A Physical (Homeokinetic) Foundation for the Gibsonian Theory of Perception and Action

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Homeokinetics is a generalized thermodynamic approach to complex systems. It seeks to show that physical principles can account for the existence and operation of complex systems at any scale. It stresses that the underlying processes are physical and few. Indeed, one beauty of this approach is that it offers a natural, physical way to relate one scale to another. Here, homeokinetics particularly assumes all the morphologies of biology. Complex systems, from a homeokinetic point of view, can be decomposed into a nested series of a great number of temporal, cyclic processes. The cycles involved may range from very short to very long. Discovering these cycles in this instance is the task of biospectroscopy. Any theory of real complex systems must account for the existence of these processes and explain how they are controlled. I argue that language, as a catalyst for action, is one necessary component of such control.

To establish one context for reading this article, you may glance through McCulloch (1965, pp. 72–87, 87–136). I am sufficiently brazen to suggest that, as one of McCulloch's inheritors, what I write here is an apt piece to follow his cybernetic introduction to a physical science for mind.

HOMEOKINETIC PHYSICS, ITS INFORMATION THEORETIC FOUNDATIONS

Shaw, Mace, and Turvey (1987) stated:

In its broadest sense, ecology is a multidisciplinary approach to the study of living systems, their environments, and the reciprocity that has evolved between the

two. Traditionally, ecological science emphasizes the study of the biological bases of energy transactions between animals and their physical environments across cellular, organismic, and population scales. Ecological psychology complements this traditional focus by emphasizing the study of information transactions between living systems and their environments, especially as they pertain to perceiving situations of significance to planning and execution of purposes activated in an environment.

The late Gibson used the term ecological psychology to emphasize this animal–environment mutuality for the study of problems of perception. He believed that analyzing the environment to be perceived was just as much a part of the psychologist's task as analyzing animals themselves, and hence that the 'physical' concepts applied to the environment and the 'biological' and 'psychological' concepts applied to organisms would have to be tailored to one another in a larger system of mutual constraint (p. iv)

Unfortunately, Gibson was not able to find an empathetic community among academic physicists to help support his pioneering studies. I believe that there is a natural fit within homeokinetic physics, which is a physical approach to the study of all viable systems (ones created in some sheltered environmental "workshop" and then released to a broader, freer environment to a subsequent autonomous life), and the connection and reciprocity that exists with their physically embedding environments. It—homeokinetics—draws on the study resources of all disciplines for their organized knowledge, but uses the organized notions of physics for its—physics'—principled basis. Traditionally, in simple systems, physical science emphasizes the bases of energy, matter, momentum, and electric transactions via the varied basic forces in matter–energy constituents and their physical environments, among the many hierarchical scales in nature. Homeokinetic physics complements this traditional focus by emphasizing the study within complex systems, wherein, because of their long extended internal time delays within their atomistic components, one must treat a more complete characteristic spectrum of actions emergent from their rudimentary momentum interactions. Because of the intertwined force complexes that make up their governing command–control systems, one must also deal in language, information, and communication transactions as higher ordered complexes. Perception, as a similar higher ordered complex, emerges naturally out of transactions in this organized construct of matter–energy flows (Iberall, 1992), as does purpose as an additional component of internal pressure within the systems (Iberall, Soodak, & Arensberg, 1980).

Expanding on these ideas: Consider a collective of simple interacting atomistic-like entities (atomisms). A prototype can be a considerable number of neutral molecules interacting in a gas or liquid phase by continued paired collisions. This is because they are confined by a container with a given wall temperature or by some weak or moderate attractive force—also with an internally radiating shell—that holds the collective together. The simplest

physics for such a system, a Newtonian physics, indicates that it maintain its state (e.g., gas or liquid) as a result of pair-by-pair particle collisions in which three physical conservations govern the interactive atomistic processes. Before, during, and after every set of paired collisions, the pair conserve mass, energy, and momentum. If the particles are electrified (plus and minus), then a fourth conservation of electric charge is conserved, but I will appear to neglect this additional conservation at this time, assuming electrically neutral particles of one or more sorts. (This is only a subterfuge, because all of the chemistry of these varied molecular sorts involves the electric force intimately. So, one way or another, the electrical force has to be acknowledged).

That description of how the collective moves and adjusts if different regions of the collective exhibit differences in macroscopic temperature, pressure, and density, makes up the equations of state and of change for the macroscopic collective (Hirschfelder, Curtiss, & Bird, 1964). Such descriptions, with moderate extensions, hold for all of the fluid processes in the universe, for example, the universe itself, galaxies, stars, fluid atmospheres, hydrospheres, and interiors in planets; and all other molecular and atomic flows, such as those in the pipes in your house or in your body. As a general construct, they are known as the Navier–Stokes equations of hydrodynamics or their extension into magnetohydrodynamics (which takes care of the electric force in a more complete fashion). They include stability transitions of flow in laminar, turbulent, and even chaotic fields of flow.

But, as researchers, my colleagues and I were required to generalize that description when we came to systems involving complex atomisms (see Soodak & Iberall, 1978a). In complex atomisms, when they interact externally by pairs, a long internal time delay must be recognized because of a complex of internal fluid processes. A successful description cannot be achieved only by summing over the external pair-by-pair collisions; there is a long time delay in internal action. Thus a valid description must be summed over the entire repetitive internal "day" of action. Thus, if and only if there is an overall composite system that repeats its atomistic factory day of action, then the same physics can be applied to the system as before. The new conservation is not for the collisional time–momentum exchange of the atomistic pairs but the long time delayed internal action of the factory day (see Iberall, 1987; Soodak & Iberall, 1987).[1]

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[1]The "factory day" was described like this in Iberall (1987):

The physical conservation of momentum transfer between participants requires conceptual extension when there are significant time delays in the action within atomisms. In simple systems the salient relevant time scale (out of a sequence of subordinate processes) for momentum transfer is the average time between interactive collisions, and is called the relaxation time (more appropriately for our purposes here the principal relaxation time). In complex systems the principal relaxation time scale (which I shall call the "factory day") over which all processes within the atomistic interiors complete a cycle, thereby reaching an "equilibrium" in the sense that the system is then ready to repeat another similar day starting

The physical measure of the external momentum exchange is the shear viscosity of the fluid medium; it is a major governing transport process in simple systems. For complex systems, the internal exchange for complex atomisms is the bulk or associational viscosity. The ratio of bulk to shear viscosity defines the internal to the external action or time, which, for complex atomisms, is large.[2] Thus, for a complex system, we have to deal with the entire spectrum of activity emergent

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from approximately the same initial conditions. That cycle of processes is made up of action modes . . . The factory day is characteristic not only of living systems but also of all complex atomistic systems that persist and that express much of their action internally. For an individual human atomism the factory day largely, but not completely, coincides with the earth's day. For the species, the principal factory day is the generation time. The factory day of the individual commonly begins with awakening from sleep, voiding, and looking for food. The cycle is finally closed again with sleep. (pp. 523–524)

Soodak and Iberall (1987) wrote:

The primary biological factory day is the earth day. Seasonal variations among interacting members of an ecosystem define another factory day—the earth year. There are natural factory days within any species consisting of generation time (approximately 20–30 years for us) and of an individual lifetime for each species, because each unit is itself a complex system that is born, develops into maturity, begets a new generation, becomes old, and dies. There are also intermediate time scales, such as multiple days, months, and years, associated with biological, economic, social, and political activities (e.g., 3- to 6-year business cycle; average time scales for political rulers; and for wars) (p. 468).

[2]In an extended account of these concepts, Iberall, Wilkinson, and White (1993), I wrote:

I was pleased to find two formal physical measures for those [complex] field systems. They were *field systems* because their distributed interiors represented fields, separated from but operating within exterior world fields. These measures were a measure of condensation, the mechanical–thermodynamic bulk modulus, β, and the internalizing transport measure of bulk viscosity, λ. The fantastic beauty of these two measures is that they furnish a space and time scale for such complex natural systems. If

β = bulk modulus
ρ = field density
C = propagation velocity in the field medium

then

$\beta/\rho = C^2$
$\lambda/\rho C = \delta, \lambda/\rho C^2 = \tau$
τ = the relaxation time constant of the field
δ = the effective mean free path of the field

and if the bulk viscosity λ is compared with the shear viscosity, μ, the transport measure of external momentum, their ratio is a measure of the internal complexity.

λ/μ = internal action/external (translational) action
$\approx$ internal time constant/external time constant

That is, it can be shown that the bulk to shear viscosity is the ratio of the internal action within the system to the external, translational, action that appears out of the system . . . Action is the physical product of energy and time. That action ratio is essentially the internal time delay in action compared to the translational time delay, or external relaxation time. In complex systems, by our definition, that time ratio is very long. (pp. 217–218)

from the interior of the complex atomisms. For living social systems, the atomisms are the organisms; for an organism, the atomisms are the cells. This already suggests the hierarchical nature of complex systems.

