Chapter 4 – Mind and Brain in Phase Space

'Mind permeates the universe'. This is an ancient theme, reflected in many varieties of human thought, from pre-historical animism, to the philosophy of the Greeks, to Hindu mythology, to continental Idealism. Recent advances in philosophy of mind and in chaos theory allow us to give a new reading of this old concept. It is my goal in this chapter to put forth a new theory of mind, one that suggests it is a truly universal quality. This theory, which I call hylonoism, is fundamentally participatory as I have defined it earlier: it is based on the exchange of matter and energy, wherein the subject gives something of itself, receives something from the object, and incorporates it into itself. This whole process I see as having a deeply noetic quality.

An understanding of the dynamics of the human brain and its relation to mind is central to the discussion at hand, for two reasons: first, the mind coexisting with the human brain is something that we know most directly and immediately; and second, because the human mind is a particular case of the more general phenomenon of participatory mind. Things that we can intuit and learn about our own minds will have necessary implications for the broader understanding of mind. The brain dynamics that coexist with our minds gives us a model of interactive systems that we may apply generally, and analysis via chaos theory will show that a number of important aspects of mental operation are describable in a new way. In this chapter I explore the dynamics of the brain, suggest an approach to understanding it through chaos theory, and extend the resulting insights to physical systems in general.

1) The System of the Human Brain

Paraphrasing Skolimowski: The human mind is a participatory mind; it partakes of reality, and reality partakes of it. The focal point for the human mind is the brain, an extraordinarily complex system compressed into an exceptionally small space. It consists of perhaps 100 billion neurons interconnected in massive feedback loops, continuously exchanging energy and mass. Each neuron transmits and receives signals from up to

10,000 other neurons. It is primarily the action of these neurons that results in the mind being expressed or mediated via the brain.

The portion of the brain believed to be most responsible for higher-level thought is the neocortex. This comprises up to 80% of the brain's volume. If we could extract and unfold the neocortex, it would look roughly like a thin disk about 60 cm (2 feet) in diameter, but only about 3 mm (0.1") thick[1].

It is well-known that the brain is partitioned by scientists into a number of different regions. The standard Brodmann map identifies some 43 different areas of the neocortex. In broad terms, these 43 areas can be organized into four main functional groups: visual, auditory, somato-sensory, and motor. Additionally, there is the readily identifiable physical structure of the symmetry of left and right hemispheres. And the well-known 'triune brain' description identifies roles for both the 'reptilian' and 'paleo-mammalian' parts of the brain, in addition to the neocortex. And even these three can be subdivided into a number of subsystems – see for example Gazzaniga (1985). Each sub-region clearly has its own function, and yet all share certain common features, and all seem to be integrated by the unifying action of the neocortex.

Here I want to focus on the (perhaps surprising) *homogeneity of structure* throughout the neocortex. Neocortical neurons are primarily of two types, 'pyramidal' and 'stellate'. Stellate neurons are specialized cells that accept input signals to the neocortex from the sense organs, via the thalamus. Pyramidal neurons are the data integrators of the neocortex, summing up signal from adjoining neurons, and then transmitting an output signal (the 'action potential') to other cells in either the neocortex or other parts of the brain. Pyramidal neurons constitute the majority of cortical cells, and they appear to be the key elements in the processes of higher level thought.

Virtually all of the neocortex has a common functional structure. The two most significant organizational features are *layers* and *columns*. All parts of the neocortex (with perhaps the exception of certain parts of the motor cortex) have six interconnected layers: there is the thin outer layer #1, layers #2 and #3 consisting mostly of pyramidal cells, layer #4 acting as the sensory input layer (thus with a higher density of stellate cells), and layers #5 and #6 serving as output areas. Electrically, information flow occurs mostly up and down within 'vertical' columns of cells, about 0.5 to 1 mm wide.

