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CHAPTER 13

CYBERNETICS OFFERS A (HYDRODYNAMIC) THERMODYNAMIC VIEW OF BRAIN ACTIVITIES. AN ALTERNATE TO REFLEXOLOGY

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A Topical Outline

1. What thermodynamics requires of the universe.
2. What a thermodynamic engine is.
3. What mathematics and physics can satisfy thermodynamic engine properties?
4. What an autonomous viable system must do.
5. A note on the physical concept of modes – diagonalization.
6. Switch modes in a viable system – from ingest-cease and grow-divide on up.
7. The nature of outlook.
8. The four logics of the human brain.
9. The character of the human brain.
10. Physical achievability – an engineering outlook.
11. Physical achievability – foundations for the character of the brain.
12. The great mystery – self-organization.

Having been asked to offer views of some perspectives in psychobiology from a physical-cybernetic point of view, we will attempt this in two steps. We will attempt to outline in condensed form how one proceeds from fundamental questions in the physics of systems to some comprehension of brain activities, and then we will elaborate on these notions with some added detail. If we can convince the reader that thermodynamics governs the organization of every other level in the universe from nuclear particles to the universe, then perhaps he may be willing to concede that it governs the levels of living organization.

1. WHAT THERMODYNAMICS REQUIRES OF THE UNIVERSE
(Munitz 1957, Gamow 1956, Gal-Or 1975)

Given an initial distribution of electromagnetic radiation, highly concentrated in a region. As a result of natural processes, there is an expansion and conversion of this high temperature radiation to low temperature matter. But the process does not take place smoothly, uniformly, and homogeneously. As a result of local hydrodynamic instability, inhomogeneous processes and forms emerge and persist for awhile. Galaxies, stars, planets, chemically reactive matter, life, molecules, nuclear particles are all examples of emergent formal systems (Iberall

1972a). The thermodynamic strictures are that, overall, energy is conserved, but that the ordered form of the energy is always in process of being lost to lower ordered form. Nevertheless systems persist locally, for a 'lifetime'. How? (Order is associated with the concept of the direction of the flux of time. For an exposition by a biologist, see Blum 1955, or by a physicist, see Gal-Or 1975).

2. WHAT A THERMODYNAMIC ENGINE IS

As a result of natural processes, one would expect a degradation of locally ordered energy to the lowest order locally possible (e.g., a uniform expansion to rest in which all that remains are mass particles vibrating with some low constant thermal energy). Nevertheless, it is possible to put mass particles into local sustained more highly ordered motion (namely as a local cyclic process), if locally there is a source of energy of some high ordered form (e.g., temperature or chemical potential) and a sink of some lower ordered form of energy. The system of particles then can draw energy from the high potential source and reject it to the low potential sink, but meanwhile it can enjoy the transfer by a cyclic process. The field in the large will pay according to the strictures of thermodynamics, but in the local domain the system of particles can be maintained in a sustained cyclical motional state, and repetitively convert some energy into the higher ordered form of work. That is a thermodynamic engine. For the living systems on earth, the sun is the potential source, and the earth and space the potential sink.

3. WHAT MATHEMATICS AND PHYSICS CAN SATISFY THERMODYNAMIC ENGINE PROPERTIES?

No linear system can persist in such cyclical motion. To illustrate both the physics and the mathematical issues, consider a mass-spring acted on by a constant force

$$m\ddot{x} + Kx = F_0$$

This linear system would apparently show a persistent harmonic motion

$$x = \frac{F_0}{K} + A \sin\left(\sqrt{\frac{K}{m}}\, t + \varphi\right)$$

A, φ = amplitude and phase.

But the second law of thermodynamics assures us of losses, namely the only linear form permitted by the second law would have to be

$$m\ddot{x} + c\dot{x} + Kx = F_0$$

The middle term $c\dot{x}$, a resistance or viscous damping term, results in a decaying motion

$$x = \frac{F_0}{K} + Ae^{-at} \sin (\omega t + \varphi)$$

The question arises whether there is any nonlinear means for overcoming this defect. To illustrate, consider

$$m\ddot{x} + c\dot{x} + Kx = F_0 + \varepsilon(\varphi)$$

It is possible to add a function $\varepsilon(\varphi)$, for example an escapement, that will make up for the linear loss term. As an escapement, the extra force can be added impulsely in accordance with an appropriate phase. As such it is a nonlinear element that drains energy from an external source to overcome the loss. (It is highly disastrous to have an improperly designed escapement. While quite clear in engineering design, it is worthwhile emphasizing the point to biologists. For, in fact, in developmental biology it is likely the major source of rejection of inappropriate genetic mutation.) In prototype, this example illustrates that nonlinear processes can make up for local thermodynamic losses to maintain an engine cycle, in a field undergoing degradation of free energy. The cycle of sustained operation is known as a limit cycle, because it returns in the limit to the same closed cycle in a displacement-velocity phase space regardless of moderate disturbances which may speed up or slow down the cycle. (An instantaneous racing or slowing down of a clock or a heart beat is quickly restored to its regulated normalcy when its nonlinear escapement is in its normal working state.)

4. WHAT AN AUTONOMOUS VIABLE SYSTEM MUST DO

Local thermodynamic engine cycles are capable of coming into existence by self-organization. A spinning, falling leaf, or an Aeolian harp, or the tides in the atmosphere illustrate such processes. However, if many such processes develop into or around a formal system, and become self-entraining, self-serving and persistent (e.g., an erupting geyser or a tornado), then the system may ultimately become viable, that is, it may be able to persist beyond the range of the local 'workshop' in which it was created, and may be able to seek out and draw from scattered and even randomly-appearing energy sources, in a fully autonomous fashion (Iberall et al 1972). How a complex factory process comes into being, during its early start up evolutionary phase is not within our scientific competence to describe in detail. It is often the accident of initial association (e.g., as in the origin of life, Iberall 1971). But as sustained process becomes entwined and entrained on top of sustained process, to where their operation becomes more self-supporting, or in Claude Bernard's terms, becomes more and more independent and immune to the external vicissitudes, this co-operative ensemble of engine cycles becomes globally stable and truly autonomous. Basically an autonomous viable system can operate in more than one mode, in which each mode is adaptive to some condition of its surrounding only slowly changing environment, but also relates to required internal functions.

5. A NOTE ON THE PHYSICAL CONCEPT OF MODES - DIAGONALIZATION

In conservative linear systems, with more than one degree of freedom, it is possible to transform the variables so that they have the following independent form

$$\ddot{x}_1 + K_1 x_1 = 0$$

$$\ddot{x}_2 + K_2 x_2 = 0$$

In this form, the response matrix is said to be diagonalized. Each such composed variable x_i has an independent spring motion. In the original observational variables we find a composite motion, beat phenomena, in which the system oscillates and cycles through these normal modes. As a simple example, a double pendulum has two normal modes – one in which the two pendula swing in the same direction and the other in which they swing in opposition. The first is a low frequency mode, the second a high frequency mode. A motion started at random will warble through these modes and produce beats.

In a nonlinear system, this concept of pure normal modes does not exist. Nevertheless it is presented as a conjecture, based on our decomposition of nonlinear hydrodynamic fields, that there commonly exists selected sustained nonlinear oscillations in which the subsystems are co-operatively locked into a variety of different constellations, and that these co-operative configurations resemble normal modes. The diagonalization is not as perfect as in linear systems, namely they are not as independent, but they are quite similar.

If the reader accepts our example of the nonlinear escapement which essentially balanced out the lossy terms, he can intuitively sense the notion that the remaining harmonic complex appropriate to each nearly normal mode appears in turn. Perhaps the appearance of each mode is not as pure or smooth as the appearance of beats in the case of linear modes, but small interlocked melodious harmonics appear and switch around among the system's instrumentalities in some complex ring.

6. SWITCH MODES IN A VIABLE SYSTEM — FROM INGEST-CEASE AND GROW-DIVIDE ON UP

In the living system, one first finds four simple series-parallel modes: ingest-cease, and grow-divide. As one ascends the ladder of phylogenetic complexity, the number of modes increases. In mammals, about 9 common forms of behaviour are recognized. According to Scott (1962), these forms are

- ingestive behaviour
- eliminative behaviour
- sexual behaviour
- care-giving behaviour
- care-soliciting behaviour
- agonistic (conflict) behaviour
- allelomimetic (immitative) behaviour
- shelter-seeking behaviour
- investigatory behaviour

Regardless of the degree of complexity of the organism (e.g., whether single-celled, or with complex internal organs), modal behaviour must arise from the complex fluid mechanical, electrical or chemical chains that are engraved as formed and functional process within the organism's interior. The chains are enabled by streams – the flow of fluids through conduits, of interacting chemical products, of mobile electric charges. Thus in the organism's internal milieu, they make up a complex chemically interacting electro-hydrodynamic field. However, all complex self-serving thermodynamic engine systems must have an internal command-control engine system to govern the switching of internal modes, using both, internal and external state information. In a system in which long life is preserved, there has to be a useful adaptive switch algorithm.

It is an hypothesis that the combined command-control system of the nervous system (NS) and endocrine system can also be viewed as a complex electro-hydrodynamic field which can exhibit organized motion around different singular states of the field. These singular states, loosely, can be regarded as switch states. (Such switch systems exist already in single cells – Llinás and Iberall 1977.)

Basically the NS, in its origins, exists for chemical secretion, for chemical communication. In its later form that secretion is speeded up by added electrical transmission, but the fundamental function, as still clearly seen in the neurohumors, is not lost, but only augmented. We would tend to regard all switch states as hydrodynamic (perhaps preferably electro-hydrodynamic) instabilities. These topologically branching hydrodynamic states (in phase space) represent the primary modalities of the organism. (We regard a physiological-psychological mode to be a physiological state which is characteristically sustained and achieved by locking up a constellation of organs and fluxes into a particular correlated pattern. These patterns, in the main, are largely independent of each other. But the progression from state to state takes place largely as dynamically connected Markovian processes.)

What that thought means is that it is only nonlinear lossy systems which can exhibit limit cycles (for which, we offered the example of a nonlinear escapement making up for the losses and thus locking the system into its limit cycle), but that the system may snap into more than one modal arrangement of its parts and processes. The various possible modes that the system can switch into are its branching states. However, if these states were far separated in energy, it would be difficult for an autonomous system to reach them without some deus ex machina. In the living system, the NS (and CNS) have so developed that the selection of states has itself become part of a thermodynamic engine. Thus the system rings through (or snaps through) its modes also as a thermodynamic engine. In coma, for example, a deus ex machina is required to ring the system through its life preservative modes.