I use this homeokinetic physics as the basis upon which I offer a foundation for a psychological theory that links communication, language, perception, and action in complex living systems with an embedding environment.

Consider the following nested sequence of concepts, each leading toward a more primitive sense of the origin of the notion of perception. Start from the notion of perception itself. More primitive is the notion of sensation. More primitive than that is the notion of sensing. More primitive than that is Bridgman's instrumentality view (Encyclopedia Britannica, 1975) that we know our embedding environment by our abilities to measure the properties of that environment (i.e., by our sensors). Since a full third of my career was spent at the National Bureau of Standards in a measurement and instrumentation section, to me, such measure characteristics and the subscience of metrology are more than a simplistic philosophic characterization of such processes. More primitive than sensing is the metaphysical principle wherein a field connects systems A and B. The latter now contains the modern gauge invariant view of force. This has replaced the Aristotelian–Newtonian view of force as agent of change, or as commonly derived as an agent for action at a distance. The Gibsonian view does not equate the stimulus for perception with the psychologically classical view of stimulus as sensation. Rather, among the chained variables leading to perception, it includes the entire environment. Our chain of physical variables is similarly embracing. Our purpose in enunciating that chain is to indicate that, by perception, we mean a near field–far field resolution of how an autonomous system (electron, proton, person, star, crystallite, gas, liquid, solid, galaxy, cosmos—each of these viable and all exchanging with an embedding vacuum) receives the sensational language (a catalyst of the field at hand) competent to deal with its outside environment.

A MISSING FOURTH THEME—THE MODERN VIEW OF FORCE

If the progress in thought from the 1960s to the present is examined, a major change in the physicist's notion of force as the effector of change is found. (Aristotle, for example, very formally introduced the notion of force as the agent of change.) Newton's action at a distance is found replaced by the notion of gauge invariance, wherein virtual fluctuations in a vacuum, involving a gauge measure carrier entity (matter or energy), a so-called gauge boson exhibiting integral spin measure, represent the basis for force interactions between matter particles identified as fermions. Although the total structure of current physics involves four forces reduced now to three with an expected reduction to two or

even one, here it is only necessary to concentrate mainly on two of these forces: the gravitational and the electrical (one with a graviton carrier, the other with a photon carrier). The other two nuclear forces (strong and weak) mainly provide further detail at the very microscopic level. In any case, how these forces split in macroscopic operation and further entwine in their actions to produce higher ordered realizations is what makes up the many levels that are found in the physical reality in and among and outside of biological organisms.

The terms *gauge field* and *gauge transformation* correspond to the freedom to changing one's standard or measurement gauge for, say, the electromagnetic potential via an equation set that represents the field (e.g., the Newtonian mechanics invariance under Galilean space–time transformations: Lorentz invariance in the electromagnetic field: general coordinate invariance in Einstein's theory of gravity in relativity). One of the major contributors to these modern views was Schwinger. In respect to his recent death, I offer this tribute to his contributions to current modern views of force (see Lerner & Trigg, 1991, and Schweber, 1994).[3]

As a result of that new depiction of force, we obtain an enriched sense of how things work. We see a force transmission, from sender to receiver and back again, as the basis for information, as the source-sink for action, but now we see it clearly in purely physical terms. Precisely what the information community and the information science conferences of the 1950s and 60s did not complete (see Iberall, 1966, for a bibliography) we can now say is much deeper in hand. In such a fourth theme, I simply mean that a fluctuation emerging from some storage source is a source of information to a complex receiver wherein it acts as a basis for an internally driven action, which itself looks like the basis for another force fluctuation. This is a step removed from the simpler notion of stimulus–organism–response traditional in psychology and physiology.

The modern view of force as a view of interpersonal force was first expressed in Iberall and McCulloch (1969). It was put there to tease the physicist as well as to explain the problem to the physiologist/psychologist. We stated

> Why individuals are bound into orbital constellations . . . is a mystery. A model is suggestively found in the quantum mechanical system known as exchange forces. An individual projects his [or her] body image – totally or in part – into the other's object shell (it is obvious that the organism can direct its attention). This image

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[3]For reasons that are still not clear, force interactions fall into the four types named. It is not seemly in an article like this to spend much time on the current complexity of the fundamental physics of fundamental forces and matter–energy particles except to note the existence of these problems. So, for the interested reader, only two references are offered by which the subject may be explored a little further. Examine Lerner & Trigg, 1991, in sections on baryons (pp. 89–90), on elementary particles in physics (pp. 328–346), on fields (pp. 395–396), and on gauge theories (pp. 427–429); also see Schweber, 1994, for the history and physics of those changes and the scientists like Schwinger who developed the new force construct. The first reference is encyclopedic; the second is a marvelous physical and personality history.

and the physical image are internally compared, for their complementary or congruent character. From this exchange of body image arises empathy, antipathy, indifference, all the shadings possible of interpersonal force. It is a binding to be likened to the analogous quantum process that binds atom to atom as a shared electron cloud (p. 291).

What was being expressed here was the key notion of the well-known Heitler–London depiction of exchange force, the kind of process that only such beginning quantum theory could explain physically. The usual comments of that time was that there was no classic analog for that process. We were teasing both physicists who made that claim and nonphysicists who considered the quantum theory as the basis by which they could deny the efficacy of physically causal theories, in spite of the fact that continued development of that quantum theory as a field theory has resulted in the greatest known quantitative predictive accuracy of theories now available. The interpersonal exchange force differs from the more primitive view of the electric force, acting as a higher-ordered chemical realization of that electric force.

For all those who might be disturbed by the previous paragraph (and many people are disturbed by the underlying character of quantum physics), I add the following comments: Note that the gauge carrier for the electric force is the photon. That force is what created the great richness of form in intramolecular systems. It is particularly rich in the case of the electric field interacting with matter. That becomes what is basically chemistry, but it is a chemistry of many levels. What I learned from the Iberall and McCulloch (1969) article, is that the way that the various levels work in the organism is by any of the basic Ur-forces splitting and recombining in many ways to create higher ordered forms of that force. Thus, though many people may not like it, what are perceived as the operational, sensory forces of electromagnetism—pressure, temperature, sound, intero- and exteroreception, and emotional reactions—are all elaborations of the electrical exchange force. This is the sensory part that ecological psychologists should or do understand, because the limiting sensitivity of many of biological sensors is quantum mechanical. Now it is necessary to understand comparable electrical foundations for action, particularly motor action.

FORCE FLUCTUATIONS IN COMPLEX LIVING SYSTEMS

In this instance of dealing with the human or mammalian living system, homeokinetics was offering the nominal time scales up from the nerve impulse, for example, as found in a 0.1 sec response or reaction time, as the base for the force fluctuation that leads to the basis for interpersonal force. Obviously, our work (Iberall, 1969; Iberall, 1970; Iberall, Schindler, & Cardon, 1973) meant to

restrict our attention largely to mammals and human beings as our prototypic, nerve-impulse governed force system. We could have generalized our result to all nerve-governed animals, or, more generally, hormone-governed plants and animals (in which hormones may be regarded as a slow form of chemical signalling that is ultimately speeded up with an evolution into nerve transmission; see, e.g., Elliott, 1969), but in each case the electrical–chemical foundation for the fluctuating force basis would have to be particularly identified. It was sufficient, for a first model, to stop at the mammalian level. As we showed, we could, in time, begin to develop a general physical scaling for all mammals that would fit its electrical–chemical formulation.

In accordance with its homeokinetic physical base, our biological theory had to be a fluctuational force field that is the basis for moving from perception to sensation to transforming into flow to converting into action, particularly as we wished to identify the results in mammals in their physical environment on Earth. What sort of field processes are encountered? They are electromagnetic, acoustic–mechanical, and chemical. The fundamental forces out of which these forms of more macroscopic force fields emerge always remain the same primitive ones. But, as the systems emerge hierarchically, these forces split and recombine; the matter–energy systems develop into higher complexes. These systems exhibit extended, temporal, spectral domains, including their many factory days, which may represent growing physical complexity, and spatial, morphologically complex domains. This last statement is the keynote of homeokinetic systems. Whereas simple fluid systems have a near-unitary mean free path and relaxation time emergent from their atomistic interactions, within complex systems, there is an extensive spectrum of near-independent atomistic time scales and their internal complex factory design. They have to use a catalytic linguistic chemistry for their command–control. The Navier–Stokes equation set, or its extension as a more complete magnetohydrodynamics (i.e., its hydrodynamic part without its high frequency plasma processes) is sufficient for command–control in living systems and is generally all that is required for most systems except very large ones. These tend to be generated by the gravitational force underlying the biological range; gravity acts as a weak force binding matter and organisms to Earth. Systems involving extensive sharing of nuclear level processes require further extension by a quantum chemical kinetics.