There are regions of the neocortex that specialize in the input (from senses) and output (to muscles) of information; these are the "primary projection areas". They constitute a small portion, perhaps 10%, of the overall neocortex -- Brodmann areas 1, 2, 3, 17, and 41 for sensory inputs, and area 4 for motor output. Even though small, they play an important role in differentiating the varying qualia (subjective or phenomenal feeling) that we experience via the different senses. The remaining 90% is referred to as "secondary" and "tertiary" projections, but these are ill-defined regions, and function more as general information processing areas. Also, even the hemisphere distinction is, structurally speaking, of relatively minor significance. Most inter-hemispheric connections occur between corresponding Brodmann areas[2], and thus they function more as single units than distinct hemispheres.

Thus most of the neocortex, which in turn is most of the brain, is a large matrix of interconnected, non-function-specific neurons. There is only minor variation within the neocortex, the difference being primarily the number of stellate cells (more prevalent in the sensory regions), and the cortical thickness (thinnest in sensory, thickest in motor regions).

2) Action of the Neurons

In simplified terms, each neuron acts as an individual decision element. A neuron receives both 'positive' and 'negative' inputs from other neurons via synapses on its various dendrites or even the cell body itself. The neuron acts to integrate, or sum up, the incoming positive (excitatory) and negative (inhibitory) signals. When the internal neuron voltage reaches a critical threshold, it 'fires' a signal, called the 'action potential', out along its axon. This is a small electro-chemical potential (voltage) that moves rapidly -- something approaching 100 m/s -- out toward other neurons that will receive this signal. They in turn are stimulated upward or downward to fire, transmit to other cells, and so on, in endless interconnected feedback loops.

The axon extends out from the body ('soma') of the neuron, and then branches out at the end into numerous collateral axons that serve as the connections to other recipient neurons. Each axon branch terminates in a small bulb ('bouton') that communicates with a similarly-shaped bulb ('dendritic spine') on the dendrite of another neuron[3]. The intervening space, the *synaptic gap*, is on the order of 20×10^{-9} m. Any given neuron communicates with between 10 and 10,000 other cells, and often will have multiple contact points (boutons) per cell.

The region around the synapse serves not only as communication channel, but also, equally important, it may play a crucial role in memory. In a theory dating back to Donald Hebb's work in the 1940's, the synapses are able to physically and permanently change their state, and thus 'record' information. Hebb's theory is that memory results from the repeated use of certain neurons or groups of neurons, sometimes referred to as 'neuronal loops'. If, for example, we were to reread over and over a certain passage of text from a book, it is reasonable to assume that certain groups of neurons will be repeatedly firing over and over. Through the repeated firings, the synapse connection becomes 'stronger', and, in Hebb's words, the "efficiency [of communication] is increased" (Hebb, 1949: 62).

We can think of the synapse as initially being resistant to energy exchange, but becoming less resistant with use. In electrical terms, we can view it as a resistor that changes in value over time. Neuroscientists have now identified a number of specific ways in which a synapse can change; these include changes in (a) the size of synaptic components, (b) the number of vesicles in the bouton, (c) length of the dendritic spine, (d) size of the postsynaptic thickening, (e) subsynaptic plate perforation, and (f) presynaptic dense projection. Hebb's model is thus confirmed by recent research, and in fact his theory "remains the best attempt to combine the principles of psychological reality and the facts of neuroscience." (Kolb & Whishaw, 1990: 529). Few brain researchers today doubt that physical changes in the synapse play a central role in memory: "[I]t seems likely that long-lasting behavioral change stems from a morphological change in neurons." (ibid, p. 531).

If we accept Hebb's model as true, then the amount of information stored by the synapses is extremely large. If the brain has 10^{11} neurons, and each has an average of 1000 synaptic bulbs at the end of its axon, then the brain has something like 10^{14} synapses[4]. If we assume that the six synaptic variables mentioned above can take on, conservatively, three values each, then we have roughly 1000 different states (3^6) per synapse. These 1000 states correspond to 10 'bits' of information ($2^{10} = 1024$). Therefore, we can conservatively estimate that the human brain holds on the order of 10^{15} bits of information[5].