At the present time, not enough is known about the co-ordination of that CNS electro-hydrodynamic field to identify it by its chemical co-ordinates. (The simplest form was the ancient Greek identifications of phlegm, bile, etc.). Thus we can only identify, functionally and behaviourally, an animal in an eating mode, etc., namely we tend to use the state of particular organs as indicators of modes. This is far from an accurate description.

While the ethologists have identified the general descriptive categories of modes, we believe their more specialized constellational nature can be named.

Man, we believe, exhibits a number of specific human modes of behaviour in addition to his general mammalian repertoire. These depend largely on his possession of a co-ordination centre, a language centre, which permits abstraction and translation of internally identified input signals into other sensory-motor-internal channels (Iberall 1973b). We identify as human modes, the following (Iberall and McCulloch 1970):

sleep (e.g. a sleep mode)
work (directed motor activity)
interpersonally attend
  (body, verbal, or sensory contact)
eat
talk
attend (indifferent motor activity,
  involved sensory activity – here to
  nonpersons)
motor practise (run, walk, play)
anxious
sex
euphoric
drink
void
anger
escape (negligible motor
  and sensory input)
laugh
aggress (~~nonpersons~~)
fear, fight, flight
envy
greed

We denote the general physical scheme as homeokinetic by which a viable autonomous system runs self-regulatory through all of its operational modes. The principle of homeostasis, regulation of the internal state variables of a complex organismic system, independent of the vicissitudes of the external milieu, is a central dogma of biology. For physical realization of homeokinesis, a mechanistic-thermodynamic process was offered of mediation, mainly by inhibition or release from inhibition, of a constellation of interacting nonlinear oscillators (thermodynamic engines) whose operating conditions determined the mean regulated state of the organism. Since such homeokinetic operation of the biological system – particularly its self-referential nature – historically has seemed so puzzling, it is appropriate to suggest a primitive physical foundation.

A factory system, operated by a decision-making homunculus, is one transparent animistic model. An inpersonal hydrodynamic field, organized only by inhomogeneous gradients and detectors of such inhomogeneous gradients, seems to be remote from the richness of organismic processes, although it is quite clear to the meteorologist – with comparable richness in the patterns of weather – that he too only has such limited mechanisms.

The physical key is contained in the notion that the stress tensor in a field is *not* only made up of a hydrostatic pressure uniform in all directions plus transport from region to region by momentum transport. Instead internal processes can well up out of the local structures. These arise because atomistic units (e.g., cells, clouds, complex chemical depots do not quickly equipartition energy among each other during collisional momentum exchange. Internally these units are factories, undergoing internal hydrodynamic processes that too casual an inspection judges as 'thoughtful', a remnant of our animistic heritage. But there are no 'spirits' in the interior of cells, only 'fluids'. They create modes.

As corollary, these processes are not animistic 'computers'. The processes they are involved in can be ordered as equivalent to various types of logical processes. With no homunculus, there is a Turing machine-like computational competence. It is rich because the hydrodynamic field is not constrained to the holonomic coupling of mechanistic Cartesian clock works and gears. Instead a nonholonomic rolling boundary condition, involving thermodynamic losses, for both molecular and cellular interactions, introduces a freer coupling.

7. THE NATURE OF OUTLOOK

(Iberall 1972b)

The complexity of a self-serving autonomous viable system is so much greater than that of a simple served thermodynamic engine that it is useful to attempt to identify the nature of its outlook by some descriptive operational characterization. For example, the algorithm of a simple engine may be stated "as long as there is fuel, run". For a thermostated engine, it might have the additional algorithm "If the sensed ambient temperature is less than T_0, run, but if it exceeds T_1, stop."

For a human, as well as other higher living species, there are many such local algorithms that tend to govern eating, sleeping, sexing, fearing, angering, agressing, talking, etc. But we would like to suggest an overall governing algorithm that is more developed in the human than in other animals, although its rudimentary form can be discovered in primates. It is the nature of the 'outlook' of a human. (Namely it may have started in its modern form either with the hominids like Australopithecus, or with the homos – erectus, neanderthalis, or sapiens.)

In the human, there is an overall basic instability governing the brain state, so that two disjoint states can emerge. For want of a better name, they can be referred to as the euphoric and dysphoric states. This dual represents the overall action 'outlook' of the system as it reacts to the vicissitudes of the day. It is our hypothesis that the time scale for outlook is of the order of a month. Namely, that the states switch with an average frequency of a month, and that the stability is changed by the integrated weight or inclination of the vicissitudes facing the organism for the past month.

The switching does not take place as a purely mechanically timed routine. Large disturbances – grief-provoking incidents, or joyous events – can hasten or retard the switching, but given a run-of-the-mill experience, the approximate 30–60 day duty cycle of switching becomes more routine. The regular nature of a woman's menstrual cycle sits as one common source of signalling tending to regularize the switching. (Not only for herself, but for those males with whom she may be involved.)

What is the nature of outlook? We view it as a dynamic operator. As a best guess, we hypothesize that it represents a response to the average spectral displacement produced by the daily vicissitudes from an image ideal held within the mind (in the euphoric state), and a response to the average spectral rates of change of vicissitudes (in the dysphoric state). The one operator state is sensitive to the recent state of displacements, the other operator state is sensitive to recent derivatives.

If it rains less than expected, is warmer than expected (in winter), if food is more plentiful than expected, etc., there is a tendency for the organism to take on a euphoric outlook. And the euphoric outlook is held and weights inputs by that measure.

On the other hand, when the organism is thrown over to the dysphoric state, it is hyperexcitable and responds to jitters in the environment. Each signal amplitude is added on to the state of jitter.

There is a consequence of these two states in the human. It is manifested as two polar types of personality. There are those who react to social vicissitudes by derivative action. They are preponents of change. Then there are those who react to social vicissitudes by attempting to bring the state back to a past image ideal. They are preponents of conservatism.

These two polar outlooks are responsible for a social action scale which has been identified politically and sociologically as the 'law of the wings'. The scale is usually identified as:

radical	middle-of-the-road	reactionary
liberal		conservative

These outlooks, although perhaps best known within a political context, are not really political but neurophysiological concomitants of human brain structure and function, the concomitants of language and a co-ordination centre.

Other animals are essentially middle-of-the-roaders. They form early a nearly common epigenetic view of behaviour out of their genetic code and the more limited training available within their infant-mother orbit, and there is very little change from a fixed pattern for the species. In mammals, there is often a pack leadership established by individual fighting, and with various symbolic means to indicate submission. Particularly accentuated in primates, there is a group leadership based on a dominant male and an order of submission extending therefrom. In fact, some very specific forms of social organization seem to develop (Eisenberg et al 1972).

But outside of establishing such ordered social patterns there are few innovating patterns. Also there is little organization of longer term behaviour into euphoric and dysphoric states (except possibly for the nursing mother who may show a considerable range of mood in many primate species).

Thus in the human, one finds this dual extension, first of variation of mood outlook in time, and second variation of action outlook among different individuals.

The ability of drugs to change the nature of human outlook is quite suggestive of a chemical base. The appearance of differences of outlook among humans, much more prominent than in other animals, suggests its neurophysiological base. The troubling problems, as with both short- and long-term memory, is to visualize some general chemo-electric construct by which the outlook operator of mind can be determined. We will say something about these problems – outlook, memory, the NS – later on.

8. THE FOUR LOGICS OF THE HUMAN BRAIN

(Iberall 1972c)

It is useful also to be able to descriptively characterize how the brain deals operationally with input signals. Clearly there is a sustained flux of internal and external signal being received and processed by the brain. These 'sensory' signals are received in specific channels and sliced up, abstracted, and transmitted through appropriate channels. The brain handles these data in characteristic ways that are isomorphic with four different logical systems. First there is a brain logic which, as a result of receiving and slicing up signal, recognizes invariance in the input, and so can put a name on the object in the object field. That we refer to as a naming logic. It recognizes mother, warmth, food, softness, wetness.

Second, there is a numbering logic. It recognizes invariance in objects in the object field and can identify their conjunction. This we refer to as an arithmetic logic. It recognizes person as interchangeable with person, toy with toy, food with food, etc. and can identify person and person as two persons, and so forth. Ultimately the idea of both the cardinality and ordinality of number is recognizable.

Thirdly, there is a field logic, a Gestalt of the elements that make up the field without denumeration. This we refer to as a geometric logic. Its characteristic nondenumerability is seen by its inability to exhaust by enumeration all of the properties of a field. Yet an image of the field is held in the mind, and its properties can be named, but without exhaustion. The collective idea of a geometric picture (e.g., a visual field), of people, of a long lost cousin who is one hasn't thought of in years, etc., depicts that geometricizing property.

But the human brain has a fourth logic which might be called reverie. Why? Because with a human brain we can call up images independent of space and time. There must therefore be a logic which can deal outside of space and time. (Even though the brain is space-and-time bound.) We have identified this an ordering logic. Namely, reverie is a metalogic which can order perception. We would say that we do not know how to characterize that logic, yet we believe we could build mechanisms capable of reverie.

Note that it is this fourth logic that is used by humans rather than a much more routine neurophysiological process that switches the dynamic action modalities of other animals into a ring made up of rather stereotyped Markovian chains of behaviour. (To be noted in various etnologists' reports of animal field behaviour.) In the human, 'reverie' intrudes – internally reversing time, converting time into space, expanding or contracting time, etc. – and is responsible for the introspective modes which are quite typically human. Yet by the very nominal descriptive nature of 'reverie', as a key signature of an individual, it is also quite possible for any trained observer to identify the individual.

9. THE CHARACTER OF THE HUMAN BRAIN

What, specifically, makes the human brain different from other brains, particularly mammalian, more particularly primate? We see a higher degree of hemispheric difference and the presence of co-ordination centres that lead to language. These two facets, plus some other known or surmised characteristics of the brain, it seems to us, lead to plausible hypotheses (Eisenberg et al 1972). But first a few notes.

(*a*) A characteristic response noted in many neural nets is lateral inhibition. Namely a transmitted signal pursuing a particular path (whose reason for selection is not fully established) will laterally inhibit side branching chains. The merit to this scheme is that it prevents signal from diffusing out to all reaches of the NS.