LOCATING THE PHYSICS OF COMPLEX LIVING SYSTEMS

Because in this article, I concentrate on complex living systems, I will not generalize my model for all complex systems. Is this an arbitrary election? This question must be answered because Gibson and Gibsonians tended to make a distinction between ecological physics and traditional physics, claiming, rather

arbitrarily, that intentional systems must be restricted in scale between the very large cosmological scale and the very small quantum mechanical scale. As my colleagues and I have established in homeokinetic physics, there is a hierarchical nesting of atomistic and continuum-like field processes, and it is not immediately clear whether any particular level will be a simple or complex physical level. All complex levels will be, in fact, must be, language-using, requiring the identification and the use of information flows to elect from the large multidimensional stream of space–time processes with which they are capable of dealing. They will all appear to act intentionally. But what is found very specific in the system level that we identify, homeokinetically, as complex living systems is not only an ability to handle energy flows, motor action, and sensory flows, but also continued reproduction, both as a birth and a death process. Stars show capability for one or two, perhaps even a few, generations of reproduction, but they have no capability for continued and sustained generations of reproduction. Cosmological time is not sufficient. As far as physics informs us at present, we are forced to consider the only force system rich enough to create sustained generations of reproduction, as well as the other physical processes, to be atomic–molecular–ionic chemistry (or the universe as a whole). It is only this chemistry that is rich enough to provide the large number of states and processes that can handle the particular complexity required for the living state. Except for those particular characteristics, there is nothing unique in living systems to differentiate them from other complex systems. By this time, physical science essentially knows enough to be able to make the claim from empirical knowledge of the entire universe. Of course, some much more specialized novel findings (e.g., regarding the physical vacuum) could yet upset that conclusion, but the extension of science within this century makes it nearly unlikely. So it is necessary to depend upon our now more specialized chemical knowledge to close in on our theme. (Chemistry consists of the making, breaking, and exchanging of force-governed bonds at any systems level. Such a process is, of course, physical at its foundations.)

So how, homeokinetically, do we define the physics of complex living systems? I will refer to the foundation which was begun in Llinás and Iberall (1977). It is not inappropriate to begin with a living cellular system. What is found making up such a field system is a continuing influx of liquid, largely water, entering a cell as a major component of an osmotic flow stream. (See Iberall, Soodak, & Hassler, 1978; Soodak & Iberall, 1978b, 1979, for an introduction to two or more stream osmotic flow theory.)

A fundamental homeokinetic physical result (Iberall & Soodak, 1987) was the theory that in any field system there are only three types of field processes: diffusion, wave propagation, and convection.[4] We claim that these three

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[4]See the footnote in Iberall and Soodak (1987, p. 502). These processes were discussed earlier in Iberall and Schindler (1973) and in Iberall (1976, chapter 3). Any atomistic array in which

processes produce the field form of all systems, and that atomic–molecular–ionic ingredients acting as the physics–chemistry in such field form produce the character of living systems. The fundamental flow of action that emerges in cells is a continued growth of volume that, upon reaching a critical size, divides. A sustained process of grow–divide thus emerges. This represents reproduction. The multiple-stream flow of osmosis supports the chemical potentials that drive the system and regulate its internal constituent concentrations. The internal reproductive chemical processes for making DNA–RNA create the chemical machine forms, and functions that the cell makes use of, including capability both for motor and sensory actions. As we described it in Llinás and Iberall (1977), the bilayer membrane of the cell separates inside from outside; catalytic enzymes suspended within the membrane act as the chemical gating material. These enzymes govern the important exchange fluxes between inside and outside. The nature of incoming material from the outside interacts with the internal coding material to trigger its reproduction capability by use of the internal cellular production machinery. This material not only maintains the internal form and function process, but also modifies the production of gating material that reacts to the influx of material from the environment.[5] These

movements–both external and internal–take place from near equilibrium to near equilibrium in a small space-time box of approximately effective mean free path-relaxation time scale will show incoherent (random) fluctuations from outside to inside the box (Random because they involve arbitrary interchanges across the boundaries of one or a few physical units or their physical measures, e.g., mass, energy, momentum, charge, spin, or color.) That represents *diffusion*. A coherent straight line one-by-one transport from outside through the box will represent *wave propagation*. Globally, the entire array may be replaced from outside. This represents *convection*. There are no other possible processes at the flow scale near thermodynamic equilibrium, the Navier–Stokes-like description. However, the fluctuations may involve any change possible in the atomisms in state property.

[5]Here is an expansion of the ideas expressed in Llinás and Iberall (1977), which were written to honor the ideas and contributions of Onsager. It is an addition to the idea of the ionophoric gating processes. It has appeared through our own studies of transport in and out of the cardiovascular system (Iberall & Schindler, 1973). Noting that capillary walls are arrays of flattened square pancake cells, which are cemented electrically at their edges as helical slits between the pancake cells, it appeared further that the regions near the slit-like pores are occupied by such gel-like material as hyularonic acid and that outside of membrane pores in cells there are polysaccharide networks. More recently, Kandel (1991), indicated that the bounding regions within cells near such ionophoric gates are occupied by other gel-like network materials, as the lead in to trabicular networks. I began to believe that these inner and outer vestibule polymeric gating materials play a very influential role in determining the throughflux of materials and processes entering or exiting the cell. This concept provides a striking parallel to the gating control of complex urbanized civilized societies in which such similar gating control is provided by human governing law and by gatekeepers.

One final note that can be drawn from the Llinás and Iberall (1977) article. It contains the rather cryptic remark that the regulatory control of admission to the cell takes place by the physical mechanism of electric control of the bulk viscosity. Expanding this thought, this means that, as in all complex systems, there must be a "radial" ingathering control of the very many fluid streams that make up the complexity of such systems, and that it is necessary to locate the physical machinery by

notions detail Bernard's (1957) classic view of homeostatic regulation as regulation of the [chemistry of the] interior milieu independent of the [physical–chemical] vicissitudes of the external environment. That process has been evolutionarily successful for the past 3.8 billion years, formed, in our conjecture (Iberall & Soodak, 1987; Robbins & Iberall, 1991; Iberall et al., 1993) within the first narrow slot of 100 million years (3.9–3.8 billion years ago), during which the geochemistry of Earth made such evolution possible from a first generation of the Earth's hydrological–meteorological cycle. For an example of a competing group that does not acknowledge our thesis or supporting data, see Schopf (1993, 1994).

The first round of cellular chemistry evolved from prokaryotes (3.9–3.8 Gya) to eukaryotes (the appearance of an internal nuclear membrane, and a gateway to more rapid processes by which the cooperativity of multicellular organisms could be supported) within, perhaps, 1.5–2 billion years (metazoa: Robbins, Porter, & Haberyun, 1985; algae: Han & Runnegar, 1992). It is quite clear, in an evolutionary sense, that living system complexity was there from some such early period onwards. However, the history is clouded over by the poverty of the fossil record. One may examine Elliott (1969) for some flavor of the entire developmental sequence. Thus, it seems best to skip over any historical account for the early period in which internal communication, for example, hormonal signalling, was mainly by slow chemical diffusion. Instead, I ask the reader to jump to the age of nervous transmission, which is chemoelectric–electrochemical. More particularly, I jump to the Cambrian (500

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which that process takes place. Otherwise, as one sees here, one finds it necessary to appeal to some such metaphysical quality as intentionality, perhaps of the ruler. The crime is the same as unintentionally evoking "loans of intelligence". A new source on channels is Peracchia (1994).

Another example of being misled metaphysically by the difficulty of understanding the physics of complex flow fields is uncovered in the case of Marx–Engels dialectic materialism. See Iberall and Wilkinson (1987), or chapter 6 in our latest evolution book (Iberall et al., 1993). In the case of the cell, we believe that the basic control takes place by the linkage among the ingredients in the street flow outside of cells, the vestibule gating inside and outside the membrane, and the enzymatic gating ionophores within the membrane, plus the internal genetic coding material and the organellar machinery that the genetic coding regulates and controls. There are also two street systems within the cell: The "wired" trabicular networks and the "to whom it may concern" diffusive field within the cell.

