures of both

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‡That identification may be found in Ayala's work (Ayala & Dobzhansky, 1975). Also see Bunge's piece (1977) on levels of reduction. In Bunge's language I am a moderate reductionist, although rather total in my effort to apply a physical reductionism to systems at all levels of organization. As a moderate, I try to reduce as much of the dynamic phenomena of any system as I can. Applied to systems of different levels, that means—to me—dealing, minimally with the conservations. All other properties of the level may be novel, pluralistic (we may be blonds, redheads, browns, blacks, or bald—I have no great sense of wanting to account for all of this detail), or perhaps even 'chancy'. However, it is my belief, premise if you will, that it is only a description by conservations that can come close to being an autonomous description.

§There is an Enlightenment literature, pre-sociology and anthropology, devoted to a first generation of social physics modelling of the social system. It includes contributors like Saint-Simon, Comte, Quetelet. It ended in this century with a last desperate cry by the historian, Henry Adams.

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physical scientists and social scientists.[†] Such unification is not in tune with the existing scientific paradigm, which encourages independent developments in each field of study. Natural systems are explained differently from biological systems, and both differently from social systems. This paper is likely an early form of a rapprochement. It offers an analytical framework (homeokinetic) for such interdisciplinary studies. It assumes differences in morphology, but not in the basic principles of ensemble movement and change.

I. The general construct

1. Fluid systems of atomisms

In proposing to deal with complex systems, we are concerned in the main with fluid-like systems, in which the atomistic participants (e.g. atomis, cells, persons) are involved in interaction and movement relative to each other. We shall treat Man and his social organizations as such a fluid-like system. (There is a very comparable physics which can be developed for solid state-like physical systems but it will not be our present concern. In physics, the solid–liquid–gas triad is used as a central characterization of the differing states of matter among systems. More complex systems exist which are combinations of these three simple states.)

It is important to be clear how we regard the atomistic doctrine.[‡] Since Greek times (e.g. Democritus, Leucippus, even Aristotle who argued against their existence) the notion of atomisms has been accepted by western culture, and since the Enlightenment, the physical reality of atomisms is accepted. A living creature is an atomism among the organisms with which he associates and interacts. For the purposes of social-system analysis, that atomism possesses certain properties which are involved in interactions with other like atomisms. No metaphor is intended. What is needed is an identification of the forces of interaction.

2. Conservations

In a system of such atomistic participants, the physics of motion and change within the ensemble of participants is tracked and measured by means of those quantities which are conserved upon interactions between the participants (Hirschfelder, Curtiss & Bird, 1964).

3. Conservations in simple systems

In a simple system, there are three quantities which are conserved upon interaction—mass (the quantity of matter), energy, and momentum (the product of mass and velocity). The system is simple, basically because the atomistic participants are internally simple.

4. Conservations in complex systems

In a complex system, processes emerge from the atomistic interiors which are long-time delayed compared to the interactional time between the participants (e.g., time between collisions). These resultant processes emerge because long-time delayed complex processes are involved in the atomistic interiors. These long time delayed processes modify the basic conservations in the following way.

[†]A striking example of how much distance the social scientist generally wishes to put between his field of study and the 'natural' sciences is made quite explicit in Quigley's *Evolution of Civilization* (1961).

[‡]An atomism is both the doctrine of atomistic-like entities and the entities. It is used like the word 'organism'.

(a) Chemical change may emerge, as atomistic participants (atomisms) are transformed. This appearance of new forms requires a statement of conservations for each individual new type of atomism (e.g. different mass species) that may emerge dynamically and persist.†

(b) In the case of living systems, in which a complex chemical reproductive process involving birth, growth, life, death, dissolution may take place, one distinguishes between the conservations of mass species (e.g. internal body ingredients) and the conservation of population number. The new interactional conservation that emerges from living species is contained in the statement that generation begets generation. It is the generation which is conserved, not the precise number which may fluctuate. That process lengthens the total effective interactional time to the generation time.

(c) The physical conservation of momentum transfer between participants is modified. Instead of the relevant time scale for transfer being the interaction time (known technically in physical science as the collision or relaxation time), it is the time scale over which all internal processes within the interiors of the atomistic participants complete a cycle and reach an 'equilibrium' in the sense that the system is then ready to perform another such 'day'. In a homeokinetic physical methodology, this time scale is denoted the factory day of the atomism. It is not only characteristic of living systems, but of all complex atomistic systems which conduct a great deal of action internally.‡

Such interior actions are not immune from physical law. It is just that the action takes place internally, at another (lower) hierarchical level of smaller atomisms (e.g., cells in the living organism, or molecular clusters in the living cell). That action consists of a large number of time-delayed fluid and chemical processes. Over the factory day, instead of movement and change solely by external momentum, by external collision, what emerges is a matrix of action modes, those characteristic actions which the atomistic participants perform. The technical meaning of action is the integrated product of energy and time, what the atomism do, measured by the energy–time product each type of action costs them. (For living systems, atomisms perform psychological actions, partially internalized, partially

†In chemical change, the participants (atomisms) making up the field may undergo change, e.g. their internal ingredients may turn over, or the atomisms themselves may transform from one type of mass species to another. We are concerned with atomistic species that persist in the field, and, in the social case, with an atomistic species (persons) that turns over material chemically, but does not transform its type. Persons beget persons, but remain persons. There is a longer evolutionary process which we are not dealing with here.

‡This transformation from the conservation of momentum to the conservation of a matrix or ring of action modes crosses the Rubicon from the domain of physics of simple systems to the physical domain of complex systems. The former is applicable to the collisions of simple atomistic balls. The latter applies to the interaction of internally complex atomisms—cells, people, and the like. Group action, associative bonding that arises from internal atomistic requirements is what results. The social scientist doesn't find this strange, even if he has no reductionist theory to explain how such internal actions arise. To the physical scientist we would point out that terms may exist in the diagonal components of the stress tensor which, even if the off-diagonal components (which depend on velocity for a fluid) vanish, still influence action. This is the mechanistic avenue through which atomistic complexity can emerge. Modern fluid theory clearly indicates that such symmetry-breaking dissipative action can arise from correlated cyclic fluctuations that originate from volume associations at the atomistic level. These are known to begin to achieve some significant complexity in the liquid state (e.g. Kneser liquids). See Croxton (1974) and Herzfeld & Litovitz (1959). They are the lead-in to rheological thixotropic, memory-laden systems.

In the case of simple systems, the ring of atomistic action modes consists of the space–time pair, mean free path-relaxation time. In the case of complex systems, the action modes involve an entire complex of atomistic activities. For example, for a human atomism, the ring commonly begins with arise from sleep, forage for food, etc., till the cycle is closed again with sleep. Just as in the organism's interior, which itself is a factory involving cellular and organ atomisms at a lower level, in which various associative linkings take place to make these action modes occur, so in human society, various associative linkings take place to make the action modes occur within the social ensemble. It takes associative bondings to hunt, to engage in sex, to farm, to nurture, etc.

externalized, as well as physiological actions. For mammals, they number perhaps nine kinds of modes (see Scott (1962)); for humans perhaps 20 (see Iberall & McCulloch, 1969). For long-lived species, most of the action modes are discharged (as activities) over the 24-hour geophysical day of the earth (we refer here to the individual, not the species). If most or all of the basic action modes are encompassed in a day (as a cyclic near-equilibrium), then there is a social physics possible for a social group of such individuals from the daily scale on up. Since the human is tied to a complex ecological web, the action matrix is more nearly complete (more nearly at equilibrium) in a societal or ensemble physics when taken on the geophysical scale of the year. But if the conservation of population is to be invoked as a constraining conservation for the species (when the species is the ensemble, rather than a group), then social physics at the generation time is the first, minimum scale for near cyclic physical equilibrium for the species.† Note at this scale, the individual's actions are hardly to be detected anymore. Instead, the historical process, stripped of individuals, emerges.