Compare this to an ordinary desktop PC. At the present time, a 'large' PC memory is around 1 gigabit, equal to 1000 megabits, or 10^9 bits. This memory size is sufficient, as we know, to store in exact detail thousands of pages of printed text and hundreds of photographic images. If we allow that the brain holds 10^{15} bits, this is equivalent to 1 million gigabits; in other words, the brain has the storage capacity of at least 1 million PC's.

Consider the complex, clever tasks that a computer can perform, given its dual limitations of (1) 'only' 10^9 bits of memory, and (2) the ability to process only one operation at a time, as opposed the parallel processing of the brain which executes around 100 billion operations simultaneously. Dualist philosophers like to ask how this mere mass of cells in our heads could produce the exquisite performance and abilities of the human mind. Such comparisons should help alleviate this kind of concern.

Of course, one must be cautious of such mechanistic comparisons, and I make this one only to illuminate the physical complexity of the brain. My main point is that this 'mere mass of cells' consists of 100 billion neurons and 100 trillion synapses, and that this degree of complexity can reasonably account for a considerably high level of thought, behavior, and action.

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Neurons are stable patterns of matter, or rather of mass-energy, that exchange mass-energy with other neurons and with other organs in the body. I have focused on the voltage of the action potential, as communicated across the synapses, as being central in this process. When the action potential reaches a terminal bouton, neurotransmitter chemicals are released into the synaptic gap[6]. The neurotransmitters act as a key and unlock an opening on the other side of the synapse, into which flows '+' or '-' ions from the surrounding fluid. The effect is a small net increase in '+'/'-' charge of the recipient neuron, which is summed with all other inputs. Neurotransmitters may then be absorbed back into the bouton, via a process called 're-uptake', to await the next pulse.

It is interesting that a 'voltage' traveling down an axon results in a 'voltage' accumulating in recipient neurons. This seems to be significant for at least four reasons: First, the electric potential can travel down an axon much faster than could a chemical substance. For an organism needing to react to a swiftly changing environment, this is critical. Second, the charge itself can be carried by individual atoms, such as sodium and potassium, which are smaller, lighter, and more mobile than larger molecular compounds. Third, electric potential is 'generic' in the sense that any ion could play a comparable role; nothing is inherent in the nature of sodium or potassium that would make them the only possible carriers of charge. Fourth, electric charge is 'automatically additive'; the total net charge of a collection of '+' or '-' charges is determined instantaneously and without any processing required, by the very nature of the electric field.

So ultimately, energy itself is passed from one neuron to the next. How much energy is transferred is not necessarily predictable in advance. The transfer may be modified by the conditions around the synapse — for example, the amount and types of neurotransmitters, surrounding ion concentration, presence of other chemical agents (such as narcotics), physical changes to the synapse via repeated usage ('memories'), and so on. These conditions may result in less, equal, or more energy being transferred than arrived at the bouton. Energy may be blocked completely if conditions in the gap do not allow the opening and in-rush of ions to occur. Or, a very high density of ions could flood the recipient neuron, resulting in a much larger net charge than that which triggered the event (much like the action of a transistor).

Neural firing is correlated with changes in the synapses. Part of the energy transmitted from one neuron to the next is absorbed by the synaptic region. The 'loss' of energy is recorded in the synapse. The change, as we know, is such that future firings become more efficient, transferring more of their energy.

Perhaps a simple analogy will be useful here. Consider the synapse as a section of a riverbed. The water flowing steadily through the river represents the base level metabolic activity, such nutrition for cells, carrying away of wastes, etc. Every once in awhile a boat comes along. Each boat can be thought of as a firing. The river is in a very sandy environment, and tends to silt up quite quickly. So each boat drags behind it a dredging tool, which scoops out some small amount of sand. The dredging effort slows down each boat a bit, but makes overall travel much easier for all.

Each boat that passes makes a small change to the riverbed, which persists for a time, but tends to get erased by silt. If lots of boats travel down the river, two things happen: the river channel becomes very deeply cut, and the incremental effort by each boat is small ('many hands make for light work'). If not so many boats come, then the river silts up — the channel becomes shallow, and the occasional boat that does come along has a very slow go of it.