Llinás and I (1977) were stuck for agreement at this level of description, except for one additional fact. In this description note, we offer a motor–sensory connection from the bathing street flow outside the cell to the genetic coding material inside. In ever extending hierarchical pathways of connection, additional higher ordered connections were made within the organism, both by informational (meaning catalytic control) and material–energetic (other organellar and organ stream connections). It is this extended network of connections and processes that develops the total factory complex of the atomistic organism. Note that connections originate from within the cell and outside the cell, but, with ever increasing hierarchical chains of connectivity, such connections weave their way through the entire organism, and then, beyond, throughout the entire society, the species, the total ecology of species, up through all biochemical and geochemical pathways over the entire Earth.

million years ago) and post-Cambrian age, to the age of dinosaurs (250 million years ago), and on to the age of mammals (60 million years ago). The only reason we must jump so close to our own time is that the experimental foundation (e.g., of dinosaurs, of the Cambrian explosion, of the detailed history of the metazoa) is too slim to support a more detailed mechanistic story. Thus, I tend to use the detailed mammalian story as a metaphor for earlier characteristics of complex life. I am forced to confine our story to the mammals, using their evolved nervous state as a prototype for our model. (A more complete draft form of the entire story of chemical evolution exists [Iberall, in preparation], but it is not available as a publication.)

FOCUSING ON MAMMALS

Because physics is concerned with space; time; matter; process energetics; momentum or action; and, in this case, the dominant forces of electricity and gravitation, it is desirable to define the mammalian family in these terms.[6] My first round of biophysical work was spent in identifying the biospectroscopy of the human organism (Iberall, 1960). My colleagues and I then followed up by attempting to provide a physical dynamic base for organismic morphology (Iberall, Cardon, & Young, 1973). The reason was compelling to us. We knew that we had influenced a considerable number of physiologists with our view of dynamic processes running the internal machinery. But we surmised that this would leave that audience perplexed as to the view of how organized form originated. It was therefore very important to establish, in accordance with the earlier history of notions of D'Arcy Thompson, that form also emerged as a

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[6] I call attention to one piece of current naivete in physics, not necessarily broadly shared, but not an uncommon error. It involves the so-called anthropic principle in one of its less savory forms. For example, Coles and Ellis (1994) made out an interesting but convoluted summary case argument for an open universe, one that is expanding quite a bit more rapidly from the critical density condition at which the universe just barely continues endless expansion. In examining one of the arguments for a critical density universe, they raised one condition as the Copernican principle that suggested to them that the universe has always been flat, rather than curved. But they offered, as a counter for that argument, that our planet or solar system seems to exhibit a special temporal position because of its implicit requirement that that there had to be enough time between the Big Bang (10–20 Gya) and the present epoch for life to evolve. This, they offered as an example of the weak anthropic principle, "though often dismissed by cosmologists, this kind of argument is actually essential to the correct formulation of probabilistic arguments in cosmology" (p. 610). This is only true if there is no determinate physical theory for the creation of life. But the very point of our 1993 book on evolution (Iberall et al., 1993) was to fix such a theory in the 3.9–3.8 Gya epoch, to indicate the physical conditions under which life had or could be begun, and to claim that we could make an experimental demonstration. As long as theory is/was lacking for the formation of galaxies, stars, planets, life, and the like as simple or complex systems, then probabilistic physical arguments must be presented. Our homeokinetic purpose, as was the case for thermodynamics and the demolition of perpetual machine notions in the 19th century, was to destroy the need for that aspect of the anthropic principle.

dynamic process. His views receive a great deal of lip service but little scientific study.

Specific contributions that we have made included:

1. Demonstrating the metabolic background of all mammals (species' adults). We showed that daily mammalian action scales with the 0.8ths power of adult mammalian mass, in which the first power scaling emerges from the commonality in the blood and oxygen demands of all the homologous mammalian organs, and the 0.2ths modification of the exponent come from the extra burden placed upon the organism by the gravitational force on Earth (Bloch et al., 1971; Iberall, 1972d, 1973).[7] The solution to mammalian design and its thermodynamic cost burden comes from the parallelism of the chemical demand and the viscous flow, both of which are proportional to the stream velocity of blood (Fick's law, in which the chemical demand in driving the supporting blood flow for homologous organs is proportional to concentration change and flux velocity, and the Poiseuillean mechanical flow cost is proportional to the blood viscosity and the same stream velocity. However, one spatial dimension must face Bernoulli's law in its gravitational form: namely, the blood does have to confront the gravitational force and climb uphill in one dimension). The design solution to that additional problem is to evolve and use a common topological vascular design and a common velocity in all mammals. McMahon (1973) used these ideas to derive a 0.75 power scaling for plants on a related but somewhat different physical basis for the governing gravitational force. There are physical issues in this that are commonly misunderstood. The physical basis is quite different for a 0.75 power scaling theory and one for 0.8 power scaling.[8]

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[7]The early phase of our biophysical program, 1940–1970, was concerned with demonstrating the temporal dynamics of the mammal, mostly human. (Our high altitude work [1940–1945] began, of necessity, from the well-known respiratory cycle, but we had to carry it on to other unknown metabolic processes starting in full pressure space suits [1947–1949], then in evaluating clothing covering [1955–1960], then demonstrating the entire metabolic and behavioral spectrum of the organism [1960–1970]; see Iberall, 1960; Iberall, 1969; Iberall & Cardon, 1964a, 1964b, 1965a, 1965b, 1965c; Iberall, Schindler, & Cardon, 1973). By the latter date (e.g., Bloch et al., 1971) it seemed clear that we had done enough in attempting to define that biospectroscopy and that it was timely to begin to define the dynamic morphology of the organism. I freely acknowledge D'Arcy Thompson (Iberall, 1973) as the major source of inspiration. Our National Bureau of Standards (NBS) work benefited from the earlier presence of Edgar Buckingham in my NBS section. As the father of dimensionless scaling, for example, the pi theorem, he was inspirational in much of my scaling work in instrumentation for high speed flight and flow instrumentation. This carried over into my biophysics work.

[8]If one examines the cardiovascular literature, one finds efforts to scale oxygen uptake in mammals with their body size, both at a whole organ level and at local vascular relationships. Such scaling presumably arose from a sense of modelling the basis by which the oxygen-carrying blood succeeded in matching the metabolic needs of the organism over a tremendous range in size. One easy line of thinking was to relate the sizing to match the thermoregulatory characteristics of mammals by a homologous geometric scaling. That sort of assertion would suggest that organ uptake was

2. We demonstrated that such physical–chemical diffusive scaling of mammals limited their size from 3 gr small adult size to some number in the neighborhood of 100,000 kg large size. It is of interest (although it has not been completely explored) to find the same large size limit – about 100 ft in length – for dinosaurs.

3. Timewise, we showed that temporal scaling of processes in mammals scales approximately with the 0.2–0.25 power of body size. To illustrate, over the entire nearly eight-decade range of mammalian size, the heartbeat ranges from about 6–8 beats per min at the mammoth size of giant whales to about 800 beats per min for the smallest adult shrews.

Because many of the timing processes in mammals, particularly the higher frequency ones (Iberall & McCulloch, 1969), originate from nervous system characteristics, it is important to understand how such compression is determined. I cannot casually dump an entire theory for evolution (Iberall, in preparation) into this article; at most, I can provide some tiny hints for the processes. As I said, a commonality of stream flow is achieved in the emergent design governing the blood stream. This is achieved by vascular scaling at a great

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proportional to the two-thirds power of adult body mass (if heat flow per unit area were constant, and mass scaled as the cube of a characteristic length). This gives major credit to mammalian thermoregulation, a rather recent biogeological system. Homology of mammalian organs suggests that uniformity of blood flow per unit volume (and mass) is a more likely process. That, and the commonality of the hemoglobin blood–oxygen exchange carrier suggests that a first power dependence is more likely. Thus, power limits between 0.67 and 1.00 seem likely. An earlier empirically based study, Kleiber (1961) suggested a 0.75 power relation. A restudy of the experimental data of both blood flow and oxygen uptake scaling over the entire size range of adult mammals (e.g., 3 gr shrews to 100,000 kg large whales), taking into account that limits on the action of the hemoglobin carrier precluded more than a 0.05 power variation between oxygen uptake and blood flow scalings with body mass (Iberall, 1971b, 1972c, 1972d, 1973).

The experimental study of available data showed scalings in the range 0.79–0.85. Having pinned down a rather sharp estimate of the experimental situation, it was timely to provide a theory for that data set. This was achieved in Iberall (1973), in which the effect of two dimensions of fluid resistance (Poiseuille flow) to viscous flow in the arterial system and one dimension of Bernoulli pumping against a gravity load (ρv^2) resulted in the power 1 perfusion law from the homologous nature of organ component design being transformed into a four-fifths power law. The hemoglobin carrier and Fick's law guarantees that the oxygen uptake law will be nearly the same as that four-fifths blood perfusion modified by gravity force law.