5. *Ensemble physics emergent from conservations*

The science of ensemble physics relates to and only to the quantities (e.g. energy, matter) that are conserved upon interactions. Thus, individual to individual interactions are described by kinetics relating to these conservations. Motion and change in an atomistic ensemble is described by summing up these kinetic interactions, within a statistical mechanics, to produce a continuum-like thermodynamic description of the ensemble's internal motion. That continuum-like description has three facets, all relating to the conservations. First, as a result of continuing interactions throughout the ensemble of atomistic participants, the conserved quantities are partitioned (shared) among all the participants to produce what is known as the *statistical distribution functions* of the ensemble. These are statements about how matter (density), momentum (or action) and energy (e.g., kinetic energy) are each distributed throughout the space (or in any local region‡). Second, the statistical measures form the *equation of state* of the ensemble. That equation expresses how ensemble average measures (macroscopic variables) of the essential conservations are related. Such an equation holds both if the entire ensemble is in equilibrium in all of its contiguous regions, or if it is only near equilibrium. (At equilibrium, for example, atomisms in all localities will share the same kinetic energy measure and momentum measure.) If the ensemble is only near equilibrium, then there will be equations of change which will express

†There is an age-old argument about determinism or free will of the individual. Of course the individual act cannot be made significantly determinate. No more can the individual act of the simple billiard ball in an ensemble. Nineteenth-century physics gave up the search and, properly, substituted statistical mechanics, the summed motion of many collisions. That was shown to be deterministic. Here we cross the line for social ensembles and show that we are dealing with group actions not individual actions. The poetry of the individual is not affected thereby. On the other hand, the fact that population fluctuates among generations in no way prevents that variable from being a conservation. Generation begets generation. It is the requirement of both society and an explanatory social physics to account for the positive definite projection of population over a number of generations. In the form of thixotropy, whose explanation depends in no little part on the Eyring theory of rate processes, memory functions and scaled responses with a variety of time scales begin to emerge. Thus while it is true that many long-lived species make breeding choices on a yearly basis (or humans copulate a few times each week), there are a number of fluctuating time scales at which breeding fluctuations emerge. As a parameter, the net birth rate is quite variable. It is not a given but a response. See for example Baker & Sanders (1972) for comments on the ephemerality of carrying capacity, or *New Scientist* (1973) for some pertinent comments on breeding strategies.

‡For an ensemble of human beings, the distribution function is presented by such statements as: the daily metabolism of adults is, say, 1900 ± 200 kcal, the weight of adults is, say, 150 ± 30 lbs (refinements permit distinguishing male and female). So far we have only mentioned the external conservations.

fluxes (flows) and transports or diffusions of the conserved variables between regions of the field.†

The functional forcing of flows between regions of the field results from the gradient differences of conservation measures between the regions. Detailed kinetic studies are required to model the actual transport measures (or they are found empirically; physical theory requires both to agree).

Besides such transient differences of conservation measures between field regions, there may be depots of such conserved quantities within the field or at its boundaries. These are known as potentials‡ (noun, i.e. potentia, acting as storage bins for conserved quantities). Since these may be the source of the field's gradients, the general notion in ensemble physics in a field is that the potentials drive the fluxes, and thus establish the equations of change.

6. *Equations of state and change*

These two equation sets, *equation of state*, *equations of change*, the existence of underlying atomistic participants, and boundary conditions that are constraints put on the field, complete the construct of physics for field ensembles. The boundary conditions generally are potentials (storage bins) from which sources for the various conservations (quantities conserved in atomistic interactions) may be drawn.

7. *Applications to a social field*

Let us now consider the analytic process whereby these two sets of equations are applied to a field, e.g., a social field. First, having identified the basic atomisms (e.g., molecules, or in this case people), we must identify the minimum space and time scale at which such near-continuum descriptions hold. For example, to approach aggregate human behavior, one commonly aggregates atomistic performance over the earth's day rather than being concerned with momentary postures of the individual (the action mode matrix is largely completed in a day). And one aggregates over the local community in which daily activities are performed. Second, there is a maximum of space and time scale for which the field results are intended. For example, if civilization and Man's evolutionary history of civilizations are of concern, then the time scale likely has to be as extensive as Man's recent 40,000 year history, and the entire continental surface of the earth becomes the spatial field. Thus the range: a day to 40,000 years, a few acres to the earth's land surface, defines the bounds of concern. Within those bounds, there will be an extensive spectrum of effects. If we can tease apart a variety of forces external to the ensemble of concern (e.g. human), and separate out a variety of spectral domains, the equation sets can be conceptually or actually developed systematically for each specific domain of interest. The basic objective is to build up the descriptions of each domain, starting at the smallest space–time scale, integrating (or aggregating) up to the next unit scale, until the maximum scale for which the results are desired is reached.

†Careful note should be taken of the parsimony of ensemble or statistical physics. The variables used are only those associated with conservations. At the microscopic or atomistic level, the first problem is to determine how kinetics determines the statistical distribution function for each conservation. This elucidates the various statistical moments which physics permits. But, second, at an ensemble or macroscopic level, these statistical measures are functionally related to define the equation of state, e.g. how many independent measures can be determined by boundary conditions before another statistical measure is fixed. And then, third, the description by means of transport coefficients or diffusivities, one for each conservation, show how local regions not at equilibrium, one with another, create fluxes of these conservations.

‡This storage bin use of the term potential is an appropriate translation of the standard thermodynamic version for application to complex systems.

Large scale external causality (independently representing authoritative processes) can often be deduced from the existence of exogenous cyclic behavior. Social processes among the human atomisms may then reflect these 'natural' time domains. The following temporal domains furnish some natural divisions in the social process.

The social process of the day (dominated by earth's day–night rotational variation, it is marked within the chemical encoding of most biological organisms as the basis for an endogenous clock).

The social process of the year (dominated by the seasonal variation, the ecological web within which all higher species depend for material and energy supply is entrained in that periodic process).

The social process of the generation (each species has a generation time scale, associated with its chemical genetic code. For human beings this is approximately 25 years. All clocking devices do not have the same precision. Thus it is not the accuracy of the generation span, but its reliability which is pertinent).

The social process of the life span (the life span, differing from the generation time or the life expectancy, e.g., 90 years for humans, marks a period over which the likelihood of any survivors on the social scene is essentially negligible. All social continuity then has to depend upon some form of information and memory transmission).

These scales are clearly physically–chemically–biologically determined, ones over which the species, as a higher order atomism, has little or no control (as yet). They are exogeneous to the social field process. The same is true for the following scales, but the theory and data base are more controversial or speculative.

The social process associated with the life span of a culture. We would argue that this is of the order of 500 years. We would suggest that it is the scale at which a small isolate culture can maintain coherence, i.e., the scale at which it can retain a founder figure myth, and transmit its cultural epigenetic heritage generation to generation without an extensive, recorded, abstract written language. We made an a priori estimate of the number of generations (about 20) for which reliable information transmission might be expected. Then we found confirmation of that estimate in Murdock's *Ethnographic Atlas* (1967) which suggests that cultural independence exists for a small group if it has been separated either a few hundred miles or a thousand years from neighboring groups.†

The fact that civilizationists (e.g., Mencius' estimate, and more modern estimates, such as Blegen's dissection of the levels of Troy, or Spengler's estimates) identify a scale of about 300–500 years for civilization even in complex social systems, is added evidence for the intrinsic nature of the information transmission process time scale. The numerical result implies that social processes remain coherent and only diffuse slowly with such long time constants even in the presence of other groups in a coupled interacting ecumene. Ethnicity, for example, usually does not disappear in a few generations.

Even more speculative is a time scale of the order of a few millenia. Over this scale, as the process time for a number of 'independent' cultural waves to cross a large land mass (diffusional time scales are of the order of 1 mile per year (see for example van Doren Stern, 1969); thus in a few thousand years, the chance of a number of diffusions and refractions to have taken place increases), one may expect reformations of social strategies, changes in the character of the epigenetic value potential, to have taken place. Such a 'rapid' (compared to evolutionary change) process scale would not exist among stimulus-bound animals, not

†We are suggesting that the existence of such a cultural process fluctuation or 'cycle' is exogenous to the ensemble, although the details of each fluctuation will appear endogenous to that particular civilization. The issue is not really different than the question of when an individual will die (and the very specific causality) as compared to what determines the life span for the species of individuals.

even the higher primates. One would have to associate it with the extra interneuronal capacity that developed with Pleistocene cortical evolution, and likely with the increased destabilizing lateralization in the human brain (Iberall, 1973).

The appearance of the extensive epigenetic value potential in the human brain has made that brain more unstable, not so tightly bound in its decision making. This is associated with the characteristics usually identified as 'free will'. Nevertheless, a successful system's life, in a physical sense must have a physical program for persistence of action, for survival. If it is not genetically pre-programmed, that program has to consist of a strategy. In time the strategy may become sterotyped (for example, regarding human social strategies in modern times, Aristotle illustrates a first effort to count the types of political systems), but it has not yet become so.† Thus one may seek a scale, an intellectual scale, at which strategies are reformed. Obviously, the individual and the individual culture are engaged constantly in defining such a process.