(*b*) We continue to entertain Papez' theme that the rhinencephalon is a potential 'seat' for the emotions; or in another parlance, MacLean's broader identification of the limbic system as one which has centres for food, sex, aggression, emotion.

Now in the scheme we visualize, loosely speaking, we expect input in a sensory channel to be discharged in an animal with some direct appropriateness of response. A food signal is discharged by the body taking on an eating mode; a sex signal similarly, and so forth. Obviously in such species, there is a priority ordering among simultaneous signals or signals of different strength, which depends both on the species and the recent previous states (Iberall and McCulloch 1970) of the whole organism. (Namely it may no longer be appropriate to switch at that particular time.) Clearly the work of Pavlov (and later Skinner) outlined the form of conditioned reflexes, whereby inputs in one sensory modality may be translated, by discharge, into some associated neighbouring channels. A visual signal can be discharged by the body taking on an eating mode, and so forth. Clearly, a capability for the establishment and extinction of such parallel channel translation is not an easily achieved switch capability. Transfer cannot be achieved throughout all channels, nor in all species, and some efforts show a large degree of distortion in the experimental result. Clearly, survival utility becomes the major response to the selection pressure applied by the dominant vicissitudes as the modus for developing such conditioned reflexes. This long range result is more important than the short-term laboratory ingenuity by which conditioned reflexes are ordinarily demonstrated.

The human has an even more elaborate capability. Signal entering into one channel is 'immediately' (namely at neural rates of processings per tenth second) translated into all channel modalities. The sight of food can evoke internal memories of smell, of taste, of time, of place, of other images, e.g., of other foods or other things; it can evoke motor responses appropriate to eating, to turning away from eating, to vocal response, etc. This multiple translation is beyond the competence of other species. (For example, present studies are considering whether chimpanzees can be taught 'language' by signs. An earlier attempt at spoken language failed. It is clear that a large degree of 'sign language'. e.g., stands for, is being achieved, but so far, the 'conditioning' represents translation only into adjacent appropriate channels. Namely it does not appear that a level that is highly more involved than a complex 'conditioned reflex' is really being established, and – most telling – certainly not at neural rates).

That human capability to translate into all modalities because of the co-ordination centre in the cortex, in our opinion, carries with it the implication that the mind (namely the dynamics of the functioning brain) can abstract an 'essence' out of the input. That 'essence' is the abstraction of the image, as an internal language, which then in fact can be externalized by speech. (The abstractions are used in two modes. In one they are immediate causes for action in adjacent channels. That portion of signal soon becomes stereotyped, even in the human. In the other mode, the abstractions tend to run aimlessly through the NS until they act as a source for the metalogic of reverie.) We posit that the internal ability to abstract and think in terms of an internal language was soon followed chronologically (we speculate 40,000 years ago, upon the appearance of homo sapiens) by vocal 'linguistic' speech at *neural rates* (say in accord with Miller's magic number 7 rule.) Howerer we have no model for syntax.

As to what this means within the human brain and as applicable to the emergence of human cultural behaviour, we postulate the following:

In modern man's brain the precondition for speech is neural signal engaged in a passage back and forth between the two hemispheres. This helps to accentuate what will become a linearly unstable process. The co-ordination centre translates any input signal into all modalities. This nearly transformed signal passes through the limbic system. But in that system, a large class of switch signals are closely associated. Thus the input now appears in all channels of the limbic system and the hypothalamus. By signal recirculation out of the limbic system back through the cortex, namely acting as a reverberation, a linearly unstable signal pattern is built up flooding all channels. But the mother, in early life, puts some sort of epigenetic shape on the response which is also stored in the network. ("Don't cross the street.", "don't eat off the floor.", namely, mother and later father, and then the tribe teach the repertoire of "thou shalts" and "thou shalt nots", appropriate to each culture.) Thus all channels are not equally flooded, just broadly flooded. The human responds, speaks, or thinks, with any internal selection of abstractions.

That process represents an electrohydrodynamic instability. It restores a broad spread of signal at the overall brain systems' level to overcome the lateral inhibition that takes place at the local neural net level. It makes for a more colourful and adaptive biological species, also one that is always closer to schizogenic failure, but that is a price one always pays in high performance automatic control machinery.

Thus in the human, response modes no longer have to be immediately appropriate to the input excitation. They may be delayed, they may be displaced. The patterns of response become characteristic of the individual, and in toto of the species. Perhaps it may be somewhat clearer of how the content of a reverie function and logic of the brain is to be pictured.

In some crude sense, thus, we premise that there is a gross comprehension of brain and body functions and the structures that are likely involved in an information theoretic, cybernetic, sense. But now we must move back one step to see what we can say about the internal systems with some more focussed detail. We now examine our construct for the system from a more engineering oriented point of view.

Taking note of the basic 'irritability' of the command-control apparatus of all living system levels, clearly what is involved are biochemical (e.g., chemoelectric and electrochemical) states which determine switchings among the various systems' modalities – whether the simplest ring of say a bacteria of ingest-cease and grow-divide, or the human's sleep – arouse – void – motor activate – eat – interpersonally attend – work – . . . The switchings we can recognize as non-linear stability issues.

(It is essential to note that we offer this essentially thermodynamic 'homeokinetic' scheme as an alternate or augmentation to the heretofore more aperiodic and passive base of reflexology – e.g., as initiated and developed by Sechenov, Sherrington, Pavlov and probably culminating in Skinner – Iberall and McCulloch 1970.)

Even though the internal 'language' of such switch states is on the agenda of history, clearly we cannot read it yet in the engraved record of the biochemical state (although it is the purpose of a summary article like this to help prepare the way to that day when the biochemical record can be read in the hormonal and bioelectric fluxes and states that make up the internal 'world' state of the organism, even human).

Thus we require, at least, an intermediate stage of discovery, which if not a fully scientific description provides at least an engineering description of the functional operation of the brain. We have already provided a simplistic version of this in the nature of outlook (Iberall 1972b), namely how the human and other complex organism, say mammalian, transform the total 'sensory' input state, both internal and external, into motor output state, both internal and external.

The basic thought was that the human takes an outlook that is largely dominated either by the deviational state of the world from an image ideal held in the mind's world view, or by the rates of change of the world image. The first was denoted as the euphoric response, the second as the dysphoric or anxious response.

The net effect of this total outlook set is to develop a gradient of human responses from reactionary to conservative to middle-of-the-road to liberal to radical. These are not political polarizations, although they perhaps were so first identified, but the style of both the individual and the existing state vector representing his world image. (The response *is* political within the neuron community.)

There is a rhythm to the nature of outlook, as it swings from its search to optimize its deviational state to its search to optimize the rates of change of its deviational state. The highest frequency rhythms are near 0.1 second response time. Here one can note the individual's response. (Outlook does not change in this time scale). Then at perhaps a 6-second rate, his characteristic attention fragments may be found. It is perhaps useful to give this time scale some experimental content, because its existence is not so commonly known. Four experimental situations will be described. We discovered the second scale first by noting small changes in postures in people sitting in a lecture hall, public transportation vehicles, or working at desks. Approximately every 6 seconds average, there is a small postural change. We found a similar time scale in resting cat and dog. Gulls (birds, not mammals) on the other hand dramatically change every 2 seconds.

We earlier found in the literature this average time scale for eye blink.

A third, even more dramatic confirmation was the technique developed for preparing the American TV programmes, Seasame Street (preschool children) and the Electric Factory (1st and 2nd graders) to test the attention holding merit of any programmed bit (Seasame Street and the Electric Company, in New York Times Magazine section 1973). Every 7½ seconds, a disturbance slide is included in the child viewer's field to see if it will distract him. While originally developed with the younger children, the authors of the scheme had doubts it would work with the older ones. They found it ubiquitous and better than any other test they could devise for attention.

A fourth, easily tested by the reader, is the ambiguous black-white cross figure. The reader can check for himself the average time each state is held in a long sequence of variations. The same 6–10 second scale will be found. We propose this as a segment of functional organization in the sensory – central command-control – motor system that comprises the organism.

A fifth may be taken from extensive studies, which in the end encapsulate their findings by the statement that the "present" is a period of time lying between 2.3 and 12 seconds (Woodrow 1951).

All of these observations tend to support some sort of overall integrated mental set of the order of 6 seconds in time scale. Perhaps it could be described as the flickering (or fluctuational) impulse of attention of the mammalian brain. There are a number of autonomically dominated rates of somewhat longer times (typically characteristic 2 minute responses as a consequence of some fast action hormone modalities that the body has been trapped in), but the next significant behavioural fragments emerge at the scale of the day. Typically one finds a number of fairly characteristic patterned changes of modalities during the day, for example, 6–8 in an 8-hour day. There is a suspicion that this is associated with the same brain mechanisms that makes up the 90-minute epochs of REM sleep. We have speculatively associated this, in humans, with an instability related to the dynamic clutching between two brains (i.e., two large compartments of the brain. From its very nature, we would believe that the reticular activating system, RAS, is one such compartment.)

However the main scale for human outlook, we believe, is the mood changes that scale at the 30–60 day range. It is much more difficult to assign a specific biochemical cause to this process, except to suggest that it involves cellular changes arising from changes in biochemical synthesis and its concomitant bioelectric changes and biases of outlook. Our present conjecture is that this process time scale may be actually involved with the effective time scale for the actual turnover of the chemical constituents of the body. It is more than a metaphor to regard a human as becoming a "new person" every 30–60 days (Schoenheimer 1942). Note that a month is a significant recovery period for many brain injuries.

Since its consequences are so much more pronounced in humans – whereas in other mammals the outlook is more associated with weather and sexual state – clearly the 'new' aspects of human cortex are involved, namely the co-ordination centre. We must infer that the instability links – neocortex-limbic system, left-right hemispheric instability are involved. And as we have suggested, it stems predominately from a bioelectric bias. (Those poorly known issues that are to be found in weather listlessness, humidity, positive or negative ions and the like.) The one clear signal is the menstrual signal. Others are the state fluctuations found in periodic manic-depression.

In general, it should be clear, other mammals have some of the same character of outlook, but in much less pronounced degree. In our previous frame of reference, they tend to be more 'middle-of-the-roaders'.

But there is another piece we can add to illustrate the nature of 'outlook' in an engineering sense. Suppose an organism is confronted with a complex task (namely, without making the task as multidimensional as conducting life itself, or running an establishment – factory, household – yet we wish to refer to such highly committed task, but we wish to view it as one that can be reached in laboratory test). What is his response? We believe that studies on high speed jet aircraft trainers have exhibited the full range of response (Cacioppo 1956).