Although plants, particularly trees, must all deal with the vertical pumping issue, their empowering source comes not from material food that they ingest but from the solar flux that provides them with energy through a chemical pumping dye in their leaves. In order for that system to work, their branches, which support and determine how much energy their exposed leaf surface can absorb, must have an upward cast. Otherwise, their branches and leaves would droop. In successful operation, their metabolic scaling must be very critically adjusted by the elastic beam characteristics of the branches; thus producing a scale for the mass of the branches in ratio to the branch producing trunk. That mechanical (actually hydromechanical) scaling for the branch size leads to the three-fourths power relation between metabolic flow and above ground tree mass.

range of diametral levels of bifurcation, ending, in each case, in a commonality of capillary transport design (In Bloch & Iberall, 1982, we said that mammals, in their microvascular design, all consist of a shrubful of shrews.) A companion piece to that hydrodynamic design is that nerve diameters are scaled both according to the animal size and the function they perform. What seems to emerge in common is a general fittedness of a 0.1th second scaling for the fast nervous processes throughout the mammalian family. The following result cannot be guaranteed, but it is conceivable that the physical meaning of that 0.1th second process can be stretched to as much as 0.03–1 seconds, or there may be an additional scaling beneath the 0.2–0.25 power of time over a 3×10^7 mass scaling for mammalian size that cuts time even further for nervous–mechanical scaling. (Our subtlety is that scaling differences between one dimension of length scaling and three dimensions of mass scaling may result in a fuller dynamic geometry of three dimensions. For example, mammals tend to be bilaterally symmetrical, with many long pendular mechanical chunks, rather than being fully radially symmetrical, as many local nervous chunks tend to be. I have not fully explored the scaling change this makes in the physics as one compares the fluid mechanical–chemical scaling issues with the chemoelectric–electrochemical issues in the nervous system). As illustration, Kugler and Turvey (1987) gave data from Pennycuick for animal walking–cantering over a mass range from 20–1000 kg ranging from 1.25–2.6 Hz to 0.48–1.2 Hz. For that 50 to 1 mass range, the frequency range is about 2.5 to 1, representing, again, a 0.25 power law for time or frequency. Extrapolated to 3 gr animals, it would represent a walking frequency of about 10 Hz (0.1th second scaling, which is quite reasonable) to about 0.15 Hz (6 second scaling) for 100,000 kg animals. We have no guarantee that these numbers are on the mark, but, lacking a great deal more data and study, they are not far from quite reasonable. In fact, they point up much of the current controversial problem that exists in scaling large dinosaurs, for example, as fast-running or slow-supported animals, and whether they were thermoregulated, like mammals, to support other mechanisms of rapid activity. In any case, these numbers indicate the problem found in extreme-size-range multicellular animals. Their metabolic and motor–mechanical processes must be considerably constrained. Thus, without any definitive answer, I am inclined physically to accept a chemoelectric–mechanical basis clustering around 0.1 to a few seconds for the centering mechanics of mammals. In the nervous system, it represents a chemoelectric propagative process scale as extensive as 200 m per sec at the largest sizes and 0.2 m per sec at the smallest sizes. The nominal mammalian range commonly reported is perhaps 2–100 or 150 m per sec. Again surmising some more extensive process multiplexing, we do not find these numbers so extraordinarily far apart. I do not offer a good theory at this time; rather, I offer a not bad preliminary conjecture.

Turning to topics in Iberall and McCulloch (1969) and Gerstner (1992), the following may be inferred: Extensive investigation of chemical sensing and

perception, by means of the physical processes of acoustics–mechanics, electro-magnetic wave phenomena, and chemical pheromone detection, exhibits a temporal scaling range as extensive as 0.03 to perhaps 3 sec across the board for all mammals. In a Bridgmanian and Gibsonian sense, the measuring process is not that of a simple instrument response. In a homeokinetic physics sense, once a simple process is found by which a thermodynamic engine process can be locked up into place, and then be reproduced mechanistically by a chemical genetic code, it is not impossible for that machinery to evolve and produce extensions of that thermodynamic engine machinery and its processes. It is that sort of extension that increases the span from simpler detection to perception. Such growth in extension was very clear to us in the discussions involved in collaborating with Rodolpho Llinás about the nature of the proprioceptive and the exteroreceptor systems. Note that even though such evolution may then be found traceable in a particular phylogenetic family, this does not mean that in mammals, for example, all mammals will show the same range of detection. In some species, there is greater or lesser extension than in others. That is the character of chemical evolution.

In Iberall and McCulloch (1969), we surmised the existence of a miniscale of about 6 sec in human actions. We attempted, to no avail, to encourage an ex-perimental program to examine the greater generality of that scale. It wasn't until Gerstner's (1992) graduate work that my colleagues were able to find verification in a rather general sense for that scale in mammals. Gerstner's (1992) studies

> consisted of two parts: (1) A detailed temporospatial characterization of mastica-tory jaw movements in 6 mammalian species (viz., 7 giraffes, 4 okapis, 4 roe deer, 6 kangaroos, 4 red pandas, and 3 raccoons), and (2) A temporal characterization of all movements produced by these same 6 species over ~ 10 hour periods. The goal of both parts was to determine what movement characteristics were highly conserved in evolutionary time scales, and to thereby gain insight regarding the evolutionary potential of neuromotor systems. (p. xxxii)

Gerstner's (1992) data showed many activities (e.g., postural adjustments, chewing bouts, wrestling, locomoting bouts) that had roughly 6 sec periods. Because the dominant time periods in turtles — also studied — were much longer, and in birds much shorter, he suggested that the "6 second process" was, in fact, characteristic of mammals (p. 327).

Our current conjecture is that the more localized perception scale falls in the higher frequency range of perhaps 0.03 to 3 seconds, and that the cognition scale at which internal action (attention) and external action result from an integra-tion of the higher frequency perceptions to a higher ordered cognition takes place in the domain of perhaps 1–2 to 6–10 seconds. Viewed as a chemical language among mammals, we consider this the *phoneme* language aspects of motor behavior.

Gerstner's (1992) study went somewhat beyond those high frequency 1–10 sec limits. Noting the Iberall (1960) time scale of metabolic processes that he had detected among mammals, Gerstner (1992) also showed some data that indicated action filling the time domain up to 3.5 hr (p. 416; Iberall, 1960, time scales of 6 sec, 2 min, 7 min, 35 min, 90 min, 3.5 hr; among the process scales from 6 sec upward, Gerstner identified perhaps 20 major behavioral categories). However, his data breakdown is still much too primitive to establish the linguistic characteristics for that extended range. Suffice it to say that it suggests that such temporal study will, with little doubt, begin to fill out a rather extensive spectroscopy for perception and action based on a complex of electrochemical–chemoelectric processes. Further, as per the Iberall (1960) conjecture, these will consist of both wired diffusions, for example, nerve-carried signals (electrical conductance), and to-whom-it-may-concern random diffusions carried by hormones in blood. Those processes will organize to become the language of perceptive–active behavior, built from phonemes to words to sentences to paragraphs to chapters to books, for example, of life. Those language components, operating as low energetic, catalytic components, evoke or continue to change state in the living system (Iberall, Soodak, & Arensberg, 1980).

As has been shown and stressed (e.g., Iberall, Soodak, & Hassler, 1978), language seems to be Zipfian; word usage is ranked inversely to frequency of usage, like $1/f$ noise.[9] We have said (Iberall & Soodak, 1978, 1987) that such signal noise is just noise to most systems but has a specific linguistic character to those who share the language. This has been demonstrated in verbal writing, in music as complex as Bach, in speech, in electrical nervous signalling in membranes, and, most telling, in the electrical signalling of a complex single-celled animal like paramecium conducting the normal activities of life. Hassler (in-house studies; private communication) has shown such extensive phenomena in the sizes of corporations and countries, when they are able to freely compete in their autonomous existence. We checked it out in the action spectrum, as originally used by Iberall and McCulloch (1969), and, although the latter data

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[9]To us, these two ideas are equivalent. A complex system has to demonstrate action over an extensive logarithmic range, for example, many decades or many octaves. These actions must be governed by catalytic linguistic switching or evoking components. Those components must be low in their energetic dissipation. Thus, an efficient coding of such switching components can be an $1/n$ or $1/f$ ordering (n-rank order, f-frequency). If a most used catalytic signal has a unit usage measure, the second most used signal will have a half unit of usage measure or double the frequency, etc. Alternatively, the sum or integral of $1/n$ or $1/f$ usage is $\log n$ or $\log f$, so that each logarithmic of usage would be the same $\log f_1 - \log f_2 = \log f_1/f_2$. Furthermore, the total band width of such language or catalytic usage would have the $n \log n$ measure that is identified in entropic systems, and which Shannon identified by the term *message entropy*. I prepared an extensive resume of the ideas developed in the information sciences, including Shannon's (Iberall, 1966).

are a crude test, the Zipfian character seems to be fulfilled.[10] We have also conjectured that such language character would be found in the chemical detector linguistics of cellular receptor processes. If that conjecture were put to experimental test, it would be an enormous achievement in decoding the character of cellular chemistry. I propose it as a very significant test for the homeokinetic program. How such a program result might be achieved would be

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[10]We never tested the issue in the primitive Iberall and McCulloch (1969) data set, which, after all, has only 20 "words." We test it here. Note the prediction (now a retrodiction) that the data set would by Zipfian.