But is there a supracultural time scale related to reformations of social strategies? We suggest that such a change occurs at the few millennia time scale. Why? It is a property of nonlinear detecting and decision making in comprehending motion and change. McCulloch, for example, illustrated why the briefest reaction moment of the individual organism is made up of about three response units, e.g., 0.1 s to determine position, 0.1 s to determine velocity, 0.1 s to determine acceleration. Or, another example, it has been shown that business activity has a fluctuation time scale of the order of three years (see, for example, Dewey & Dakin, 1947). One can conjecture that investment and business activity decisions require a minimum observation of the yearly balance, but that–as before–3–4 units of independent binary decision units, one each year (e.g., yes–no) have to pass before a decision can be entrained by the nonlinear, discrete brain process. When it comes to social change, through cultures, an ecumene cannot change its outlook until a number of cultural changes have been observed.‡ In any case, we realize that these longer scales may very well be speculative.

However, the equation sets would apply to each spectral domain, starting from the shortest scale unit and integrating (or aggregating) up to the next unit scale.

Summary of the fluxes and potentials. Within each domain, as applied to living systems, the following conservations are involved in making up relevant equation sets:

energy flow (e.g., the daily caloric expenditure, roughly 2000 kcal/day for Man);

matter (loosely speaking, the conservation in the adult of the carbohydrate, fat, protein, minerals, ions, water content of the organism);

action modes [the 'factory day' budget of actions (energy–time product) that are characteristic of the species; e.g., among mammals, such behavioral modes are noted –ingestive, eliminative, sexual, care-giving, care-soliciting, conflict, imitative, shelter-seeking, investigatory behavior (Scott, in Havez, 1962); in humans, perhaps 20 modes are noted (Iberall & McCulloch, 1969)]; and

population (for systems that grow, live, die, conservation of the species requires that *invariably* generation begets generation).

†As of today we sense that the national polity of the sixteenth to twentieth centuries may still undergo evolution.

‡It seems only necessary to suggest, post Aristotle and Mencius, that civilizationists (e.g. almost all those identified with or by the ISCSC in its sessions) have proposed standard typologies of political evolution. It is not the rigid typology that I accept, but the underlying process of change, what it is that the cultural actors saw was necessary to move away from, if not precisely what to move to.

The following potentials (storage bins) are involved, as boundary conditions:†

temperature (the solar flux, interacting with earth's atmosphere, produces a temperature range that supports life and its ecological web. Both the solar flux and the atmospheric temperature represent governing potentials);

chemical potential (the earth, as substrate and depot, provides both materials, i.e., foodstuffs for building materials, etc., and energy, i.e., foodstuffs that produce energy by chemical reaction);

genetic potential (an internal chemical potential, carefully carried from generation to generation by germ cells in the form of a specific hereditary molecule, DNA);

geographic potential (the lithosphere, hydrosphere, atmosphere are available as substrate and surround to support life processes); and

epigenetic potential (another internal potential, emergent from the command–control system of living organisms. That system furnishes various competences for action, such as memory, stimulus bound responses to cognition, and in higher mammals, the basis for value systems which become central to the system's strategies for both individual and social behavior).

The general character of physical law is largely contained in the statement that potential gradients drive fluxes. This is almost tautological because the potentials are storage bins for the flux quantities. The physics becomes interesting when we explore how potentials come into being‡ and begin to drive fluxes within systems.

II. The construct specialized for Man

Tools–a new potential for hominids

Up to this point, the construct can deal with all living species, as systems. To extend this construct to Man with some greater detail–but still in a generalized fashion–we must make some modifications and additions to the conservations and potentials. First, retreating to Man's Plio–Pleistocene hominid ancestors, one finds an enlargement of their epigenetic potential. As evidenced by the appearance of tools, they begin to extend their mammalian and primate memory system to where it can be transmitted as an epigenetic heritage from generation to generation.§ We surmise that such epigenetic 'freedom' included a growth in value systems as part of the epigenetic heritage. We think it fair to say that a new internalized potential emerged within that hominid brain. Let us call the new hominid potential a technological rate potential. (Tools, we note, are found before modern Man's cultures.) This potential is represented by the capability of each generation to add additional

†That is, they act as forcing functions for the human species. Such study may not be convincing, at this time, to many social scientists, nevertheless many disciplines are currently being exposed to the general problem of nonlinear stability (see for example Gurel & Rössler, 1979; Helleman, 1980). In such physically-motivated theory, the emergent processes are not so sharply determinate as much as they are selections from two or more comparably probable paths of ensemble history. In fact this description being offered here is one of a number of competing descriptions. (To be noted in Gurel & Rössler, 1979; Helleman, 1980.)

‡Physicists genuinely find it interesting to determine how the cosmos becomes the nurturing source for galaxies, or galaxies for stars, or the sun for life. Comparably, no scientist could think that the identification of how the potentials came into being that drive modern society could be regarded as a trivial problem (e.g. how the epigenetic potential arose as a biophysical construct within the central nervous system of hominids).

§It is quite valid to concede that other animals exist who use 'tools' as an intermediary between self and outer world. However there is little evidence of epigenetic transmission from generation to generation as a learned process. Even in the case of higher apes, there is no explosive growth in the richness of their abstract language capability. Nim Chimpsky cannot debate Noam Chomsky on this subject.

tool-making complexity to the epigenetic heritage. The technological capability is likely best measured by the amplification in power handling capability of the individual. As far as we can tell, for the period of such tool evolution, e.g., perhaps two or more million years, that technological rate of increase has been grossly linear for Man's hominid ancestors. Each generation (e.g., measured in units of hundreds to thousands of generations) could make an equal increment change in tool complexity. We base that assertion on crudely estimating the gain in power-handling capability of the various evolutionary tool assemblages that have been identified with the past few million years (e.g., eoliths, hand axes, flakes, microliths). This will strike many as counterintuitive.

We assert that the technological rate potential is an independent component of the epigenetic potential because it represents a specific form of abstraction, beyond memory transmission, and because other components of an epigenetic heritage can be imagined independent of changing technology.†

Human social life: hunter–gatherer

However, the social life that emerges from those higher primate hominids hardly differs, at first, in general character from those of other higher species, e.g., mammals, primates. One surmises that one major difference, as these prehensilely facile, upright species gradually transformed from predominantly frugivore gatherers to omnivore hunter–gatherers, is a band organization of camps with a considerable division of labor (Steward, in Lowie, 1936), rather than the more common pecking order organization of these other species. Yet among primate social organizations, the gross social organization of hominids does not appear to be unusually different (Eisenberg, Muckenhirn & Rudran, 1972) at the beginning of cultural evolution. However later, by the final epoch of the Upper Paleolithic age, the emergence and differentiation of a new, human, organization is very great.

For the study of that problem, we turn to the specific species modern Man, fixed by an evolutionary process to the past 40,000 years. Whether the species *Homo sapiens sapiens* (who appeared then) and *Homo sapiens neanderthalensis* (who disappeared at about that time) were members of the same breeding pool, or the same species is not really known. Some significant anatomical features make them different, and there is a sharp difference in what has been identified with the characteristics of their cultures. We take the position that on the criteria of handedness (Iberall, 1973), change in speech capability (Lieberman, 1975), the distinctive change in tool making that marks Middle Paleolithic assemblages, and the appearance of abstract artifacts and symbolic art forms, as well as evidence for magico–religious social practices, such evidence points to association of these characteristics with a new species or breed, the current human species. This new species seems capable of all the performance of current Man, speech at 10 Hz neural rates,‡ abstraction, a much more rapid rate of technological development; in short human culture.§

Thus, we wish to bring the start of our boundary conditions up to that new species,

†There is a variety of evidence of cultures that transmit a learned heritage from generation to generation, yet show little or no change in their technological rate potential. One recently discovered example, Tasmania, involved a large 25,000 square mile isolated island on which the dwellers regressed over a period of about 5000 years in the use of a major technological mode of existence by fishing.

‡e.g., 10 phonemes per second.