The specific result seems to have been that a person untrained in aircraft control of any sort reacts with a highly undercontrolled 'wild' high frequency response; a person well trained in a like task (propeller craft) reacts 'conservatively' with a slow frequency overdamped response (he creeps up toward control); whereas a person well trained in the high performance task again has a high frequency, but this time quite precise response to control. We can well imagine one or two 'abnormal' responses in which the person absolutely freezes 'catatonically' or 'autistically' to the task.

But basically, we submit that these three 'normal' responses exhaust the engineering nature of outlook. Namely 'dysphoric' responses are large high frequency responses, with large derivative actions, in which the person seeks to find a control mode that will serve.

If he gets experienced, then note he can use his high frequency response in a 'euphoric' response in which he will follow the changing vicissitudes easily. Namely he is reacting to the deviational states since he 'knows' 'automatically' how to wash out derivatives.

But if the experience is beyond his capability, he withdraws and operates at a slower rate that will try to follow the main changes of the world image about him. He returns to the paths that 'mother' has taught him.

Thus the progression is not a simple one from 'radical' to 'reactionary', though it is often thought so. One may start 'radical', switch then to 'conservative', return toward a mild 'liberalism', drift toward 'middle-of-the-road', and perhaps wind up at either extreme, although the general belief is that one tends to become 'reactionary' in old age.

The point of this description of change in life outlook is to illustrate that it tends to be a broadly swinging transform that changes in various long terms with experience and the changing vicissitudes. (As one more illustration, a competent orchestral musician accustomed to a standard concert repertoire may be horrified with modern 'classical' music, Bartók and beyond, or with jazz, boogie-woogie, rock and beyond. Thus training experience and changing vicissitudes are both involved.)

Clearly the reason that the brain must be able to change its 'transformational point of view' in handling input is that otherwise it could not be adaptive to the broad multidimensional field of input. It would (and sometimes does) break with a rigid machine-like response. Animals, with their lesser range of extremes of outlook, when caught up with man's high speed operational capability often do not adapt and survive. The so-called domesticable ones do, but they often pay a long-term survival price for that adaptability. It is quite possible that they lose their regulatory capability for control of their reproduction rate (Domesticated animals breed on regardless, in New Scientist 1973).

"Intensive farmers, accused of treating their animals too harshly, often argue that the beasts must be content, or they would not be so productive. That argument has long been suspect with respect to rate of growth, since in humans overeating, leading to obesity, is often associated with depression. But the argument did seem on firmer ground when applied to the intensive animals' propensity for rapid breeding, since in wild animals reproductive performance suffers in times of adversity. But at the joint meeting of the Society for Veterinary Ethology, and the RSPCA, Professor Peter Jewell cast severe doubt on that part of the argument as well. Jewell reasoned that one of the key features of domestic animals is that they have quite simply lost the ability to respond to the adverse conditions that would suppress breeding in their wild progenitors".

We can pursue the consequence of this overall modelling of 'transformational outlook' one more step. Here we have left scientific characterization, even 'engineering' characterization, and proceeded to an 'engineering-behavioural' characterization. While dangerous and highly speculative, it at least makes artistic connection with the behavioural sciences, perhaps psychiatry, psychology, or even ethology.

We have described a 'rational' response, namely given a great variety of multidimensional inputs, we have offered a feasible scheme for regulation and control by an organism of its sensory-motor apparatus so as to achieve a useful end goal of outputs for the organism. That 'goal' is sustained autonomous operation of the system independent of the vicissitudes – homeokinesis (Iberall and McCulloch 1970).

In fact, we believe we could build such an operative system. In an engineering sense, that tends to be the most severe test of a series of ideas.

But we wish to turn to the question – suppose the 'rational' response is not satisfactory for the operation of the organism. Of course one recognizes that one solution is death or breakdown. But we want to show the rational path toward breakdown.

How can breakdown occur? One way is internal breakdown. At this time it is outside of our scope to deal with the various biochemical malfunctions by which breakdown could occur. We assume that some reasonable classification, even if not perfect, can be constructed.

Our concern will only be with an introduction of breakdown due to changes in external conditions in which the organism loses competence to deal with the vicissitudes.

First with moderate increase in severity of change in the vicissitudinal impulse spectrum that the animal (e.g., human) faces, if slow enough there may be time to learn (epigenetic) or adapt (genetic) to those changes. In fact, as we have suggested it was the vicissitudinal weather changes of the Pleistocene acting on the primates (and other species, e.g., ruminants and burrowers) that developed the selection pressure from which man emerged with a genetically modified brain, and learning and memory capability for tools, speech, and other items of culture.

That aspect of accommodation or adaption will not concern us here. We have discussed it elsewhere. What will concern us is the shorter, within a lifetime response to badly changing vicissitudes.

If confronted by vicissitudes which are very fast, as we have said, the tendency is to try to follow them, if one has no experience. But if they continue (which in itself is an experience), the human begins to filter his response and not try to follow all the detail. If you will, the RAS 'sets the gain' and you do not try to follow as much.

But now *either* the slower response is effective to some extent, whereupon the human becomes quite expert at extracting or pattern recognizing that response potential among what is otherwise high frequency noise to him, *or* his response has no effect. To what can he turn?

It would seem that the most characteristic animal response (mammalian) is to turn the regulatory transform into the internal system. The system's outlook becomes 'depressed'. Namely it seems that if events follow – 'good' events or 'bad' events – that do not depend on the individual's actions, that the animal tends toward an outlook of depression.

An idiot machine responding with a fixed algorithm, regardless of how complex, will not become depressed, although it may become schizogenic. (Namely unstable, if it discovers motor active and sensory modes by which it can try to reconcile conflicting signals. To illustrate, fix a cooling air conditioner and the heating system in a house with a control band that is not sufficiently discriminating.) It may break down from the extreme stresses put on its operation (e.g., as in humans, a double bind).

While a human is not an idiot machine, again we must discover experimentally how its breakdown will occur. While 'depressed' levels of external operation and 'schizogenic' levels of external operation are physical – in fact thermodynamic – characterizations of systems' operation, the details of malfunction depend upon design. Thus what we describe is physical, cybernetic, but observationally scientific too.

A number of responses are recognized as characteristic of depression. These are:

Passivity of response. – The organism sits and withdraws from much or all active response, not only to the initiating vicissitudes, but to all vicissitudes.

Negative image (or associated retardations). The withdrawal is not only passive, but it is associatively passive, in fact negative. As one group of investigators have characterized, it is a learned helplessness. Any required action sets up a whole chain of negative reactions to every aspect of a response. Even from successes nothing is learned.

Lack of aggression. Clearly it is not only a controlled inhibition, but a basic systemic inhibition in which the limbic system is not freely in the excitation loop as it is ordinarily.

Loss of weight

Lack of interest in sex. Note that in all three of these functions (aggression, eating, sex), basic biochemical modalities processed by the limbic system are highly reduced. It is as if the systems' gain (of the limbic system) has been highly reduced.

Depletion of catecholamines in the brain. At present this note is only a most primitive example of brain languages. Nevertheless it is one of those pieces that indicate the reality of biochemical, bioelectric involvement.

The point in developing this extension of cybernetic ideas is less to provide a basis for insight on how to view and treat depression (e.g., by dragging the depressed animal from extreme to extreme until he begins to break up his reactive depression by the beginnings of protest reactions, rather than by passive neglect), than to attempt to justify the notion of derivative and displacement reactive outlook, by showing what happens to outlook when the system 'gain' becomes highly depressed. Clearly one does not switch violently from outlook to outlook – although it may on early transient response – but one settles down to a broadly linked lethargic 'displacement' outlook. High derivative 'anxiety' is no longer the response. The system decays almost to rest. In some extreme cases, schizophrenia and the like, a very conventional limiting kind of 'anxiety' response emerges. The system bounces between extreme outlooks, but with no erratic flexibility. The response is routine.

The point in such descriptions is that, even for the richness of characterization required for the human mind, nevertheless one can begin to detect the limits of its mechanistic performance. The human mind is innovative, cognitive, abstract, memory rich, learning prone, but the patterns and ways are quite characteristic and the mechanisms that promote these patterns are beginning to emerge.

We propose now to take one step further back, namely to turn to some of the fundamental themes by which the NS becomes organized.

11. PHYSICAL ACHIEVABILITY — FOUNDATIONS FOR THE CHARACTER OF THE BRAIN

The brain is an elaboration and emergence of ancient themes (Llinás 1974).

We propose to show that the evolution and emergence of the brain is not such a unique cosmological event as to defy imagination, but an elaboration and emergence of simple ancient themes that have arisen over and over again to provide us with ever increasing hierarchical orders of complexity.

To illustrate this thesis with a systems' level that is just below our ken, we may first speak of molecules as a structural level below our interest. Molecules draw upon and organize from a corpus of material – the electrified "fluids" that make up nuclear particles (protons, photons, electrons and neutrons – or, dealing with the nominal fixity commonly facing chemical association of these electrified fluids, from diverse nuclei, photons, and electrons).

We find four characteristic entities in being or transformation:

1. The existence and preservation of the diverse electrified 'fluids' making up an internal environment.
2. A sensing ('prescience') of the external environment.
3. A controlled motility of a command space within the external environment by characteristic modalities.
4. A secretion of mass-energetic fluxes between interior and exterior environments.

Although this level is meta to our interest, the players and their actions are sufficient, given enough time and appropriate physical conditions (which is not our present interest to define), to produce autonomous viable living cells (Proof – cells have come into existence in perhaps 1–1½ billion years after the formation of our planet with its solar source).

However, note that what our nuclear particles do in a community of nuclear particles is hardly different, in a primitive sense, from what they do by themselves. Therefore except for extremely rare, or slow events, they seem to have an independent highly fixed existence, as far as it concerns the more active chemical processes of life (Iberall and Schindler 1973).

But now our attention turns to the 'social' character of these nuclear particles when they are organized into the patterned and ingathered ensemble known as a primitive living cell.

What living cells do, or rather what their characteristics are in being or transformation, follow:

The persistence and preservation of an active water pool (plus a number of other material pools).

A sensing (prescience) of its external environment.

A controlled motility of a command space by characteristic modalities.

A secretion of mass-energetic fluxes between interior and exterior.