Presented below is an approximate table. It is based on testing the language of loosely 20 modes, not a highly extensive language. We did not bother to provide the names of the modes and we only test them in column 2 as activity versus time rather than as action–time, if they were properly given.

Rank order	Activity–time %	Action-time (if truly Zipfian)
1	30	27.8
2	25	13.9
3	8	9.3
4	5	6.95
5	5	5.6
6	5	4.6
7	4	4.0
8	4	3.5
9	3	3.1
10	3	2.8
11	2	2.5
12	2	2.3
13	1	2.1
14	1	2.0
15	1	1.85
16	1	1.7
17	1	1.6
18	1	1.5
19	1	1.5
20	1	1.4
	100	100.0

If we changed the ranking (column 3) to action A, the agreement would be even closer. Namely, we would change the activity fraction of the first two lines (work and sleep) to about 25% each and weight them by their respective power levels of about 2800 Kcal/day and 1400 Kcal/day, while leaving all the other levels at about 2000 Kcal/day. Thus, the first two levels would have the fractional daily action of about 28 and 14% and all the rest of the levels would remain the same fractional daily action as activity–time values indicated before. It is not the fiddling with numbers that interests us, but the fact that a nominal human action spectrum or menu is so fairly complete, in accordance with our estimates or guesses. It consists of only a double handful of modes, such as work, sleep, interpersonally attend (to members of own species), ingest, communicate, attend (sensing of the world outside), motor practice, sex, rest, become anxious (jitters in the external environmental space), become euphoric (slow movements that visit action modes that can be inferred to be pleasure-giving rather than disturbing—in an ultimate sense, we literally mean that there exists a pleasure center in the nervous system that can be inferred or found to be repeatedly stimulated, whose responses are the same), etc. Further, all languages, by definition, must have a

more of a test of the so-called volitional or "free-will" or "intentional" scaling in complex systems than almost any other test imaginable. At least it would begin to furnish a uniform theoretical foundation for all complex systems and the Iberall and Soodak (1978, 1987) conjecture that all complex systems are language using, and, if freely autonomous and freely competing, their distribution functions for command–control must be Zipfian (or some other well-identified distribution function). We believe that the characterization of near-noise is another basic requirement to identify complex systems behavior (viz., that its signalling complex spreads over many decades or octaves of logarithmic performance, but its phase identification is "random"–although many human languages do put stress on particular syllables. That thesis of randomness suggests why binary or tertiary or higher ordered correlations with phoneme groupings do not rapidly converge to make language sense).

   In joining this conjecture with a Gibsonian view, we hurdle the problem that has disturbed Turvey (and Gibson), namely, why they have considered a traditional view and connection between sensing and perception to be too limiting. The pathway from sensing to perception to cognition in complex systems is itself quite complex. Thus, it requires the evolution of considerable intermediate mechanistic complexity. As I have indicated, every natural system does not undergo an evolution into complexity, even if it is involved–of necessity–in evolution. When it does, its elected pathway is unique. But it always requires the catalysis of language as a low energy system that can manage each complex atomistic level. Our general physical modeling via the essential forces of nature comes out with an answer similar to the one that Gibsonians seem to like (see, e.g., Shaw & Kinsella-Shaw, 1988), namely, that there is an intermediate scale between the large relativistic scale of processes in the universe (largely gravitationally determined) and the small quantum scale (largely related to virtual force fluctuations in the vacuum, at the scale of Planck's action

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semantics and a syntax. As we have indicated, the general syntax is derived from the physical dual (Iberall, 1983) that we now extend to a triad, of being and becoming and acting or doing. Therefore, we have the order of noun, verb, and the action or actions of reference. The simplest forms—I, or I am—are degenerate. Note, for example, that Descartes had to start with, "I think, therefore I am." It is at least partly clear (to all others, if not to philosophers) that any statement of action would have effectively done as well. Thus, the assertion "I" by any sentient creature, however asserted, already implies an action, for example, that action (of asserting, if it wasn't noticed). "I am" is degenerate because the "I" in assertion already is. But the copula is so very useful that no one minds the occasional degenerate use (including the commonness with which it is used). The assertion "I am" is thus not being becoming, but being being, possibly with the shading that the being in asserting is also becoming being. Mysterious? No. It is simply the statement that the "I" (who is by asserting) is also the "I" who is asserting. It is the most primitive form of the arithmetic operation of association in which 1 plus (2 plus 3) is the same as (1 plus 2) plus 3, and the class idea that a class and a class is the same class.

   The other question is, why noun before verb? Because humans often choose it that way and save the opposite way to denote a question. But one can have it either way.

constant). But they then pursue this as a mathematical thought. The homeokinetic foundation pursued by me and my colleagues differs. We find a rather large separation among the major process levels in cosmology as an empirical fact (cosmos, galaxies, stars/planets/gas and dust clouds, atoms/ions/molecules, fundamental particles, the vacuum). One or two exceptions lie in the intragalactic scale in which the appearance of both high energetic processes, for example, nuclear chemistry of stars, and low energetic processes, for example, atomic–molecular–ionic chemistry (so-called cold chemistry) both emerge and intertwine. That seems to produce an unusually rich number of cold chemistry processes that can be supported by the hot chemistry at a distance from above, and from the rich micro processes that arise from atomic–nuclear scaling below. (See, e.g., Iberall, 1972a, 1992; Iberall et al., 1993). Thus it is that richness at this intermediate scale that makes complexity, or the particular chemical complexity that we find in life. At that, the living size scale, cell size of perhaps a fraction of a micron to a hundred feet or more for the largest animals and plants is rather enormous (3×10^7 to 1 in size extension, or about 10^{19} to 1 in mass range). Also, we regard it as the less-than-fortuitous homeokinetic entwining of Coulomb and exchange forces in atoms that further encourage the particular complexity that emerges. Note that we regard it as a physical process, not a mathematical process. Although the particular highly condensed form of that complexity arises at this level, the complex processes that arise are not unique. It is only their concentrated form at this level of living organisms that makes its particular evolution so rich. As a general illustration at all levels, there are not many universes that we know (e.g., as large black holes); we know a few types of galaxies, and star types, a handful of fundamental particles; there are a hundred types of atoms, but they fall into relatively few kinds of behavioral classes. Yet a few of those atoms (COHN, Si) and perhaps a few more metals (Na, Mg, Al, P, S, Ca, Fe) explode into complex functions and a capability for evolving species types that number in the order of a billion. That extended range of forms is physics, not mathematics, and it is a physics that requires no loans or loaners of intelligence, only a repetition of enough similar processes to produce the diversity of temporal, spatial, action, and energetic complexity that we pursue here.

Culture

I add one more physical note to keep from falling into the further reifying trap of making life or the human a unique process (see Iberall, 1984a). Through their entwined force and physical evolutionary history, all systems in nature are cultures and encultured for the apparent novel interactions that they encounter. In other words, it is to the credit of anthropologists to discover the process of enculturation, by which the long lived complex systems learn, use languages, and increase their stored field knowledge of new physical processes generation

by generation. However, the process is not anthropomorphic. As my colleague, Llinás, said when he grasped the point, "A carbon atom entering a living organism doesn't know it's in a living organism"; yet it is already encultured in its actions for the meeting. And this has been true for the entire 15 or so billion years of physical history of this universe. The physical intelligence, the matter, the energy, the actions, are out there all the time whether viewed as Einstein's well-known pantheism, or his cosmological principle, or the anthropic principle, or Gibsonian ecological realism. The only difference that our homeokinetic doctrine insists on is that, in accord with Einstein, Newton, and all the other great founders of physical doctrine, the foundation has to be strict physical principles, for example, to discover whether the proton has a life expectancy of perhaps 10^{32} or more years by experimental test. All we have added to make up the homeokinetic doctrine is that the same physics holds in its long time delayed internal hierarchy of atomistic forms as it does in the physics of any particular level. We have shown that complexity embraces most of the processes that human scientists have uncovered by themselves. It puts a strong burden on physics to condense on the detailed physics of those processes and to act as a sharp referee. Thus, sensation, perception, cognition, language, action, and enculturation between sender–receiver organisms via near and far field processes are both physical and social science litanies of processes among complex systems whether or not their practitioners are yet ready to fully take up that challenging description.[11]

I state unequivocally that, as yet, I have not been able to assert the complete chemical–physical theoretic by which it is possible to reach a level of system complexity that can create a language of encoded principles that describe the lawfulness of nature. I believe that I have proved that complex systems are and must be language using. I do not believe it is difficult to build complex systems that have processes that represent consciousness. That complex systems do begin to have a world image of self and outer world I do not find difficult to understand and to simulate. I still have not suggested how to transform the linguistics of internal chemistry in some complex systems into the complete lawfulness of a value system and an operational belief system. I try here to offer some small basic intellectual foundation for that capability.