§Note that in this section II we are focusing in on Man as a particular specialized species, but our treatment has not been specialized for a particular epoch. In the section that follows, we will begin to treat Man as a historical boundary value process, retreating back to his hominid ancestors. Our purpose, in that section, will be to pin down the source of a change in system's stability, in the emergence of civilization as Man's modern social strategy.

modern Man, emergent about 40,000 years ago with new tool assemblages and a richer technological potential (a higher rate of change) than the subspecies that came before. The new species begins as a highly competent hunter–gatherer. Evidence exists that within the subsequent 10,000–20,000 years, the species is spread lightly through all the continents (Prideaux, 1974) except possibly the Americas, to which the species crossed likely in more than one wave, with few reliable datings earlier than 10,000–15,000 B.P. (before present). Its highest latitudes are up into northern tundras.

Dynamic transitions in social field phenomena

The question we wish to address is why does a later series of discontinuous cultural changes occur wherein the species is subsequently found highly precipitated into place, 'sedentarized', and eventually organized into what we now call urbanized civilization? Note that from a physical point of view, the only potentials and fluxes available are the ones we have named. No sharp exogeneous force of a special character brings about the change. Why then the subsequent rapid social and cultural evolution?

We can ask two sub-questions. First, are there any analogous changes or forms known in the biological kingdom and second, what sort of physical process do the changes suggest? (Mathematically, it suggests an instability transition.)

With regard to the former, it is possible to analogize with regard to the plant kingdom wherein there are mobile phases of existence and finally a fixed existence, but much of that is related to the different way the woody plant is tied to its chemical potentials and to its different time scale for metabolism. Many more investigators have been attracted by the social insects who seem well-organized and secure as physical forms in place. There is little doubt that this insect analogy (model?) has inspired the creator (Wilson, 1971) and many of the proponents of sociobiology to their metaphor (that social adaption can be tied rather specifically to genetic encoding). However, the metaphor is still a far-fetched one for mammals, let alone people, because of the fact that much if not most of the behavior of these lower species is stimulus bound and they are limited in the capacity of their central nervous systems. The characteristics we seek are much more to be associated with the physical freeing of the central nervous systems of higher animals (Elliott, 1969), which because of their increased interneuronal richness become increasingly less bound in their behavior, take on increasing computational and storage capability, and which in the case of the Pleistocene hominids become explosive in their growth in cortical capacity. The contrary problem (the subject of the second question) is thus created (see, for example, Iberall & Wilkinson, 1984).

The very clear physical answer that this question foreshadows is that the problem of human social evolution is a matter of dynamic stability, one in which a transition takes place from one type of field process operation to another. Ever since pioneering work in elastic stability by Euler (e.g., the buckling of a column), in hydrodynamics by Reynolds (transition from laminar to turbulent flow), in mechanical orbits by Poincaré and Lyapounov, the subject of mechanistic stability has flourished, and it has been realized that the problem is associated with nonlinear dissipative processes. Recent conferences have assembled a large amount of material on the generality of the problem. We have offered a prior conjecture on its application to the social transition problem (Iberall & Soodak, 1978).

But there must be a biological and social cast to the answer. That cast is set by the social–behavioral strategy that the epigenetic freedom, fed by an abstract high speed linguistic capability, can 'light' on or condense upon. From a biological and physical point of view that strikes us as a key issue. The problem that has to be confronted is to translate this physical process of instability transition into terms that can be recognized as applicable in the social sciences.†

III. The transition process toward civilization

Beginning anew–hominids and tools

In this section, we begin the study of the boundary value problem of modern Man. It is clear from what we have said that the initial epoch of modern Man, 40,000–20,000 years ago say, was represented by a style of life not much different from other earlier hominid species or, except for the particular band characteristics that anthropologists identify (Steward, in Lowie, 1936; Service, 1975; Iberall, Soodak & Arensberg, 1980), much different from many other modern primate species (Eisenberg, Muckenhirn & Rudran, 1972). This is true even though specific human cultural artifacts can be found.

What was that style of life, particularly as described in a physical sense? We begin our lead-in from earlier hominid ancestors.

Even before knowledge was available for a conceivable evolutionary progression of hominid species, it had been possible to distinguish a difference between Paleolithic, Mesolithic, and Neolithic tool assemblages, and in the Paleolithic, between Upper, Middle, and Lower periods. Even though accompanied by a great deal of uncertainty, it has been possible to conjecture the life-style from a knowledge of the tool assemblages, the climate, the geography, and the available ecological web. We, of course, are concerned with human transitions, and we can speak–in an ergodic sense‡–with some authority for the human processes of thought (we are human). But to the modest extent we wish to invoke one particular thought process, we can surmise it to hold for Man's tool-using ancestors. In particular we surmise that evolution of tools is simply not a process that follows automatically in time upon the thought process, but that in general, there are perceived needs and the hominid brain–dealing in abstraction–creates tools as abstractions and manipulates their modifications to deal with those needs. (Animals can distinguish self and other than self. That is they possess such world images of an inner world and an outer world. Recent work, on recognizing self in mirrors and as objects of manipulation, have begun to clarify the existence of graded differences in higher apes. Thus evidence is building up for the graded

†*One more potential: value systems.* To serve as one note of introduction, we would like to offer both social scientist and physical scientist some preliminary notion of the content of the epigenetic value potential. Certainly this is the strangest potential from a physical point of view and also one that social scientists have not attempted to completely qualify. Yet it is a potential whose qualification we had begun to discuss with the political scientist Harold Lasswell because of a common recognition of the need.

Tentatively, we would view the manifold dimensionality of the epigenetic potential (as a value system) as consisting of a world image:

(a) of self;
(b) of interpersonal relationship;
(c) of nature;
(d) of society;
(e) of ritual and institution;
(f) of other living organisms;
(g) of technology, more broadly of culture;
(h) of spiritual causality (fathers, leaders, gods) and
(i) of art forms (abstract representations designed to attract attention within sensory modes).

This potential, via its many dimensions, guides the ordering of the action modes.

‡The ergodic hypothesis involves the similarity of spatial averages in an ensemble of mobile atomisms and temporal averages at arbitrary points in the field. Here, far removed in time from our human ancestors, we use our knowledge of ourselves to surmise *one* of their thought processes. Without some such process, no chance for communicational and descriptional, including scientific, metaphor could exist. Language not only commands action, but it also evokes perceptions (Iberall, Soodak & Arensberg, 1980).

difference in abstraction abilities among primates. Nevertheless it is still one further step of abstraction when hominid primates began to incorporate an epigenetic heritage of tool using into their regular existence. A tool is neither self nor outer world, but an object which can be precisely manipulated between self and outer world to affect motor and sensory competences. The triangular relationship is an abstraction.) But the continued evolution of such tools has to follow additionally perceived needs. Nevertheless, while an epigenetic heritage including tools can exist, it may exist within a 'traditional' culture without change in tool making. Thus clearly there was social pressure to evolve tools. At the present we can only infer the character of the pressure from the direction that the tool types took, and only guess at its possible relation to the changing climatic–geographic potentials.

We can quickly jump to the Lower Paleolithic hand axe, which emerged in the mid-Pleistocene. This tool type is basically associated with *Homo erectus*. It was the leading tool over an immense period of time for much of the territory in which that species has been found. (Perhaps 500,000–100,000 B.P., not as far north as modern Man, but up to the northern-most latitudes of the Black and Caspian Seas in Eurasia (but not east of India), and in Africa (Clark, 1967; Hawkes, 1963). Tool evolution existed over that immense period, but it was not exceptionally rapid. This is viewed as one of the indicators of the cultural unity among Paleolithic hominids.

This brings us to Middle Paleolithic traditions, which emerged in the late Pleistocene. This epoch is basically associated with Neanderthal Man, now named *Homo sapiens neanderthalensis*. By being so designated, it is increasingly considered to be an early subspecies, later largely extinct, which preceded the current subspecies *Homo sapiens sapiens*.† The Neanderthal subspecies of hominid, associated with Mousterian and Levalloisian tool traditions, were dominant over the period 100,000–50,000 B.P., and has been found even further north in Eurasia (Klein, 1973).

Transition to modern Man and his tools

With the passing of these Neanderthalers, a change in tool evolution is usually found. It is marked by a predominance of flint tools based on the newer production of flakes. Instead of producing one tool from a large flint core, the newer tool-worker produced a diversity of implements by the continued flaking of small pieces from such a core. The new tool technique soon widely diffused throughout the hand axe province of earlier times. Although the time scale of this change is much more rapid, the succession of flake industries was still not precipitous. However, the data base available and the scatter in type of tool is still not extensive enough to let us detail changes at the level of a few millennia at a time. Nevertheless, the important characteristic of that type of tool change is that it is an advance in the tool making rate potential, and that it accompanied (and indeed perhaps made possible) a significant extension of the range of human settlement to colder climes, and it accompanied an extension of the hunting–gathering capability of the hominid species.