A few passing notes are in order: While a 'potential' exists for complex organization by nuclear species other than the pattern known as H_2O in the liquid state, there is an extended argument that suggests that the complexity of 'natural' life could only take place in the liquid state and that only the 'solvent' HOH is feasible. The essence of the argument would be that complex organization by natural means can only take place and persist for long periods with low global energetic profiles. If compactness and sparseness of organizing forces were not at stake – namely with greater fussiness and more attendees – perhaps comparable complexity could be otherwise constructed. Thus it is our tentative surmise that the watery pool won in the competition for complex organization to form the ecological domain known as biochemical form (i.e., life). A lesser degree of co-operating nuclear species – also low energetic profile – exists as geochemical form (e.g., complex aluminium silicates, and perhaps carbonates).

A second note is that, regardless of the organization level, entity to entity interaction exhibits only two classes of physical modalities – the 'incoherence' of diffusive interaction, and the 'coherence' of wave interaction (Iberall and Schindler 1973).

More primitive than the notion of ensemble modes, but basic to the physics of organization, is that the ensemble processes are governed by the laws of irreversible thermodynamics. And that roughly means that the ensemble finds itself an equilibrium or near equilibrium configuration (i.e., with regard to every degree of freedom, there is a local 'equilibrium' value from which there are as many deviations 'greater than' as 'lesser than'); there are a variety of local conservation laws (appropriate to the association – e.g., conservation locally of cycles of energy, mass, momentum and charge interaction).

We are satisfied that we have developed a preliminary descriptive image of the cellular process sufficient to begin serious modelling (Llinás and Iberall 1977).

Again, although this level is meta to our interest, the players and their actions are sufficient, given enough time and appropriate physical conditions (which is not our present interest to define), to produce autonomous living organisms which consist of an orchestrated ensemble of single cells.

But what our cellular entities do in a community of cellular entities (i.e., a colony or organism) is hardly different, in a primitive sense, from what they do by themselves.

But now, for the first real level which is not meta to our interest, we turn our attention to the 'social' character of these cellular particles when organized into the patterned and ingathered ensemble known as a primitive organism.

So, we arrive at the question, how and what shall we call the game of life? (namely is not life conducted by gamesmanship according to some rules and moves and strategies?).

We note again, it must be thermodynamic. If natural, it must run with low energetic profile. Out of diffusion or wave propagation (the only ~~true~~ two systems' modes possible in type), there arises a 'coherent' possibility of interaction, which by the cellular mechanism of 'secretion' is not inertially governed. This new theme was added to the cellular ensemble, which the individual cell did not possess. It added the diffusive-wave propagative modes to the system.

But this very note represents a significant victory for our descriptive efforts. All 'secretions' between cellular entities (as before between nuclear entities) are not 'coherent'. (For example with nuclear entities, not all combinations form 'molecules', not all associations are capable say of such binding as by exchange forces). Insofar as there was a possibility for 'evolutionary' change in cellular character, then it is only relatively specific 'secretions' that produce a capability for coherent co-operative action. The point is that the laws of physics and chemistry do not preclude the possibility, and a richness of moieties (i.e., chemical molecules) can be tested in long term to find those that might fit. 'Fittedness' at that point is likely no longer a matter of very specific chemical properties as much as a requirement for specific spatial-temporal characteristics.

So that this theme should not be regarded as too cryptic, some words of amplification are desirable. The notion of secretion itself, particularly in or nearly in watery solution, implies molecular streams (namely atoms, ions, or molecules). If our concern with these streams is functional, these 'streams' can only perform or be caught up in one of three functions (or chains). They can contribute to power engineering (the large scale energetic engineering processes), to communications engineering, or they can be nonfunctional (e.g., 'decorative') end products. If the chain is ongoing, we will not stress again but note in passing that it of course must be thermodynamic.

Thus we might expect to find co-operative power engineering for function in the organism (e.g., motor action); communications engineering via 'language' fragments for functional co-ordination or co-operation (e.g., by catalytic molecules such as enzymes. One must understand that the fluctuational exchanges between co-operative moieties at all levels, nuclear, etc., may be regarded as language fragments, without denoting an anthropomorphism. Simply the 'catalytic' property of co-ordinating power transformations is the primitive meaning assigned).

But what has been gained in the ensemble association of such moieties, here cellular moieties?

What emerges is a patterned richness of the associations due to an exponentiation of states that can emerge as co-operative modalities. (To cite a primitive notion of the tremendous gain by exponentiation, if aleph null denotes the transfinite cardinal number of the integers, two to the power aleph null is another cardinal number which is profoundly greater than aleph null, namely it is not denumerable and in fact, is the cardinal number of the continuum.)

> *Note:* The mere act of binding in an ensemble, by itself, does not create a patterned richness in modalities. For example, nuclear binding in the solid state, e.g., to form an elastic wire or bar, only exhibits a few diffusive and wave modalities. Thus, while the wave mode in a bar, say a transverse wave, has an infinite number of degrees of freedom corresponding to all of its resonances, it hardly exhibits a large degree of patterned richness. On the other hand, the variety of nuclear bondings possible in the secretion streams between cells, although largely geometric and temporal, begin to write with symphonic tonal complexity – time, amplitude, sequence, etc. – all begin to exhibit a much larger exponentiation of patterned states.

But the cellular ensemble associations, simply by their being, are not sufficient to make 'life' the dominant keynote process that it is on earth. A stronger property is needed. The property required is a peculiar one. It is not solely sufficient that such associations come into being, as it were, by accident, by some occasional interactional confluence, even if evolutionary, sufficient to produce a

$$\frac{dP_i}{dt} = KP_i$$

where P_i is the (homogeneous) associational population and K is a weakly positive 'growth of population' parameter. Because of the vigorous nature of natural vicissitudes, the second law of thermodynamics requires the existence of a negative definite value of growth, a breaking of associations. Autonomous persistence requires a strong physical reason for a net *positive* definite growth constant. (Again one must note that it is the vigorous nature of natural forces that drives the argument. A small positive nuclear energy yield can become a foundation for a nuclear power source only if highly nurtured in a particular locale. Else it requires stellar dimensions to proceed with only gravitational force. The scale issue is quite dominant.) One self-organizing nuclear explosion has been found on earth.

Thus basically, a functional need exists for a strong foundation for a 'growth' parameter that can sweep from negative to positive. Control processes for that parameter must come into existence.

Thus reproduction is a second basic communicational step that must emerge in the secretional processes of the social association (not the reproduction of the single cell, but secretive communication between cells). This, patently, was a long delayed process (perhaps ½ billion years?).

Thus, even though what the cell does in a community is primitively hardly different from what it does by itself, if we take a cell focused view, independent of organizational complexity of the organism, we see in the evolving cell, a growth in genetic coding complexity. If only a few hundred enzyme 'instructs' deal with the primitive unicell's modalities, the number grows to the tens, even hundreds of thousands, in the most complex cells.

But if it is only ancient themes that are served over and over again, of what 'advantage', what 'purpose' is served by this proliferation of instructions?

But this really brings us up to the basic evolutionary question. Let us prepare the ground work for that question in the following way:

We will regard it as certainly a strategy and possibly even a 'law' for viable processes and viable systems (ones that sustain themselves autonomously) that if there is a functional advantage* and an unoccupied temporal domain, it becomes feasible and likely to find a physical-chemical process to fill that temporal hole by entraining the process into existence, given enough time. The proviso is that the occurrence of such process 'evolution' is serial and ordered, namely while there is selection branching, the processes occur in feasibility sequence. The 'proposition' really states that process yoking is so dense that the entire state space of connected mechanisms gets nearly filled (i.e., there are branchings in the vicinity of every point).

So first the cellular coding complexity, of itself to the rest of the world, grows. But this has a limit to how advantaged persistence and survivorship can be. Thus increased genetic richness – coding – can only relate to intercellular interactions. Thus the step we visualize is coding for a primitive 'exchange' language. Thereby the richness of association can take place and be coded for.

But what is to be gained by increased complexity in the unit genetic code message? The only advantaged selection has to be basically on increase in the

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* Functional advantage – a system is functionally advantaged if there is a structural-functional unity which protects the sustained operation of the system against an increased range of disturbance variable to which the system is immune to failure by thermodynamic degradation.

growth rate constant K

$$\frac{dP_i}{di} = KP_i$$

How or why? It must do so by some new style or mode of homogenity breaking or splitting. Namely one side, or segment, or partner in association begins to take on some specialized and advantaged division of labour.

This stresses something of the very primitive nature of the summational invariant of number, that is of reproduction. Such early evolution of inhomogeneous particle type (whether a rain of nuclear particles early in cosmological evolution, or the proliferation of colonial type living associations) becomes explosive.

Thus the needed extension in DNA of enzymes and followers for more rapid growth from hundreds to hundred thousands, but also as a step that emerged quantumly, discretely, orderly in time took place.

Thus in principle, in serial phases, the first phase was a single cell engaged in a complex intercommunication with its environment, and a second phase took the complex communications up through colonial organization. (Just as at a much higher level of organization, an explosive competence in intracellular communicational organization emerged as cultural process among our primate ancestors about 40,000 years ago – Iberall 1973b.)

Since the emergence of such intercommunicational complexity might be regarded as very mysterious we would be tempted to 'explain' it as follows:

A cellular process, deriving its metabolic thermodynamic process from solar energy, came into existence. Namely a physical-chemical engine process based on solar photochemical syntheses and storage of energy, could and was entrained. At some later point, in the serial order of processes, the cell had to deal with oxygen as a toxic substance. (Did the atmosphere change from reducing to oxidizing through the action of cells themselves?) Likely not all succeeded, but at least some did. Most successful of all possible processes to entrain was an oxidative engine itself. Thus both storage, dispersion, and ultimately utilization of the high energy stores associated with oxygen were entrained. We are tempted to hypothesize that oxygenation was the first step leading to colonial organization. Namely the presence of oxygen 'developed' the mitochondria where the mitochondrion became an internal thermodynamic engine that could deal with and help the cell 'thrive' in an enriched oxygen atmosphere. Then the energetics could be supportive of a richer association, namely colonial organization.

Thus we suspect and offer as our basic ancient theme. Interactions create dynamic form, which is then followed by supportive function which finally 'precipitates' toward static form (i.e., hard or semi-hard mortar).