A deep channel, or rather a sequence of deep channels, represents a deeply etched memory. A deep memory has low resistance. It easily admits neural firings, is easily 'recalled', consciously or in sleep. Note that millions of synapse etchings are required to recall a particular thing or event; one synapse alone can in itself represent virtually nothing.

Energy continually flows through the brain. Nutrition-input and waste-output go on continuously. Sensory inputs trigger sequences of neural firings, which can result in outputs to the various muscles of the body. The patterns of neural firings are slowly and continuously etched into the physiology of the synapses, recording experiences which will alter future perceptions.

3) Mind and Brain in Phase Space

The brain is a dynamic, nonlinear feedback system. It consists of physical units, the neurons, which continuously exchange mass and energy. From the preceding discussion, one should expect two things of such a system: it should exhibit chaos, and it should be amenable to phase space analysis. In fact, there is strong evidence in support of *both* of these contentions – as I will explain.

First, recall the pendulum example. The swinging pendulum has several physical characteristics, but only two -- the position and velocity of the bob -- are necessary to describe its essential dynamics as a system.

I have already noted that the position and velocity are the two components of a 2-D pendulum needed to describe the total energy of the system as a pendulum. In more general terms, one needs position and *momentum* (equal to mass x velocity) to fully account for the system energy. More accurately, to describe a general mass moving through 3-D space, one needs *three* position equations (one for each dimension), and *three* momentum equations -- six total. Thus, the phase space for such a moving mass would require six dimensions. To plot the phase space evolution of our solar system, we would need (6 equations)x(9 planets) = 54 dimensions.

Penrose (1989) gives a good description of this process. He elaborates on the subject of my earlier discussion, explaining how phase space descriptions of physical systems are encompassed by a *single moving point*:

> A single point Q of phase space represents the entire state of some physical system… [T]he entire evolution of the system in time -- no matter how complicated that system might be -- is described in phase space as just a single point... (p. 177).

How can all this apply to the brain? If we want to capture the brain dynamics in phase space, we need to account for the essential energy dynamics. One approach would be to use brute force, and consider the brain as a vast collection of sub-atomic particles, each in its own quantum state. One could then describe the phase space of the entire system using quantum techniques. This would result in a state space (Hilbert space) representation, with a single point moving through that space. This is certainly a theoretical possibility, though perhaps not the most useful.

Viewing the brain as a collection of particles has the virtue of theoretical simplicity, because it ignores higher levels of structure. But the brain is not just some miasmic grouping of particles; it is structured in specific ways, into atoms, molecules, proteins, cells, columns of cells, and layers of cells. The brain is a hierarchy of physical structure, and it would seem that the most promising account of brain activity must take account of this structure.

Of the various levels of structure in the brain, that of the neurons appears to be the most significant. As far as we know, all states of consciousness correlate to neural states. Furthermore, it seems likely that these neural states are *unique*; that is, every possible configuration of neural states corresponds to precisely one mental state. If we could somehow track the instantaneous status of every neuron in the brain, we would find that certain combinations occurred when we were happy, others when sad, others when seeing 'blue', and so on. It is highly unlikely that any given combination could recur in conjunction with differing mental states (though many combinations would represent multiple simultaneous experiences, such as 'back pain', 'seeing red', and 'listening to Mozart' all at the same time).

The issue of tracking the instantaneous state of every neuron in the brain is complex and daunting, to say the least. Every neuron exists in a range of conditions, including rest, mild excitation, onset of action potential, potential in transit, synapse release, etc. At the most basic level each neuron can be categorized as 'on' (in the process of firing) or 'off' (at rest). Many computer models in fact regard neurons in just this way, as on/off electrical switches. But this does not capture the continuous, analog nature of its action. To view a neuron as simply 'on' or 'off' is to exclude or ignore much of its complexity[7].

When considering a system with numerous analog variables, the phase-space approach has much to offer. Every axis in a multi-dimensional space represents a continuously changing variable, and the 'point' in phase space represents the instantaneous state of *every* element in the system. For the brain, one option might be to consider the action potential as the appropriate system variable. Since the action potential captures the central dynamics of the neuron, it would seem to be a good candidate. And in fact it may. But there are some difficulties in defining even a theoretical measure of it. Do we measure the potential voltage at the base of the axon, at the midpoint, or at the ends? 'Zero voltage' at any one point does not inform us about the potential at any other point, and so may be misrepresentative.