Can we not jump immediately, then, to modern Man, a new subspecies who somehow may have lived contemporaneously with Neanderthal for some overlapping period, but then proceeded by some unknown *legerdemain* to have knocked out Neanderthal's sharing or competing for the same niche, by virtue say of superior hunting and killing tools? That is a common impression left in popular literature. However, more recent studies, relevant to the emergence of civilization have brought in more perplexing detail to the transition to modernity. A sharper picture of the transition to civilization has come to require greater

† A popular but authoritative summary of current views about the Neanderthalers is given by Trinkaus (1980).

detailing in all occupied earth regions of the conditions of the Lower Paleolithic 250,000–100,000 B.P., and the Middle Paleolithic 100,000–30,000 B.P. period including detailing of ecological conditions and to suggest more than a single theater of change.

Detailing transitions in the Nile valley

A case in point is the Nile valley pre-history (Hoffman, 1979; see also Wendorf & Schild, 1976; McCauley *et al.*, 1982; Haynes, 1982). History and evolution there was dominated by climate, just as in the northern Eurasian development. We begin our transitional test problem in this region. For example, we may start by noting that the area had a drought from about 500,000 B.P. to about 120,000 B.P. Eolithic tools are found in the Nile valley. They have a lower Pleistocene date of about 700,000 B.P., associated with a rainy period. Dating to about 500,000 B.P., hand-axe traditions are found. One can conceive (as pure speculation) that the hominid path of diffusion, of population, of tool making, might have spread through the Nile valley from southern and eastern Africa to the Near East in an earlier period.

It appears that with the end of the drought and the beginning of a new pluvial age, the Abbassian (lasting from 120,000 to 90,000 B.P.), the late Acheulean (hand axe) hominids spread from the limited oases more broadly into the former desert wastes in search of large grazing animals. (We will make the point that each time such weather changes have taken place, e.g., the later withdrawal of the glaciers in Europe about 10,000–12,000 B.P., both plants and grazing animals disperse as more broadly wetter regions appear, and tool using hominids are forced by necessity to adapt their food-searching style. What is interesting about this instance, earlier than the one we had discussed previously, is that it indicates the pressure on an earlier tool-using hominid to find related solutions and make some sort of life style transition.) The hominids that were involved were those making a transition between *Homo erectus* and *Homo sapiens neanderthalensis.* One begins to find some of the earliest evidence of houselike structures. The suggestion is that these Acheuleans ventured seasonally into the open grasslands and retreated to permanent watering holes during the dry season.

The Abbassian pluvial was followed by drying desert conditions in the entire Sahara. The Neanderthalers took refuge in the great oases of the Nile valley. At about this time, that species of *Homo* began to exhibit the Levalloisian tool-flaking tradition in Africa as well as in Europe. One type of tool that may have been of revolutionary importance in hunting efficiency was the stone projectile point. This could be hafted to wooden shafts to make a hunting spear far superior to the fire-hardened wooden spear used earlier. (Just as in northern climates, these flakes could be used as scrapers to prepare furs for clothing.)

One senses that each such technological advance, made out of the necessities of a particular climatic era, had a capability of flowering in a subsequent age if the climatic changes were suited.

Thus, the Mousterian pluvial, a period 50,000–30,000 B.P., was ushered in a Sahara much more lush than in the earlier pluvial. The Neanderthalers colonized every available niche in North Africa. (Just as they were spread across Eurasia.) Rooted in this culture, one finds the Aterian Industry, viewed as being contemporaneous with middle Paleolithic cultures in Europe, dating back to over 40,000 B.P., with a demise just under 30,000 B.P. This interpretation is new. It demonstrates a slow but fairly continuous development of middle Paleolithic to upper Paleolithic culture. While the Aterians (who are *Homo sapiens sapiens*) had a somewhat better tool assemblage than did the Mousterians, it seems that they co-existed in a cultural mosaic during much of the Mousterian pluvial. 'The side-by-side persistence of strikingly different technological (and possibly cultural?) traditions is not unique to this period in Egypt but, as we shall see, characterizes the late Paleolithic sequence in the Kom Ombo Plain in southern Upper Egypt and probably continued through predynastic times to be echoed in Dynastic traditions of the cultural duality of Upper and Lower Egypt', Hoffman (1979).

This seems to be an example of the kind of prehistory revisionism in progress. [An earlier example in the mid-60s was the work of the Binfords on Mousterian settlement traditions (Binford & Binford, 1966; 1968)]. A great deal of overlapping cultural diversity existed on the savannas and oases of Middle Paleolithic north-eastern Africa.

Thus we now must confront the question we raised before. Why should a discontinuous change in social characteristics take place? The new species, modern Man, has existed and been in place for at least 10,000 years, nominally 40,000–30,000 B.P. We wish to examine the question in the light of our previous comments about stability transformations, related not to the outer space of physical 'motional' variables, but to the inner space of psycho-physiological, nevertheless internalized physical variables. In physical parlance, such internal rearrangements, new associational or configurational transformations, are the subject of new phase condensations. A gas-like phase of matter in motion is becoming a liquid-like, gel-like matter phase.

Transition to agriculture in the Nile valley

We cannot attempt to develop (or master or wait for) the discovery of all the detail that refers to this and other theaters of prehistoric culture change. (A few references that enrich those histories are indicated in the References by *.) But the basic descriptive need, as a data base, is sufficient information to begin to trace the story of change and transition from, say, 30,000 B.P., 2000 years at a time, down to 4000 B.P. when the historical period is safely in hand. The period of interest (as the lead-in) is likely the historical period of evolution of modern man 40,000–30,000 B.P. as it was related to the climate of that period (e.g., glaciated in northern Eurasia, pluvial in Northern Africa), the diffusion of that species, and of the tool assemblages, and the whole ecology available for support of a human cultural life. Then the question is to what extent can regional predictions be made, as we have suggested, as a transition from one strategy of social conduct to another.

It would be one of our key theses that the basic relaxation process, by two millennia segments, would be a changing perception of how to conduct a life style, i.e. a social–behavioral strategy. Could social physical reasoning track such changes?

That may be. The problem we face here is to offer some sort of physical theory for the transition that took place in that time slot, say 30,000–4000 B.P., and related to the operational boundary conditions 40,000–30,000 B.P., given the conservations, their fluxes and the potentials we have named (see, for example Iberall & Wilkinson, 1984).

It seems clear that the transitions we are concerned with are phase transitions, transitions like the condensation of matter from gas to liquid to solid phases. First, how would we describe Man the earlier hunter–gatherer? Similar to most other mammalian species, Man operated in a hunting range, appropriate to his size and metabolism (there being moderate differences in such ranges for carnivores and frugivores). At slow rates, he diffused over a wide habitat. Climatic conditions, and thereby ecological conditions, in the main, governed that diffusive habitat. All this is essentially straightforward results of biological–ecological processes.

Physically that diffusion, with its near isolation of small bands, e.g., typical band separations on large land masses were of the order of 70–100 miles,† can be considered to be nearly gas-like motion, like that of a two-dimensional gas. Its mean free path was of the order of one roaming range, e.g., 25 miles; its relaxation time was of the order of one generation, e.g., 25 years. Thus its propagation speed was of the order of one mile per year (van Doren Stern, 1969). 'Information' (cultural information) could hardly be propagated at higher speed.

But note that low potentials of temperature and water and food would always cause condensation. A note on this is desirable.

One might think that diversity of form and complexity is associated with high energy. This is not the case. At high energy, e.g., high kinetic energy, systems move towards a gaseous phase. All low-energy bonds are broken. Remaining degrees of freedom of motion are each equally endowed (equipartitioning) with energy. It is only at low temperature (low kinetic energy), as Einstein showed for the specific heat of matter at low temperature, that the same energy has to make do for many ordered configurations. Co-operative co-ordinative phenomena take place; order is imposed, authority is established. Thus matter in condensation, e.g., in liquid and solid states, in the phases in which attractive forces become significant, always exhibit more diversity and complexity of order than it does in the gaseous state.‡

All species will respond to a poverty of potentials by some sort of condensation, in extreme cases in very great changes in sociochemical form. In each case, it is the internal potentials, e.g., genetic, that will select the potential condensation path. Hominids, with an additional epigenetic and tool making potential, have always adapted by means of all three potentials (genetic, epigenetic, the rate of change of technology).