Thus we have provided a pathway for staging revolutions. We can first imagine an equipartition of energy as in gas molecules in which, at most, one can get a wave-like and diffusive growth in complexity. Standing waves, vortices, intermittent flashes, shock waves, are all exhibitions of functional forms associated with rapid flow processes. But we find quantized jumps as summational invariants find new paths to precipitate into. The liquid state is the gateway to such form.

The closer interatomic associations create new patterned complexity. In one path it precipitates toward static form – the solid state (i.e., organization). In another more specialized way it precipitates toward a new state of matter – the living state (ultimately the semi-gelled state of a bureaucracy). Thus the revolution from gases to liquids to living cells to colonies to primitive plants with increased social intracellular communication takes place.

So at this level we can visualize colonial 'plant' (in the sense of a factory) systems, namely systems in which coherent 'waves' of communication take place without 'wiring'. Namely we begin to have the emergence of the homologies of the nervous system, except for its high frequency propagation.

Note that for cells to communicate, they must be the same 'species', that is they must speak the same 'language'. Namely they must do so by being coded to deal with the same 'touch' mechanisms. Loewenstein has provided us with the primitive theme (Lowenstein 1966). They must touch and couple electrically. They must deal with like processes, so that they can talk the same language.

> *Note:* In order to deal with complexes of form and function that emerge in the physics and chemistry of the living state (and that lead to the complexity of the brain), we must add a dogma, certainly a strategy, for the formation of complexity in living systems. Ontogeny recapitulates phylogeny. We find it essential to rest on this theme. For the emergence of any complex line of development, the living system evolution goes over the process by starting from the beginning. It must proceed step by step. Like all factory manufacture, it must start from primitive materials and processes, it cannot store and start from subassemblies. Any false notion that it does, will really be confronted by the point that the energetics of maintaining higher ordered subassemblies around will result in a higher cost. Thus it is cheaper – and this thus wins out in the end – to run the process through from primitive start-up.
>
> The only difference, as complex forms develop, is that the sequence of steps goes faster – i.e., formation of gap junctions for communications, fluid wave processes, etc.
>
> Naturally, therefore, the coding tape length itself, in ova, is already a measure of developmental complexity.
>
> Thus the beginning stages, bacterial, colonial, plant, etc., are always the same in sequence.
>
> Even though this dogma, this strategy, is disliked by many on philosophic grounds, nevertheless it seems to be essential for thermodynamic reasons. Namely, while there are times where energetic opulence and need can conspire to permit more luxurious assembly, in the long run the cost is too high.

But the richness of geometric-kinematic branching that becomes feasible when energetic cells bond communicationally requires some kind of physical focus. Else unlimited growth might be viewed as possibly taking place. The dynamic 'strategy' that emerges seems to be a resolution by inhomogeneity. The issue is one of dynamic stability. Namely there is the formation of a dynamic inhomogenity that relieves the stability issue. A spatial-temporal form-function quantization emerges at some cellular scale so as to form intercommunicational 'atomisms'.

These are functional forms or units. These emerge with some minimum structural competence to perform particular functions. Which such branchings emerge (because many are conceivable)? Those which are organismically advantaged, that is, those that contribute – in their ecological niche – to a relative gain in survivorship.

It is this interplay between physical branching and gain in reproductive reliability that makes for the selection and evolution of the living state, conservation of organismic number being its primary new conservational addition over simpler gas-liquid solid states of matter.

Thus in a primitive sense (not in a total organismic sense, because new synergies may arise from the total organ) what the functional unit does in a social organ community is hardly different from what it does by itself.

But there is a question which is perhaps more primitive than the act of incorporating the toxic substance, oxygen, into the interior as a new energetic base for an aerobic, oxidative, engine (i.e., oxidative phosphorylation). That is a mechanism for actively admitting substances into the cellular interior (e.g., cations) – namely all the so-called pump mechanisms. But the process becomes most interestingly in focus when we have an oxidative engine on board.

So far, primitively, we have an engine encoder in the interior, an interior mechanism for making protein (both of these as well as other mechanisms are all active local thermodynamic engines based on incorporating inhomogeneous hydrodynamic transport mechanisms), and for making lipids, and a membrane. We now have pictured the development of an interior hydrodynamic instability that crinkles up a local membrane wrapped around an oxidative engine process (the mitochondria). Now we want to call attention to a process, likely associated with the globular proteins in the membrane walls – in today's view, the mosaic protein. The problem – in getting this cell activated to do its variety of functions – is what are the operative engines? One such engine is to counter dissipative gradients which ordinarily would degrade order and result in thermal homogeneity and death. Namely what is the 'hydrodynamic' process for maintaining inhomogeneous gradients? Hydrodynamically we recognize them as nonlinear processes – e.g., convection (pipe turbulence, Richardson saltation, Benard cells), rotational momentum (G. I. Taylor rotating cylinders). Now we have to add a 'new' nonlinearity. The recognized need has been confined to a 'shuttlecock' for metabolites, electrolytes, etc. located in the membrane for the past number of decades. But currently we have the most promising answer. Design molecular packages – ionophores, carriers – some oily on the outside to be compatible and 'non sticky' with a lipid bilayer surround. Provide one with a polar snug inside so that it can carry small ions – cations in particular. Let it sit like a Venusian fly-catcher to trap small molecules and shuttle them inside with low energetics.

The point, whether precisely thus form or whatever emerges in the future, is that a mechanism, an inhomogeneity located within the membrane, associated with the protein, coded by its folding into that shape, exists to provide a shuttlecock engine for climbing over potential barriers. (Physicists will recognize this as another form of Gamow-Condon's tunnel effect.) But by its very nature, it becomes a communicational system for specific classes of small molecular moieties – ions and the like. Now intracellular communication, in colonies – particularly with a speeded up metabolism – can take advantage of this process to start rapid intercommunications between cells in organs. What heretofore was a lazy general to-whom-it-may-concern engine communicating with the general environment by such secretory (an unintended pun) processes, now can retain that to-whom-it-may-concern engine process but in a much more precise well-formed linguistic sense. Sounds became syllables – chemical metrons and logons now can exist. A generalized chemical communications network – a fluid distribution system can come into being, to orchestrate functional units of communicating cells (Iberall and Schindler 1973, Iberall 1975).

Thus the next theme emerges with an engine shuttlecock and an oxidative engine (and the necessary growth of internal enzymatic instructions to assure the continued existence of these more complex processes – note how they grow), note that the cell is *forced* into a dual line of development. On one hand the ancient theme of communicating with the external environment for the essentials of existence must continue to take place. This in-out secretory process cannot stop, but now it must be organized in a less haphazard fashion, or better put, those systems that organize it less haphazardly have increased their chances for survival. Thus a relatively rapid fluid distribution system must come into existence. The chemo supply and disposal system that will lead to the blood transport system has to come into existence. It has to come into existence, if colonial organization is to be possible (except for sheeted existence. Anything more complex has to box its own conduits). Thus cellular arrangements in conduital form must come into existence. We do not care to explore all the topological-geometric organization issues. Some of their beginning problems are clear in an engineering sense (e.g., form sheets with conduits between in a simple form of organization. What does one do for more complex form? Use diffusion for distances close enough that rapid enough transport process can exist, etc., Iberall 1973a).

But then an intercellular binding and communications system has to come into existence. Why? Because these cells are the only players available to move fluid, to provide the fluid distribution system. They – not molecules – must row the boat. And thus it is differentiating, specialization, functional unitization, language, intercommunication that will be advantaged. A 'nervous' system is born!

What are the basic mechanisms that have been used over and over again? One, local hydrodynamic field instability associated with local arrays of molecules and their fluctuations. Why can they do that, namely, why can they work as a system? Because (Iberall and Schindler 1973) a 'cell' of $3 \times 3 \times 3$ molecules (one and its close neighbour surround) already is a continuum structure spatially *in a liquid* (temporally it is continuous for the time scale it takes the centre molecule to 'diffuse' out one step on the average. The magnitude of time is about 10^{-10} seconds). Thus such local molecular aggregates are continuum or near-continuum systems. Thus they are competent to power their overlording continuum system – the cell. They act internally as deus ex machina from below for the cell. Conversely the cell acts as a deus ex machina from above for the local power aggregate. Just as later, the fluid and communicational streams act as deus ex machina from outside and above to control the cell aggregate, the functional unit. We should note that a cell with its surrounding neighbours, (e.g., minimally 4, more likely 4, 5, or 6 in sheet organization, or then subsequently 3 dimensionally spatially organized with minimally 4 (units more likely 4–20 neighbours) then force the organ (functional unit) issue of organization.

But these local molecular, near continuum aggregates, are then competent to form local hydrodynamic maintained instabilities, 'forms', that persist. These are the engines, the active sources, that power the cell.

But that now brings us up to the two streams that can 'nourish' the cell, the 'rapidly' convected fluid stream that bathes the cell (or its nearby neighbours) and the cell to cell fluxes between the cells. The issues are that these deal with power and communications aspects; but how are they to be effectively coded?

First how can cells be bound together? Here the debate begins. Obviously it must be an engine. In current thinking we would opt for an 'ionophore' engine, and it seems necessary that it be a cation to provide the end of a gradient, and it seems necessary that it be a small mobile cation so as to be part of, but not structurally essential to, the protein molecule. (Take the view of a designer who rummages around in his molecular supply bin to find bits and pieces which he can 'naturally' incorporate and bind in his structured works of art.) H^+ ? No – it is concerned with its basic electron transport role to provide basic covalent bonding; Li^+ ? Why not? Be^{++} ? Too rare. B^{+++} ? Ambiguous. Oxide too tightly bound, but boric acid complex gets too easily involved through water solubility. Be^{++} has similar problems. C^{++++} ? Yes, it's double bonding got it fundamentally caught up in the structural life process. And so forth. So it finally turns out that sodium, magnesium, potassium, calcium are the first available ones free with rich branching possibilities, and it could/not be sodium because of the fundamental tie up in sea water, the cradle of life. It needs the small cations, and apparently calcium wins the race. Thus a calcium pump is used as a fundamental binder. The electrical game of put-and-take (of electrons) can begin. THE KEY ?

Ontogeny recapitulates phylogeny

But all the cellular apparatus available is macromolecular genetic coding which expresses itself in gel-like organelle factories and some elastic components. And only one kind of process can be repeatedly used – develop fluid-like mobility at every stage.

But we are not writing a tract on the entirety of developmental biology. Thus we must jump. It is perhaps useful to illustrate one primitive form of organization before jumping, that will illustrate the dual processes of electrical fluid streams.