Loosely speaking, it must start from the Newtonian idea that motion in a system is changed by the forces acting on it. Thus, to build a system that can deal

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[11]It is not essential that the reader interested in the physical foundation for an ecological psychology of human mind also note that it holds for the social science of humans. However, it is a useful augmentation. Thus, I offer some minimal reading that suggests the connections. One may examine, in useful temporal order, Randall (1940), Quigley (1961), Iberall and Cardon (1964a), Iberall (1971a), Iberall et al. (1980), Iberall (1984b, 1985), Iberall and Wilkinson (1987), and Chapter 6 in Iberall et al. (1993). To make certain that the connection extends just as well to the physics of the universe, I offer Silk (1980) and Soodak (1987) as easy reads for the uppermost gravitational homeokinetic physics.

with the language of forces requires the equivalent of accelerometers for mechanical systems or thermometers for integrative thermodynamic systems. I have begun the development of such autonomous systems both as a basis for inertial guidance systems, and as a basis for intelligent autonomous systems (Iberall & Cardon, 1974). Although complex systems can evolve and add further complexity, they may use ordinary mechanical, electrical, and chemical processes to achieve that complexity gain. That, among other things, will have to involve the evolution of parallel pathways of language, as I have described up to the present. However, at some points, these hierarchically nested systems may begin to add parallel heterarchical systems that may be able to perform at additional internally complex process levels. Examples are additional measure processes that multiplex the internal command–control (see Elliott, 1969). It is such measure multiplexing internally that, at some point, can produce consciousness, or image descriptive measures of the internal and external processes occurring. There is no absolute reason that such levels should arise. It is an empirical fact that they do appear. But, empirically, we cannot find a level lower than the human at which integrative belief systems arise. Clearly, the chemical genetic code in living organisms does have an integrative evolutionary capability, but it has no externally expressed belief system. As I stated it in Iberall (1972b; see Iberall, Cardon, & Schindler, 1972, for a number of pieces that tie many of these issues together), what was required was at least another dimensional manifold in human mind, an ability to handle abstraction. We clearly see that value systems, starting from world images of self and outer world, begin a great deal lower than the human mind from the physical doctrine of near field and far field process entwinements. We do not see unitary belief systems such as the simplest animistic belief system (which requires little other than being able to identify acceleratory movements or fluctuating temperatures and being able to act on the measure information) at levels lower than the human. Clearly, plants and animals do measure external variables (such as movement or thermal measures) and act on the information. However, none of them can enunciate a belief system as a codified language. It seems clear that there are animals who can develop the content of some such litany within a lifetime of experience. But earlier than, perhaps, a few thousand years ago, no complex system could assert the codification in compact form, say, as a philosophy. No animal could identify and transfer the abstraction of agent of motion into a general construct. Although animals can be shown capable of conditioned reflexes and transfer of associative causation from one channel to another, the ability to transfer such ideas among all channels is only found in the human.

A brief note in our common report (Iberall, Cardon, & Schindler, 1972, p. 33) partially stated:

> The new concept that we have added is that, whereas nervous system communication is laterally inhibiting, which keeps signals from spreading and thus chan-

neled within 'appropriate' paths; and that, whereas it is through strongly conditioned paths that animals with complex nervous systems can develop associations other than those which immediately and directly discharge inputs; in the human, cortical processing via a coordination center laterally spreads input signals so that it spreads through many processing channels. The specific target 'organ' at which signal becomes multichanneled, we believe, is the limbic system; that is we believe that sustained circulating signal in the limbic system is no longer immediately appropriate to input. That property provides the foundation for 'abstraction'. The sustained circulation of an input signal via 'translation' or 'transformation', both abstractional constructs, through all compartments of the brain provides the foundation for cognition, for 'thinking' . . . Since at this time I propose to furnish no details other than the hypothesis, I characterize that view as 'naive'.

In the living system, the receipt of that near–far field message influences the receiver system to "do its thing," whichever way one looks at it. The chemical catalysis of language transforms into *action modes* via the information paths (neural; internally sensory proprioceptive; vascular; glandular, whether exocrine or endocrine) and becomes *action* (motor action or internal state evocation).

So how is the field 'sensed' or 'perceived', or just chunked into field segments, 'culturally' cognized within the organism or the organismic ensembles (cellular or organ, or organismic) in the organism and bound within its proximal milieu – ecologically realistically – only by physical mechanisms? That is the problem of all those who want to get into the compact field of general and predictive scientific answers.

The simple answer is that the field phenomena must be transduced by physical–chemical instrumental sensors. The physical answers must be identifiable, demonstrable, reproducible, and communicable.

As physical scientists know them today, the senses must derive from mechanical, chemical, acoustic, electromagnetic, and strong and weak nuclear forces, but, effectively, that is all. Nearly 100 or 200 years of attempting to show more have almost closed the books on additional sensing. These transduce through mechanistic layers. The physicist, chemist, physiologist, psychologist, and others try to trace the complex transductions to get to the motor systems as stabilized and patterned field responses.

But the information keepers of the language of catalysis must be both mechanical and chemical (and, above all, thermodynamic, through kinetics, diffusion, propagation, convection, and nonlinear processes involving stability and the lack of it).

Some of the Processes in the Nested Temporal Scale

As a brief intimation of my conjecturing on the catalytic linguistic control of motor action by modes in mammals (which have coupled sensing and

communicational systems), I provide more detail on and beyond the 6 sec cognitive phonemic scale.

When the cognitive control elects a minimal motor action, it elects a velocity pattern from the existing motor organization, for example, at the basal ganglia level. That velocity pattern controls the next 2 min interaction of the local microcirculation–organ unit interaction at the level of an atomistic functional unit in the local organ bed, for example, muscle fibers (see Bloch & Iberall, 1982). In our depiction of the process, the local metabolic demand resulted in a chemical interaction of local circulation catecholamines in the blood and the combustion byproduct of lactic acid in perfused motor units likely interacting in mast cells with a transduction to histamine to determine how the fluctuating oxygen supply carried by hemoglobin is milked from the capillaries by a travelling electric zeta potential wave. If there is no other subsequent change, the new pattern continues its particular 2 min pulsing. Otherwise, new local pulsing changes are set up in other local regions. We viewed this as the operating oxygen choke that determines the energy expenditure of muscle fibers.

This pattern of 2 min pulses throughout the body cumulatively determines the patterned throughflow of blood and drawdown of oxygen in local tissue for the entire organism. The power demand put on muscle by the velocity that the nervous system demands may be more than the local blood flow can supply, in that the blood perfusion is inadequate to support the total demand. At that point, there is a nervous system control of the regional blood flow. This takes place under hypothalamic control in a 7 min cycle. The regional blood flow is changed by the hypothalamus setting the local blood flow at the nervous level of units such as nerve bundles (see Bloch & Iberall, 1982). Those regional changes make more oxygen flow available via the increased blood supply to support the increased metabolic demand.

The alternating and changing of oxygen–carboxyl loads put upon the blood is strongly affective of the blood pH level. Its regulation takes place through a carbonate balance in the blood at about a 35 min cycle.

Beyond that time scale, we finally arrive at the thermodynamic regulation achieved within the blood flow, likely, by means of cortisol. This middle metabolism cycle takes place by pulses at the level of 3 1/2 hr. A subsequent free fatty acid metabolic regulation takes place at about a 9 hr process cycle. In accordance with an earlier suggestion, all of these process scales are tracked by the limbic system, as well as the thalamus.

Beyond lies the major circadian regulation by a complex of processes that I have already suggested (Iberall, 1986). This, I prefer to suggest, is under reticular core control. Beyond that physiological regulation, there is a 3 day regulation of tissue water (via cellular volume regulation), likely involving thyroid. That cycle then tends to appear as a regulation of weight. It is interesting that thyroid starts out in mammals as the growth regulatory until adolescence, whereupon it switches over to become a regulator of metabolism. Further on, there is a

regulation of the affective processes of anxiety and euphoria, likely through molecular turnover of central nervous system material at the 1–2–3 month seasonal scale. Additional scalings continue to the yearly scaling and the scaling of a number of life epochs. Further processes continue at the generation scale, multiple generation scaling on to the death process, and beyond (see Iberall et al., 1993).

I do not expect the reader to take this casual run-through with any detailed seriousness. I do hope that the reader will take the thrust of those homeokinetic assertions seriously. If he or she does, then it must be realized that the physiological–psychological process description is still at a very preliminary stage. My contributions to the physiological literature for the past near 50 years haven't even begun to make a mark in the relevant communities of physiology, biomedical engineering, and biophysics.