The very nature of the extreme climatic changes that took place puts the major action in the Northern temperate zone in Eurasia, from northern tundra limits (dominated by the Scandinavian ice sheet), and Northern Africa, just as a later date–when Man enters the Americas–another play takes place in that continental mass.

In the African case, it is the alternation of wet and dry which drives Man toward oases and toward dispersals. Likely as a universal theme, the more promising condensations are the populations driven toward river valleys, driven invariably to search for reliable water supplies. Of all the chemical potentials, oxygen pressure (variation with altitude), and then water are the most pressing (followed by temperature).

But the nature of the social-phase condensation depends on the state of the technological potential. What the new Egyptian story indicates is that the potential for significant condensation already existed in the Neanderthal–modern Man transitional period. The adaption, by necessity of the wide variety of mid-Paleolithic tool industries is indicative of such capability.

What can come out of these two driving potentials–change in water potential, change in

†These numbers were estimated from the number of independent cultures that have been identified in two large land regions, the Americas and Australia (the latter by Birdsell). However their interpretation is as follows: If, appropriate to his mammalian size, Man has a predictable metabolism and a reasonably predictable roaming range, e.g. 25 miles per day, then one would sense that center-separations of cultures of the order of 50 miles (or perhaps better measured by river-valley separations) would represent very little interactions. In physics, they would be viewed as long-range interactions. 'Proof' of that thesis is Murdock's identification that a distance of a few hundred miles represents almost complete cultural independence. Thus the 70–100 miles empirically found is highly suggestive of weak force 'gas-like' interactions, in which the human bands correspond to social molecularities.

‡We ask that social scientists dwell on this point. As Sahlins (1972) pointed out, pre-agricultural Man did not live by a more strenuous life pattern than agricultural Man. He lived with sparser density and with few possessions. Life at higher densities involves a greater 'efficiency' in all processes. The same potential capacity (e.g. sunlight) must make do for multiple purposes. It is difficult to decide whether such life is 'good' or 'bad'. The only thing certain is that the interactional processes are faster, more intense. (Example? Your walking speed is greater in a big city than it is in a small one.)

technological potential? Either cleverer adaptations of tools and modes of living–and there is ample evidence around the earth for such processes, or condensation in place via domestication and 'sedentarization'. The domestication of plants and animals, later the harnessing of water resources, and still later the harnessing of all available resources has become the pathway that Man is pursuing now. (In the future, he may seek to pursue genetic modification as one additional pathway for adaption.)

Thus, we would submit, that with these two changing potentials, the water resource on earth and the state of the technological resource within Man, it is only a matter of time and place for condensation into fixed agriculture to occur,† a liquid-like condensation. We believe critical detailed study could establish much more precisely criteria for such a transition, detailing even more precisely when or where it may have occurred (Flannery, 1973; Struever, 1971). In Europe, its occurrence relates to the end of the glacial age 10,000 B.P.; in northern Africa to the 9000–4500 pluvial age. In both cases, the new condensation related to the changed water supplies and the existing technology.

But the empirical data seem to foreshadow our theoretical result. The process of transition is (a) neither so difficult to occur, nor (b) so guaranteed to be lasting. Note that all that is required is for Man to adapt his action-modes of behavior to those of the species he wishes to domesticate, for example following migratory herds, and to put some selection pressure on the species to push the domesticate to adapt toward his own action modes. As such symbioses are very common in the biological world, domestication was hardly a novel invention. But Man brought to it an epigenetic memory of time and place and of sequential ordering which must have proved quite useful. Since these were the attributes that Man already had, the age long genetic adaption process did not have to take place at the more usual million year genetic evolution on the scale of species emergence, but could be foregone. Instead a facilitated diffusion speeded up a thousand-fold to thousand-year scaling could emerge. That is one striking difference between the genetic and the epigenetic process.‡

Agriculture and settlement generally

Thus, near self-sufficient agriculture could emerge in the Nile valley, in the Tigris–Euphrates valley, in the Americas, elsewhere in Africa, in the Asian steppes (and be given up), in the Indus valley, in China. Were all these independent emergences, or diffusively propagated? The question requires expert detailed study. Some were independent, others derivative. For example, the diffusive spread of agriculture over Europe at the millennial scale has been carefully documented (Cavelli-Sporza, 1974).

The emergence of a settled life and of a dependence on cultivation took a time as extensive as the period of perhaps 20,000–10,000 B.P. Without a great deal of local detailing, there is no reason to expect any lesser period of transition, and one would expect only very spotty beginnings. Thus it is no surprise that a significant *threshold* for the startup of agriculture is given by about 10,000 B.P. (Flannery, 1973), and that it is associated with major changes in water potential. In the Eurasian region, one would associate it with the withdrawal of the glaciers (end of the last ice age), dated loosely 12,000–10,000 B.P., and the dispersion of the melting front, grasses, grazers, predators, toward new 'permanent' water supplies, e.g., river valleys, well watered mountain flanks, lakes, springs. In Africa, one would associate it with wet–dry periods loosely concomitant to glacial changes, with condensation and radiation alternating in moves toward more permanent water supplies.

†E.g. with horticulture leading the transition.

‡Physics is full of many such cases, where the same kind of process, e.g. diffusion, propagation, convection, takes place as the same kind of mechanism but at more than one scaling. That is why we claim that there are few principles in physics, because they remain topologically similar.

In the Americas, with a time delay to master the land,† we can see multiple starts at a later date.

Thus, the self-sufficient agricultural village, located strategically with regard to water supplies became a new feature of the earth's social landscape for Man. The village unit grew up interspersed in some regions mosaic-like among hunter–gatherers.

Transition toward civilization

In general, what one appeared to see prior to civilization was a deterioration of environmental conditions, a pressure for technological innovation, regionalization of social groups, a mosaic of cultural types. These arose as sympatric societies–various cultures occupying roughtly the same niche, basically using different tool traditions, and with modest separation, i.e., latent condensations. In a physical context, one would say two or more atomistic type fluid-like assemblages coexisted in the field (solvent, solute?) in which one kind of precipitated out group (already condensed, or nearly condensed) could take over the superior role and would either force the other groups into opposition, or dispersal (unlikely), or absorb them into the growing condensation.

This occurred, hypothetically, as the Mousterian–Cro-Magnon transition (e.g., 50,000–40,000 B.P. (see ApSimon, 1980)); in the hunter–gatherer to agriculturist transition (e.g., 20,000–10,000 B.P.); it may have happened in various agriculturist–nomad transitions either way; it may have occurred in the Acheulean–Mousterian transition (likely a *Homo–Homo* transition), even in the eolithic–Acheulean transition (still an X-*Homo* transition, as far as the certain record of hominid types is concerned); and it occurred in the agriculturist–civilizational transition (e.g., 8000–5000 B.P.) of Neolithic and later times.‡

IV. Civilization, a second transition: the appearance of a new conservation

Given these two possible social forms–hunterer–gatherer, agricultural village settlement (also forest efficiencies and pastoralist nomads)–why was there any need for any further transitions? There is obviously pressure for continuing evolution of agriculture-based technology, as well as dwellings, clothing, further domestication. But why any further transitions? Are there needs that dominate?

Such village settlement condensations, although they are liquid-like, that is no longer with 70–100 mile separations, are not all founded in perfect strategic locations. The greater permanence of food supply, with agriculture, unlike with mobile hunting–gathering, provides greatly enhanced free energy for further system evolution and permits an appreciable growth in local population and its density. Settlements' separation can now be less than roaming range, i.e., they are less than 25–50 miles apart. But now, again, mutual needs–for materials, for breeding population, for alliances against human predation, for security from climatic vicissitudes, for common support against perceived uncertainties–all make some form of trading interaction necessary. But now, since the settlement is fixed, the materials of trade have to be carried. A fluid-like flow process known to physics as convection becomes involved, and a fundamentally new conservation, value-in-trade (or in-exchange), arises.

†The Americas seemed to have been a new continent for Man.

‡Our remarks here are not meant to suggest novel social competitions to the archeologist, who knows them much better than we, who are dependent on secondary sources. However we are trying to stress the point of flow transitions and phase transitions, as problems in social field stability. We recall having heard R. B. Lee conduct such a stability discussion, from a Marxian perspective, as to the relative stability of an agriculturist way of life as opposed to a hunter–gatherer way of life in a current African case. But rather than argue the transition by the mysticism of dialectical materialism, we call attention to stability as studied within mathematical physics.