So imagine a sheet of cells lining a tube. It can then 'electrically', communicationally, co-ordinate cell motions to provide coherent wave motion down their length (i.e., peristaltic), then they can govern the stream of fluid coursing through the tube.

Beside the process dual illustrated one should note the two classes of co-operative phenomena which can be involved – one electrochemical and the other chemoelectric. The distinction, possibly partly artificial but useful to stress, might be the following: electrochemical processing – e.g., gating – at the membrane (or cell), can be used to initiate chemoelectric fluxes through the membrane (or via cells).

But – regardless of how it climbs up the tree of complexity – what should a cellular process, an organ unit process be? We must remember what its function is. Its function is to survive, generation by generation, milieu by milieu. Survivorship – the last summational invariant added to form living systems – is the game of life.

The advantaged process in survivorship is clearly immunity to disturbance. That requires process adaptability to the environment, and that means turning every disadvantaged pebble in the path of life (i.e., energy or mass barriers – all that might destroy survivorship) to an advantage, and that also means turning minuses into pluses, and that means – most commonly – phase retarding (or leading) terms by perhaps 90° (e.g., converting out-of-phase losses into components that add some small in-phase to survivorship) and that means increasing the population law $\frac{dP_i}{dt} = KP_i$ immunity of K to disturbance, and that means wearing down the path (i.e., incorporating pebbles into the path) so as to have a low global energetic profile to every path of disturbance. Now what does that circularity of description mean?

It likely means that coding for increased immunity always has to be serial AND accidental and thus branching, but that any branching path that works has to track the entire branch again and again. (Namely ontogeny recapitulates phylogeny is likely more true at the coding level than at the organismic form level.)

How does one – any branch – survive? By folding a sequence of operative modalities into the code. At this point, we must define an operative multicellular organism involving specialization of function. It likely must be a tightly jointed formed structure of

Sensory – Command-Control – Motor

function capability, conceptually little different than the single cell.

Namely there must be increased sensitivity to detecting the surrounding milieu (there must, in fact, likely be an over-sheath defining the limits of the animal, to serve as a reference for detection). There must be transformational processes internally that can deal with such sensed 'information', and there must be a 'motor' apparatus that can affect movement and change. But such movement and change must be co-ordinated by the 'mechanism' that represents command-control.

In the first place these were ancient themes in the single cell organism – the complex multicellular organism does not let go of these themes, it augments and duplicates them in chorus, it provides co-operative processes to perform them. In the second place, it can only provide the same functional themes by co-ordinating the same processes by such chorals (Llinás 1974, Llinás and Iberall 1977).

What can it use to do that? It requires, in some sense, informational macromolecules. Used how? As squirt systems – as the escapements of biology.

Thus process modalities and squirt systems are the new themes, and in order to do this, the organism has to develop specialized cells – by growth – to be involved in these processes.

We will not discuss the physical notion of modality again, except to point out to the reader that in musical terms, modalities are both an orchestral arrangement of players and the dance mode (not the very detailed melody being played) that they are playing. These two pictures, the physical and the musical, hopefully, project the notion of a mode. They are not pure concepts in a nonlinear system. And the orchestra's attention can wander, but in the main it is locked onto a pattern. Grow-divide, or eat-sex-sleep-work-etc.

How to make a mode come off? Clearly a switch must be turned off and a switch must be turned on. Clearly such switch functions must have both a form and a function. Namely there must both be growth and transport molecules for function. Namely, while coding may begin intracellularly, the growth and switching have to be outside – intercellularly now. What is there to switch? A highly (?) primitive process for these purposes is vasodilation or constriction, namely the opening or closing of a duct, really of a stream, really the self forces induced by these intercommunicating cells to self-control the ducts they determine. Clearly the message can come (a) from the stream, (b) through the cells, but the programming issues of how to use both lines continue to exist. The beauty of having both lines is that there always is a branching possibility and thus a latent hydrodynamic instability, and thus *an engine can always be self-organizing*, if the phasing is right. The switch function becomes natural.

12. THE GREAT MYSTERY — SELF-ORGANIZATION

But where shall the escapement entity – the informational macro-molecule – come from?

It is the ubiquitous coding within the cell that keeps producing and proliferating protein molecule complexes, that keeps incorporating any 'idiot' molecule or flux that arrives on the scene via the stream (as an advance note of what storms may be brewing in the environment) by producing – almost at random as it were (as mutations) – suitable ionophores till you find one that fits the delivery schedule, and turns the idiot into a savant! This, at least is a depictable model of how a stream can be coded for as an escapement entity. Now if the switch function, for carrier molecules, for streams, for escapement molecules comes off into a temporal-spatial schedule, we are in business with a parallel emergence of added operational engines of increased complexity. Ontogeny recapitulates phylogeny but in some ordered way. New process modes can come into existence, but only if they can find a space-time domain of proper scale, of cell co-operating with cellular complex to make the scheme self-sustaining, of being responsive to what is new and changing in the environment. Physically we can taste this; we can see this in the geochemical processes in earth. In the latter case, the simpler process of ion exchange (Iberall and Cardon 1962) governs. In life, a more complex self-organizing arrangement exists.

What would be an example (if not the example) of a most primitive informational molecule for this external process? First it must be a polymer. Second it must code with an essentially indefinite length. Third the coding must be reliable, yet it must permit modifications that are not essential to the propagation and reliability of the code. Fourth it must recapitulate the fundamental property of being attractive and repulsive.

These conditions are not unique enough at our present state of knowledge to lead to nucleic acids and proteins. The physics and chemistry are sufficient to specify electrical ionic and exchange (covalent) forces. It is sufficient to suggest that hydrogen bonding, carbon double bonds, handling competence of small ionic moieties, amino acids, water-oil (hydrophobic and hydrophilic) are the available entities. It can even suggest that catalytic processes are possible.

These fundamental sciences are not quite capable of proving the higher levels of organization that might emerge, although they can justify the thought that the next level of organization beyond long polymeric chains are helices, and they can hint that beyond helices might lie a balled up sphere.

But the two emergent themes that are conceptually shocking are the exploitation of helix making helix, and the exploitation of surface coding on a balled up sphere. In engineering, we have learned through extensive experience how to assemble 'building blocks'. What is surprising in the biological sphere is the exploitation of means for building by such simple 'low energy profile' mechanisms.

The true fantastic thing about these two schemes is that they can be so easily mediated to occur or not to occur (i.e., by catalytic control).

What is missing in this so far quasistatic picture is what forces in physics can exploit these low energy exchange building blocks? We have surmised that the basic answer involves hydrodynamic instability, but different from what is commonly discussed today. Currently, the discussion is about stable forms arising from rapid flow processes (using such illustrations as vortices, Bénard cells, G. I. Taylor vortices, von Kármán vortex streets, turbulent eddies). However, we have proposed that the answer lies in the branching possibilities opened by the bulk viscosity (a measure of action – the product of energy and time – tied up in internal molecular modes, Iberall 1975).

While our conjecture is that a controlled bulk viscosity – of free stream molecules interacting with gel-like walls, e.g., at membranes – is the ubiquitous organizing force for biology, we can only indicate its definite nature in a few cases and suggest how it may work in others. For example, the transport of molecules in the interstitial space between capillary endothelial cells takes place by diffusion with a near rolling boundary condition (Iberall and Schindler 1973). That near rolling character supplies conditions whereupon surface catalysis could 'easily' take place by virtue of a number of electrical forces. A suitable reaction with coded (globular protein) molecules is thereby possible. Conditions for making, breaking, or exchanging of bonds are thereby brought into existence. The electrical control, or 'gating' of molecules is thus facilitated.

Considering now the globular proteins within the membrane, they similarly can control the passage of moieties into and out of the cell (e.g., as ionophores) with little energy. Here the 'rolling' contact acts to provide a low energy tunnel through the membrane.

Within the cell, clearly the action of significant organelles and internal structures (e.g., the endoplasmic reticulum, the Golgi apparatus, mitosis of the nucleus, the mitochondria) are dominated by hydrodynamic stability phenomena, but here the organizing processes are electrohydrodynamic and involve the tie up and release of internal configurational energies (i.e., bulk viscosity).

The temptation to consider this outlook bizarre is great. Why? Because we would consider that an extremely complex factory is needed to get all of these multipurposed functions engaged, and it would seem that there is so little apparatus to do it with. The key to the problem, which we have recently learned, is how small and compact a molecular region in liquid (specifically in watery milieu) has to be in order for continuum hydrodynamic processes to emerge. Put simply, we have shown that a 'cell' of 3 × 3 × 3 molecules in liquid behaves as a near equilibrium continuum and is thus competent to take on jobs that its big brother complexly organized fluid stream in a complex flow diagrammed factory might be called on to do. But its fantastic advantage is that as a 'switch' (or any other logical-physical process that one can dream up, compatible with thermodynamics) it makes diffusive or wave propagative movements at the 3 Å and 10^{-10} second space and time domain.

If now this is coupled with an electrically coded controllable wall (namely walls that are neither liquid nor solid, but 'gel') then we have a fantastic control mechanism. Process regulation (e.g., synthesis) likely at all time scales slower than 10^{-10} seconds are possible. Practically the entire competence that we find in higher organism has been brought into existence. 'Compact' electrochemical control 'centers' can regulate chemoelectric streams, and chemoelectric making, breaking and exchanging of bonds. This becomes the 'nervous system' control of the cellular level, a control of secretion. The cellular time limitation is of the order of elastic wave propagations across cellular dimensions (i.e., 10^5 cm/sec across 10 μm, or 10^{-8} sec). The microtubules and microfilaments are also available as remarkably competent cellular system's conductors, albeit slower.

But ontogeny recapitulates phylogeny. So what can work in the cell can be made to work in a colony of cells. The gap is long, but we believe that it only extends from what we have said to the secretory nature of neurons as investigators like Stromwasser have shown in animals with few neurons (e.g., aplysia), or as we have (Llinás and Iberall 1977) begun to develop as a chemical thermodynamic axis for the architectural growth of nervous system components.

In moving up to complex animals, e.g., mammals, we will skip the detailed nature of functional unit organization in organs. Suffice it to say that what is involved is a constellation of electrically bound cells, a coordinated complex of blood supply channels, and afferent and efferent nerves that permit long distance high speed control of secretory processes (Bloch and Iberall 1974).