I close with a few additional remarks about the 6 sec cognitive scale. Some evidence for that time scale from the literature of ecological psychology may be found in a recent vision–driving action study reported in Land and Lee (1994). Tests of drivers going along a one-way winding road, as one step in developing intelligent vehicular guidance systems, show that drivers fixate on a tangent to the inside edge of the road. But both the gaze angle and the steering wheel angle show a back and forth cycling of about 10–15 sec (e.g., perhaps 5–8 sec half cycle per gaze), with the time spent by the gaze at each tangent observation of about 6–7 sec. Whether this is a near 6 sec cognitive period, it at least suggests that the drivers are comfortable with this sort of decision making time. The authors' inference was that instrumented subjects use their gaze on a " 'tangent' point on the inside of each curve, seeking that point 1–2 s before each bend and referring to it throughout the bend" (p. 742).

CODA

Because the respective studies addressed in homeokinetic physics and ecological psychology are not completed projects, it is virtually impossible to bring any of these discussions to an end. But composition and human attention require that each piece be ended. So, in the style of the great musicians, I add this coda, creating a new musical paradox, a finish to an unfinished symphony. I attempt to define, by a theoretical measure, the complexity of a complex system in nature using the human as an example, and, at the same time, to advance the respective studies.

To capture the continuing task of an understandable social science, it is useful to provide readers of our social evolution (Iberall et al., 1993) with a common foundation in the social sciences. To that end, I devised a reading list that provides such a base. (Some of our contribution is found in references alluded to in Footnote 11; also see Iberall et al., 1993). My friends/colleagues (as physical

and social scientists) were the first test subjects in helping to develop the list. The list grew to about 20 books. We began to identify them as a second education course to be completed in months rather than years. Reviewing these friends' responses (in a short time of examination of months, rather than the decades it had taken me to acquire that background), once again, we kept confronting the homeokinetic physics problem: how to make physical ideas about complex systems comprehensible via stored information and language.

A recent article on the child's development of language (Locke, 1994) sketches the path taken by infants from babbling to acquiring a whole language. It describes the effective universality of the process under the interaction with a mothering one and other society members. I assume that such material represents obvious and well-known content for Gibsonians, constituting, as it were, "half" the interests of the ecological psychology community.

It dawned on me that the learning path presented by Locke represents the dynamic development of a complex system—the youthful human language using system and its enculturation—in only a few years. This, suddenly, also explained to me the enormity of the reading list my colleagues (Iberall et al., 1993) had devised. Although one might object that the list is only devoted to the social sciences, which is hardly the total content of human intellectual study, it is of indicative order of magnitude. It became clear that such a list offered an overview of a considerable segment of human intellectual activity and compressed the learning to a short time of months. The pressure on all of my colleagues, as busy intellectuals, was fierce and, at the same time, it again exposed us to the extreme difficulty of putting forth the homeokinetic program. As Locke (1994) stated,

> We'd like to believe that we talk a lot because we have a lot on our minds, an abundance of thoughts that can only be exchanged by talking. And yet studies . . . reveal that even at prestigious . . . universities, conversations focus mainly on personal relationships and experiences, sports, leisure activities and the like. Only [a limited percentage of] discussions . . . had anything to do with [intellectual] matters [of consequence]. (pp. 436–437)

Or, as one cited experimenter commented, "The intellectual content of human conversations is often trivial" (p. 437).

An Experimental Test Measuring Complexity in a Complex System

Dr. Frank Hassler (my Department of Transportation systems colleague) and I agreed upon a reading list of about 30 books covering the social sciences for him to quickly read through. He is a PhD physicist with important systems experience. After considering the child learning article (Locke, 1994), it was clear that

a particular task Hassler, our colleague, Harry Soodak, and I had been preparing for – a joint attack on how to run a human society – as a second modelling effort on that topic, had to involve a very significant segment of human intellectual endeavor. We quickly learned that our near daily discussions could not afford much trivia; our driven purpose was to make certain that we all understood our respective points of view to various questions, but we also understood that we needed the views on these questions to be shared with social scientists. Once again, it was clear how difficult it was to capture the homeokinetic theory we were developing and to bring it into a common understandable focus. The physics issues seldom bothered the three of us. It was always a need for a comprehendable, more universal translation to all communities.

We suddenly realized that our preparation and task and the writing of this piece for a Gibsonian community were all of one piece; we were in the midst of an almost perfect homeokinetic physics experiment designed to make clear to both Gibsonians and to listening physicists the content of a clean quantitive laboratory experiment of exquisite precision involving the measure of a complex system.

Explaining our Experiment and Comparing it With an Underlying Gedanken Experiment

There is a two-body interacting system whose history has been examined in the human social laboratory billions of times. It is the interaction between a newborn human infant and its nurturing mother. The experiment is quantitative in space, time, and energetics.

If one does not endow the human infant with miraculous and religious–philosophic, mystical–magical properties, one only has a start from a biophysical–biochemical thermodynamic engine, newly developed and released for nearly autonomous life from a womb, whereupon the actions performed are no longer tightly tied chemically but involve electrical exchange force action at a distance. Although the system is not just two bodies – it is an open system in a socially encultured field environment – the child knows very little of that. To the child, the strong imprinting interactions are effectively "all" with its mother. To that extent, we consider our experiment physically pure.

The child system at such initial startup has no language competence of any significant measure. The proof of that is to disengage the child from human contact in the environment, and the child will almost certainly die. It has little or no capability for independent command–control. Yet, many other consequential states can emerge among other living organisms. It is precisely because of those mixed resultants that our human experiment is so pure. Yet, as the article referenced discusses, in a few years of mainly mother–child interaction, the child becomes quite fully a language-using encultured complex system. Of course, it had such an internal potential, but here we have explicitly exhibited

and demonstrated its realization. How many times has the result been experimentally demonstrated? Through all of human history, of order 10^{11} times.

In an earlier article (Iberall, 1992), I characterized for Gibsonians the nominal temporal period of the cognitive response in humans (perhaps also at the level of mammals). It is of order 6 sec. That must be the proper order of magnitude of person-to-person interaction between mother and child. It cannot be meaningful more frequently. Thus, in a day, if the total day is involved in such attention and integration, 14,400 phonemic interactions have taken place. Locke (1994) mentioned numbers like 40,000 words per day; 4-6 hours of continuous speech; and 24,000 phonemes per day. In about 3 years or 1000 days of child interactive experience, the child has acquired competence or become a competent language-using system in a total of perhaps 15 million interactions. If the reader counters that most of those interactions were trivial, I reassert that most of human linguistic interactions are trivial. But they contain the intellectual content of humans.

Some youthful geniuses graduate from prestigious schools by age 12. But a much more secure average is to note that by age 20 or so, almost all those who assay the process manage to secure the more total intellectual content of human knowledge. Thus the complete measure is not 15 million, but perhaps sixfold more, or 10^8 units of cognition. This, thus, furnishes a measure of the bulk to shear viscosity measure for a complex system, one that I had not been able to achieve earlier—for example, see Llinás and Iberall (1977)—although I have grasped for it since the 1960s. Past assertions (Iberall, 1993; Iberall & Schindler, 1973) were that a ratio of zero marked monatomic atoms, of ratio order one diatomic molecules, three marked materials like associated fluids, for example, water as a magnificent solvent; that ratios of a few hundreds marked thixotropic molecules like solutions of organic molecules, rheological organic fluids, paints, inks, sewage with some memory would be higher, and that some appreciable memory might exist from ratios greater than 10,000. Yet, we could only surmise that true complex system memories might begin at the millions, billions, trillions, etc. It is remarkable to achieve the measures of about 10^8 to 1 for a real start. Furthermore, if one exhausts a lifetime of effort, one begins to surmise that it may reach up to perhaps 10^9 to 1.

Interestingly enough, those number levels are still only a small fraction of the number of neural connections that can be made in the human brain, for example, 10^{11} or greater. Thus, the machinery is not limited by the number of connections, but by the type and quality of connections. It is not a largeness of number (of atoms, of connections) in a system that defines its complexity. It is always the number of internal atomistic process units compared to the external atomistic reaction time that determines complexity. Here, we have finally isolated one such pure measure.

The experiment that Hassler and I have performed involved 30 books or so, of 500 pages apiece, and perhaps 400 words per page. This is about 10^7 words.

Expressed as the number of key ideas or cognitions, the reading for a second education may amount to perhaps 10^6 units. Considering redundancy, missed subjects, and the like, this human intellectual content, even if tripled, is only a small fraction (of trivia?) that the human carries forth, as compared to the total maintenance competence of the human to operate in a fully encultured society, which is, perhaps, the 10^{8-9} units we estimated.

We indulge ourselves in the final conjecture that this sort of number is likely to be a near universal order of magnitude measure for all medium to large complex systems in the universe of nature. With this sort of quantitative gesture, we believe we have served both our physical discipline and the Gibsonians.

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