It is a remarkable consequence of the mathematics of physical interaction that, in an interacting field, there are only three types of field processes–diffusive, wave propagative, and convective.† The first two are linear, the third is nonlinear. (Only the third is described by the nonlinear product of the field carrier's variable, i.e., velocity, and by the measure of what is carried, e.g., energy, momentum, matter, population, action, or more conveniently value-in-trade.)

In mathematical physical theory, there is an interesting consequence of having the combination of nonlinear and dissipative processes (the diffusions involve energy dissipation. What diffusion means is not disappearance of energy, which is a conservation, but its dispersion, thermodynamically, among various participants). New singular states of motion may arise, as stability transitions (Gurel & Rössler, 1979; Helleman, 1980). Generally these singular states become relieved by the appearance of new cyclic processes.

Notice that the appearance of appreciable convective trade (e.g. as a regular cyclic process) does *not* involve a new matter condensation–after all the settlements have already provided condensation–but a new social mechanism and format for movement and change throughout the field. The question is how does the human social process respond to the new internal pressure which generates the trade?

One must dwell on the requirement for social cohesion in any population center. People must recognize each other and have a basis for social bonding. Such a recognition and bonding process is well represented within the agricultural village (it probably limits the size to less than 500, a rough count of the number of faces that can be recognized (Pfeiffer, 1969). Primate social ordering (see Eisenberg *et al.*, 1972) or the more specialized hominid band formation (Iberall, Soodak & Arensberg, 1980) suggest that 'traditional' kinds of village leadership that may emerge, and the variety of possible dependences on kinship and hereditary and appointed occupations emergent from a division of labor (see Murdock, 1967).

Trade and a new conservation–value in-trade

But now with convective fluid forces emergent from internal gradients, there is pressure to permit the foreigner in for trade. Diffusion coefficients still prevail to govern conductances (a tautological statement–diffusion coefficients are measures of the conductance), but they are now facilitated diffusions. For those familiar with hydrodynamic and engineering fluid mechanical concepts, these diffusions are no longer molecular diffusions (e.g., person to person Brownian motion, per Einstein) but eddy diffusions. They are carried by the field fluxes, not by the individual atomisms. The processes are intensified, speeded up by groups, not solely by individual participants. We will now make the required connection to the central theme of social evolution among humans.

What is the essential nature of civilization? As we heard the themes in the 1979 ISCSC session on origins of civilization, it is a source of argument whether religion, or agriculture, or urban settlement, or trade, or literacy, or recorded tradition, etc., is the essential causal ingredient for civilization. Let us go to the dictionary for what is the central ingredient identified in civilization. It appears to be the notion of *civitas*‡–the existence of a formal set of objective rules that clearly set forth to the onlooker, whether insider or outsider, what the relations are that govern hierarchical, heterarchical, or stratified class members that are permitted physical access to the society; e.g., ruler–citizen, master–slave, citizen–citizen, citizen–outsider, etc. It is rules of civil organization.

†In addition, there also exists the physical–chemical process of transformation of atomistic type. However this can be related to a diffusive process.

‡A community of people politically organized.

Perhaps strange to both physical and social scientist alike, that set of formal constraints, as 'political' (flow of authority; for example, see Lasswell, 1958) constraints, determines the impedances or conductances (diffusions) to flow. Diffusions are no longer solely physically determined, but facilitated or impeded by man-made law.†

It is quite interesting, with written language going back to perhaps 5000–5500 B.P., very largely recording person to person transactions (or extolling the deeds of ruler elites), that by about 4400–3700 B.P., we find the first recorded codes governing largely class relations in the urban city–state which clearly emerges as an equipollent or heterarchical element in civilizations with the emergence of empires (ensembles) of city–states. It would be very impressive to push such city–state codes back another milennium, or even more impressive —in sharpness of transition—if such codes were found 'recorded' (instead of simply implied) for the period of about 8000 B.P. (or at the outside 10,000 B.P.),‡ but we have to allow the possibility of a number of two millennia relaxations for Man to make such drastic transitions. At the present, we cannot offer any greater precision in social scaling. An agricultural (effective) startup of 10,000 B.P. could not be accompanied by further hydrodynamic stability transitions in fewer than a few such relaxations.

How is such rationalization effected? (Rationalization—I adopt the creation of bureaucratic institutionalized forms by which human actions are regulated, e.g., laws.) It obviously involves abstractions, a functional performance which can be spewed out of human mind with great ease. But how to endow it so that it has . . . value!!

It would seem perfectly plausible that Man, as Man, with cultural symbols from his beginning (even with indications of their beginnings in Neanderthalers), could accept, in fact had to accept, value systems. (Why *had* to? Because of the new freedom of abstraction in the brain, which would permit him both to time delay and form arbitrary 'linguistic' associations.) So magico–religion became one such value system—e.g., shaman and totem and tabu, and ritual.§ And similarly, pursuing its epigenetic evolution, agricultural systems and later urban systems required much more complex 'totems'. It is hardly accidental that ziggurats in the Tigris–Euphrates mark some of the earliest structures in that urban explosion, or the probable evidence of religious formalism in Catal Huyuk (Eliade, 1978). So certainly a particular explicit form (structurally institutionalized religion) emerges quite early in civilizational interaction.

As judged by the archeological record, civilizational interaction now begins when there is extensive convection of trade among population concentration (urban) centers.¶ (They would be marked by populations greater than 500; e.g., composite groups in which appreciably more than a threshold of perhaps 2500 persons were involved. The latter number was estimated from a cut off of complex cultures of about this size in Murdock (1967), it is confirmed by the earliest trading constellations known in Anatolia and Armenia.) But that

†Note how many additional relationships have to be called into being as a result of 'freely' admitting stranger. Internal police, rules of conduct, external military, class processes, records—all of these become necessities for governing the social intercourse.

‡See for example the new conjectures of Schmandt–Besserat (1978). Since the subject of language and communication has not been touched on suitably in this essay, an explanatory note has been appended.

§A period 40,000 B.P. is rather remote from the present. Nevertheless current findings still seem to suggest a rather sharp transition from Mousterian tool traditions to the tool traditions of modern Man. At least this appears to be true for any account by evolutionary changes. Nevertheless in what appears to be a very short time, as measured on an evolutionary scale, sophisticated cultural artifacts have been found dated back to 35,000 B.P. followed by rapid growth in their number with time. These artifacts are no longer simple 'manipulative' tools. They seem easily associated with internal value systems.

¶We note, and are willing to accept, a common anthropological definition such as cities or urban centers are spatially fixed aggregations of occupational specialists who do not produce their own food.

convective interaction involves stranger and insider. It can no longer be governed by accepted tradition (an oral heritage accepted by all internal parties, as in the family, or in the local isolated village). Thus an objective symbolism must be invented. Using what? Using the intensive store of epigenetic value, but now externalized into value-in-trade, a symbolic form invented out of mind and endowed with value for all transactions. All other *real* conservations can be traded for using this idealistic conservation. The basic rule is that in each transaction, 'equal' value is traded (by whatever defines equality of value at the moment). Thus the economic conservation is invented, comes into being out of mind. With it arises a pricing system. And with it arises also the utter terror of inflation, a runaway value system. As Pareto (1963) explained, it is acceptable for society to pull the rug from out under its value-in-trade system as long as the next generation of players is not discouraged from play.

This hopefully introduces, by physical reasoning, the economic variable into a social physics as one additional and final conservation.

Civilization—a field process based on five conservations

In summary, we have not short-changed the images presented by the social sciences, only brought them into a more rounded ring of completeness. It is no longer necessary to add the restrictive proviso of 'all other factors being held constant'. We have indicated that a social model cannot be created as an independent demographic model, or a closed pure economic model, or a psychophysiological (or cultural) model of human activities, or an 'engineer's' energy model, or a chemists' material balance, but as a linked chain of all five compartments. (Plus, of course, the driving fluxes, some outside, some inside).

V. On the failure of civilizations

Why a system fails requires a great deal of study of all of the conservations that go to make up the description of the autonomous functioning of the system. Just as in a possible explanation for the life span of a living system, we would have to write another paper. However we can very briefly give some clues to our perceptions of the problem.

An optimistic note that each adolescent generation brings anew to the social experience, that this is the life, that the now of this lifetime is the only one that counts, is doomed to failure. Why? Because the system is thermodynamically unstable. The *why* of that instability is a basic piece of physical reasoning.