What is not commonly noted is that the amount of control in a complex mammal (e.g., a human, except for his 'cognitive' functions) is only for a limited number of degrees of freedom. Namely both the motor degrees of freedom and the sensory degrees of freedom are relatively limited. Most of the problem is really only a co-ordination among those degrees of freedom, and there is a large amount of nervous net available for that fact. (One should not confuse the large amount of local nervous net detail and vascular net detail with a fantastic amount of operational freedom.) For example, skipping the hands ~~and~~ mouth, there are only about 30–50 degrees of angular and displacement freedom, and a comparable number of sensory degrees of freedom. From an engineering-cybernetic point of view, this is not highly complex. It, of course, is supported by a large number of motor and sensory functional units, but they are mostly fairly 'hard wired'. The remarkable thing is their emergent developmental freedom, by which a fairly smooth programme of epigenetic evolution takes place with growth, preprogramming, and parental and peer guidance.

The thing that is noteworthy about the human is the large number of degrees of freedom available for the hands (about 40), and the mouth (about 30). One must presume that these are connected with the genetic evolution that converted primate to hominid to homo sapiens. In our view the motor degrees of freedom of the hands led first, tested by the developmental capacity to use tools. Then the visual-sensory competence to deal more elaborately with hand co-ordination pressed on a need for larger central nervous system-brain-capacity. Complexity then pressed on abstract co-ordination, here an internal electro-hydrodynamic instability (too many signals had to be co-ordinated). Thence motor-speech arose to provide external abstract (language) ability.

If we accept a variety of lines of evidence, e.g., Chomsky's deep structures for language and syntax, Levi-Strauss' structural linguistics, Piaget's emergent learning patterns, the irrationality of man, then we may see our problem in reduced form. We have proposed a format for the brain's logical structures, not one logic but four (Iberall 1972c). The remarkable character of man is not his dubious sapience, but the biological system's plasticity. At the lowest level, it is likely modification of the genetic coding chain wherein it can build its length for epigenetic (learned) storage and thus provide memory and style of the individual (Mills et al 1973). At the neuron level, there is the possibility of an early 'imprinting'. Pettigrew and Freeman (1973) suggested that a cat trained with no line structures in its upbringing does not develop edge detectors. This is a rather direct indication of the plasticity of neural development which tends to make it 'epigenetic', namely the result of a genetic code unfolding in a fairly standardized solution milieu. This note was referenced at the time of writing. Since then a spate of studies have deepened the complexity of the issue, but the original theme is still believed quite relevant. It is not clear how many aspects will be found in the development of pattern recognition capability in cells. Thermodynamics furnishes no guide to what may be used for information fluxes, except that it will be material at hand. If it could be proved that the extensive mouth and hands image in the brain of a new-born human infant unfolded epigenetically rather than genetically, the case would become highly made). At the human organismic level, then it is the entire complex co-ordination by which his epigenetic heritage becomes fixed. In all cases it is the co-ordination that descends down to the molecular base level, but its organization is different at each organized structural biochemical level.

Beyond this cybernetic introduction, then the neurophysiologist and molecular biologist must take over, if he can. We are comfortable with the problem.

There is a little explored implication and consequence for multicellular organisms of the ingredients used for metabolism by living systems in single-celled organisms. Loosely we shall refer to these as carbohydrates, fats, proteins. All we wish to note that there is both an anaerobic (oxygen-free) and an aerobic (oxidative equilibrium) chain of reactions. The anaerobic metabolism is more ancient.

We believe, in the first place, that the tripartite line of components lead to the major coded and synthesized line of formed components. Namely lipids for membranes, proteins for coding and gating structures, the third for genetic coding. Now we are faced by a basic question. R. Llinás (personal communication), among others, calls for consideration of another theme that polysaccharides are also responsible for the outlining and establishment of the nervous system evolution during the organism's development phase. The basic point, joining up two themes, is that the optimization of a communications system suitable to discharge all of the internal – generally oxidatively powered – mechanisms (organs and the like), must itself develop anaerobically.

We have already indicated (Iberall 1973a) how hydrodynamic pulsing forces acting within a protein-bound gel is competent to carve out vascular form and thus line those conduits with the form of the organism, in the case studied, the mammal. We would augment that by pointing out the additional need for interaction with the electrical properties of the protein-gel system.

Thus basically we are saying that the driving force to organize the complex organism is a primitive electro-hydrodynamic pulsing which carves out oxygenating conduits so that the life of nearby cells can be supported, and that the extravascular tissue puts forth its more nearly anaerobic demand for a growing nervous system with competence to regulate and control the vascular bed and the organ elements verging on their anaerobic limits. The process, as we might note from a Russian article, is a primitive 'acclimatization' based on a glycolytic system.*

(If true, then cancer might also be a more ancient anaerobic sport – as the Nobelist Warburg pointed out – that, once present, can take over and grow faster than the nervous system in embryo, because the body no longer has the switch means to turn it off.)

Thus growth of a nervous system, we would posit, follows a diffusional-wave propagational axis to regularize secretory function throughout the body. For us to name its local branching specialization in the central nervous system is at this time too specialized and presumptious. The details must become highly neurophysiological. We have been called upon only to provide a generalized cybernetic base.

But given the brought-into-existence nervous system, how does it work? Clearly each local cell region becomes a small chemoelectric generator, an R-C relaxation oscillator, more correctly a nearly balanced aperiodic impulse generator. Basically it is the active resistive part R which itself is caught up in a local thermodynamic engine.

That R part is likely produced by continued growth synthesis on added coded material by the mechanism that Spiegelman is beginning to demonstrate (Mills et al 1973).

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* As Z. Barbashova noted: "As is shown by N. A. Berzhbinskaya, the lower an animal is on the phylogenetic scale, the greater is the role of the anaerobic glycolytic processes in the energy balance of the brain."

"In some lower vertebrates, almost all the energy is derived from the glycolytic processes. Consequently, during the process of acclimatization, one of the factors in the tissue adaption is the reorganization of the energy processes, occurring in the cell, on an anoxiobiotic, i.e., a more ancient pathway of action." (Barbashova 1958)

And then, in our view, the change in local conductance pathways that results from such resistive changes is what carries both memory and command-control. The propagation waves and readout take place by the chemical languages of the brain and other transmitter substances, perhaps half to a dozen in all.

We take final note of a Russian reference, Anokhin (1969), who states, "As is often pointed out, the problem of memory consists of understanding the moment of memorization of a given physiological system's experience and the moment of retrieval of this fixed life experience – in a word, retrieval. Although we are presently able in some degree to form a hypothetical notion of the process by which past experiences are laid down, we are still unable to say anything about how retrieval occurs, that is, through what mechanisms the extraction of a fixed experience is accomplished exactly at that moment and to that degree in which it promotes decision making most adequate for the given situation. Based on the idea of molecular fixation of past experience, we can hypothesize that the chains of chemical reactions originating on the subsynaptic membrane continue in the axoplasm as well. Here they must surely possess high enzyme specificity. It seems to us that it is precisely along this enzyme chain originating at the subsynaptic membrane that the impressions of past experience are able to 'stretch' in precise correspondence to the requirements of afferent synthesis at the given moment. Only the chemical specificity of enzyme processes is able to explain the speed, accuracy, and timing of retrieval which is characteristic of the frequent extractions of information from memory in the process of forming a behavioural act.

"Following Hyden, we considered it quite reasonable to assume that, at some stage of these processes between the subsynaptic membrane and the generator of the cell's axon discharges, nucleic acids may become incorporated into the process. One must visualize for a moment all the dynamic diversity of the processes described above in order to comprehend the immense amount of activity involved in the synthesis. As you have seen, it includes not only the problems of correlating various types of afferent forces acting on the nervous system, but also the internal processes involved in forming our inclinations and motivations and even memory processes as well. We must only keep in mind that memory and retrieval from memory can be of interest to us only in the sense that they assist in the formation of goal-oriented behavior."

Let us illustrate our newly formed view of memory and learning. Imagine a new muscular movement (e.g., learning to swim). The cortex takes habits. Thus a suited co-ordinated connection of muscles and nerves, and supporting blood paths is found. However it is not used appropriately. Some regions along the path are highly worked, beyond the aerobic limit. Those local functional units that were involved always have in their cellular coding, the competence to use the primitive code for glycolytic metabolism. So they do.

But you repeat the pattern, again and again. That glycolytic demand gradually provides the signal (reasons unknown – Llinás has suggested the possibility of the formalism of facilitating signal for new dendrite formation along the glycolytic gradient path) for a continuation of extended coding. The additional enzyme structures develop de novo to support the more complex oxidative process. The numbers of cells that are stressed to anaerobic levels are diminished. The net effect is that path has a facilitating trace for signal in the future. Facilitating how? By a change in the conductance of that path.

From a field point of view, there is one more memory coded into the system. It cannot be measured by any local technique, except by performance as a 'learning' curve.

Thus one must note that the gain in systems' competence is all by non-oxidative processes, but ones using the primary fuels – carbohydrates, fats, proteins – by extension of ancient more primitive modes. A nervous system is extended, an enzyme coding complex is extended. What changes? The fluid and electrical conductive networks. And out of the dual of those two processes, both learning and memory are developed. We have not proved that, but we assert it as a premise for future exploration. (This is our view, which is partly in agreement and partly in disagreement with a highly admirable and provocative view of E. R. John (1972). Each researcher continues to add new pieces, until ultimately one will get the synthesis right. Perhaps our contribution too will be provocative.)

In summary, we are not proposing anew the theory that learning consists of a modification of the resistance of specific synapses within definite conduction units of the nervous system. Certainly well-developed processing centres exist in the NS, but given their existence, how are learning and memory to be secured? We believe it conceivable that it be established by chemical and neurochemical traces, in part de novo, in part as modified protein admission characteristics, throughout the body's field. It is the field form of current fluxes, governed both by the flexible axial conductances and transverse transport admittances which themselves contain the coding for learning and memory. However we have not yet been able to decipher the language.

Acknowledgement. The author must make claim and take blame for the written content of this chapter. However it has benefited from many discussions with his friends, F. Eugene Yates and Rodolfo Llinás. Likely the good ideas owe much to their guidance; while the bad ideas are all the author's.

It is more than fitting to acknowledge a considerable amount of enlightment which the author has drawn from another friend, P. Anokhin, who died since this piece was first written. Many have had difficulty understanding Anokhin's integrative views of the nervous system. Yet they have always struck the author as so remarkably transparent and fitting.

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