The young diffuse into society, diffuse and bind into its nested hierarchical institutions —family, neighborhood, local political community (now largely either urban or rural), national political community, acquire an epigenetic heritage, and gradually take on the roles of the adults they displace and replace. That turnover guarantees practically no new successes. The problems of the past are propagated, new ones are added. The conservations that have to be satisfied remain the same, what each generation does not learn is the total operational wisdom that the past generation may have acquired. That seems to take a lifetime segment of perhaps 20–40–60 years to learn something about.† In traditional societies, in which movement is slow (movement from outside), the old can act as ambulatory memories on how things are best done. The integration of notions of how to deal with complex social systems in which the convective currents (e.g., daily, weekly, monthly, yearly, per generation) are largely and constantly changing with vicissitudes is not quickly learned. It seems to be a limitation of human mind. Most elite leaders are thrown into their basically abstract reasoning role in society with less than 20 years of experience past their adolescent growth.

†A study of history seemed to confirm the ergodicity of this result. There seems little change in the range of human capability exhibited in all reported historical epochs.

Their reactions seems to be based on the biological motor-sensory responses of the moment. A political horizon of 6 months to 1 year is and has been the most common characteristic of Man since civilization began. That turnover period is fine and fits the agricultural village or the hunter–gatherer society to a tee. In such societies, the only conservations that have to be satisfied are materials, energy, and action modes. In such societies some attention has to be paid by ambulatory memories to the reproductive balance; the biological action mode of sexing itself is no issue. Each generation of young comes superbly prepared to quickly learn the mode, if necessary by trial and error. So the social action, if any, is to regulate and control the issue of childbirth. Under these circumstances, the need for longer-range planning or information, of an abstract nature, about the total value system as a potential, can be left to a few—leaders, elders, shamans, priests.

But face the issue in civilizations, with the continued influx of strangers and trade, and the requirement for symbolic balance in trade, requiring responsiveness to ever changing external conditions. Now one requires each youthful generation to develop a fantastic amount of action capability to deal with a complex series of interactions. As usual, it is not the populace who are concerned with the mastery of such operation but an 'elite' structure, if you will a new form of 'priesthood'. As usual, from the nature of command–control systems, such operation is confined in an elite of a few percent of the population.

But they are not biological queen bees, endowed by some royal jelly with special powers. They are ordinary human beings, the same youth as the more plebian followers. As young priests of the market place—whether in feudal societies, or commercial, or capitalistic, or communistic, or socialistic, or dictatorships, or anarchies—they cannot and do not learn how to operate a complex society. That literally requires understanding and controlling conservational balances for periods of the order of 1–3 generations, the period which comes close to measuring social equilibrium. In civilizations, that balance problem also involves high expectation of major wars per generation in the ecumene. Civilizations, from their beginnings, involve alternations of trade and war, commonly war each generation.

The issue, further, is that not only must the elite leader understand how to strike all the necessary balances for such periods, but he must convince the people, his followers, to follow out the requirements so posed. Over one year he can do it; for three years (e.g., the common political process), he can do it. But to impose the kind of rational regulation and control required for longer periods, he cannot succeed. The political leader (or other elites) can supply a schema for rationalization (the hallmark of civilization); he cannot succeed in supplying a schema for rationality, even if he succeeds in creating a dynasty.

And so periodically, the overall mismanagement of the social system catches up with itself and the system tumbles. We have no real belief that we can make more than a hand-waving estimate of that time scale at this time, but it also seems to come out—by any reasonable theory—to be of the order of 500 years. It takes perhaps 20-odd generations of elites before the mismatch produces incoherence.

But the societal members and local institutions, e.g., family, local agricultural community, is still designed for the year operation. So even when civilizations tumble, or come apart, or reform, as Sorokin pointed out, the local units largely survive intact, and begin the task of putting together a new form. And so on it goes, and has to go on for this biological species. This could be referred to as an 'error' theory of aging and dissolution or 'death' of civilizations.

[A public critique of this section in a meeting of civilizationists during a session on Terminations of Civilizations brought up two points. One was that skill or wisdom was not necessarily proportional to age or experience. The second was the question of why an accumulation of complex problems would occur to limit the age of coherency of a civilization. With regard to the first we indicated that we could only offer an *a priori* notion of the distribution function for managerial skills. We had tried the question on various R and D and corporate (and political) managers we knew, and found the same answer –a near linear growth (say from entrance into the system, e.g. 25 years of age) to modest competence a decade later (say 35 years), increased competence two decades later (45 years), peak competence three decades later (55 years), equal or lesser competence four decades later (65 years), and diminishing thereafter. The latter age drooping competences were largely due, in respondents' opinions, not to loss in competence, but loss in interest. However we concurred that such judgments should be sought by historians from competent political leaders about the leaders of prior ages. (Parenthetically, they all agreed that the age distribution for scientific inventiveness was quite different.)

With regard to the second question, we offered the notion that a model for civilization involved a startup phase, a life phase, and a deterioration phase. Elites acted twice. In the start-up phase, their actions helped to build the system. In the deterioration phase, their actions led to the system's deterioration. Various historical examples were cited. The basic issue was less the experience–age distribution function of the individual leader–elite, but the limited nature of the individual's judgment. What works in one context, e.g. start-up, does not necessarily work in another, e.g. a time of troubles. After invoking a range of processes, the responses became stereotypic. In a simple hydrodynamic instability, there may only be two paths to select; in the electrohydrodynamic instability of human brain, at most there may be a handful of paths. These views about brain selections may tend to sound mechanistic. They are. That is what we are stressing. The vaunted originality of the human brain has very severe limits. Why else, for example, does one expect to find war every generation in the ecumene? However we believe that the mechanism of failure is also associated with temporal processes within the ecological milieu.]

VI. A note on the role of language

Even though this physical construct may strike the reader who takes this essay seriously (whether from a physical scientific or social scientific point of view), as quite parsimonious and 'rich', he or she might nevertheless sense a need to raise the question as to where and how language and communication arises within a thermodynamic construct for systems? After all, it is commonly claimed, civilizations begins with (or nearly begins with, as Schmandt-Besserat (1978) suggests) transactional records (e.g. who transacted with whom). The following note sketchily places the missing theme.

Language is a property of complex atomisms, not of simple atomisms. It is not a conservation, a fundamental property of mechanics that 'creates' thermodynamics, yet it is associated with satisfying the conservations of complex systems. The control of the ring of action modes of a system of complex atomisms–both for the individual and for the social ensemble–is achieved 'catalytically' by an onboard command–control system which is part of the atomistic system's thermodynamic machinery. Stent, for example, has very elegantly demonstrated the nature of such command–control in leech. The catalyst (system requiring small energy) that controls the switching and evoking among modes (in humans, identified with cognition–see Chomsky's discussion (in Piattelli-Palmarini, 1980) if you consider this description far-fetched) is language. Language is used in both an internal and external mode of command-control.

In complex thermodynamic systems, language is developed by means of whatever materials are at hand. It makes use of electromagnetic forces–whether expressed physically or chemically is a matter of evolution. Among people it has undergone a great deal of evolution from its simpler use in hominid ancestors, even greater evolution from a primitive remote sensing function in the simplest forms of life (see for example Gregory, 1966).

We have offered a statistical mechanical model of the distribution function characteristics of language (Zipfian)—see Iberall, Soodak & Hassler (1978).

Also, we have hypothesized, on the basis of a limited amount of evidence, that language, as we know it, began no earlier than modern Man, homo sapiens sapiens, about 40,000 years ago (Iberall, 1973).

It would seem compatible with these explanations that record keeping and evocation in the form of written recorded language began with civilization in a need to keep track of and evoke the more complex kinds of transactions and relations which trade (and warfare) with strangers required.

VII. Final comment

The transition to civilization occurred in two steps. The first step physically was a matter condensation to agricultural settlement; biologically it was a symbiosis among species, culturally it was a social stratification. The second step physically was a hydrodynamic instability transition to the convection of trade. Little biological change was involved (except for a change in stress on physiological systems). Culturally, the complexity in stratification increased enormously.

Beyond the specifics, this essay illustrates the following observation: Whenever a complex system is studied at its own organizational level from a physical point of view, one finds a commonality of operating principles. We have been led in this way to enumerate the homeokinetic principles that are offered in this essay and elsewhere (Iberall & Soodak, in Yates, 1985).

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