Furthermore, simply looking at the action potential tells us nothing about communication with other neurons. Neurons may be firing but other substances (like narcotics) may be blocking synaptic transmission. More importantly, phase space analysis does not discriminate whether or not the neurons are in communication at all. One could create a theoretical phase space picture of the instantaneous state of one billion neurons, but these could be configured as one single neuron in each of one billion people (resulting in an interesting variation on the 'Chinese nation' problem). In such a case the phase space picture would exist, but may be meaningless.

Thus it seems to me that a promising alternative is to consider the neurons at the point where they exchange energy with other neurons, and this is at the synapses. The synapse action captures both the effect of the action potential and the necessary interconnection between neurons. If we take as a state variable the '*synapse potential'*, and allow this to vary between '+' (excitatory) and '-' (inhibitory) values, then we may reasonably claim to have captured the essential energy dynamics (though clearly not the total energy dynamics) of the brain. This approach has been suggested in the past (as I will elaborate), and I believe it to be the most promising.

This said, I emphasize that this is only one possible phase space approach. Others may well turn out to be superior. Certainly a strong case can be made that the only appropriate picture is that of the 'ultimate' phase space, that of the sub-atomic particles. Or, hybrid spaces combining aspects of the action potential and the synapse voltage may prove more useful. The particular definition of phase space is not important here. What matters is that *some* phase picture is conceivable, and that *every* such picture consists of a single point moving in a chaotic manner, bound by a strange attractor-like pattern. I would like to suggest that the possibility of alternative, equally-valid phase space representations may be seen as multiple ways of viewing the singular nature of the system. Each particular representation may be a certain *perspective* on the singularity.

The synapse is the point of exchange. We saw that this exchange is one of electrical energy, in the form of chemical ions. Functionally, it is the energy that is important, not the atoms *per se*. So what if we take the *synapse voltage* (defined as the potential difference across the synaptic cleft) as our primary state variable? In this case, we may consider the brain as a system of 100 trillion (10^{14}) synaptic voltages, each varying in response to the internal actions of the corresponding neurons.

What kind of phase space do we get? Each synapse voltage varies along a continuum, from some minimum to some maximum value. In phase space, this suggests *one dimension per synapse*, each representing the instantaneous voltage across it. Thus the brain may be seen as a system with a phase space of 100 trillion dimensions. Such a 'neural state space' model of the brain has been discussed in one form or another for more than 15 years, at least since Paul Chuchland's first articulation of it in 1986 (see Churchland, 1986). My initial presentation (Skrbina, 1994) offered some unique perspectives, all of which are elaborated upon in this thesis.

One of my novel interpretations is this: In this immense phase space of the brain there moves a single point, a point that accounts for the instantaneous state of every synapse in the brain. If we allow that the dynamics of the brain parallel the phenomenon that we call 'mind', and that mind is fundamentally a *unified* phenomenon, then we have a simple and elegant picture: *the point in phase space represents the unity of mind*.

Such a picture can help to answer a number of central problems in the philosophy of mind – unity of mind being perhaps the most obvious. From the perspective of the conventional materialist monism, with nothing but mass and energy to constitute the body and the brain, how can there arise, from only this, the feeling of singularity and unity? The 'unity of mind' or 'unity of consciousness' has been a major puzzle to philosophers of mind and neuro-physicists alike. Until now, they have been unable to devise an acceptable explanation. Phase space concepts, which are outside the bounds of most philosophical and physiological discourse, seem able to provide an answer.

The standard philosophical recourse has been either (a) to adopt a dualist position, in which 'mind' is seen as a non-physical or supernatural entity that can trivially be considered a unity, (b) to define mind or consciousness in sufficiently vague terms as a 'centrally unifying entity', or (c) to deny that the unity really exists. Recently Chalmers (1996) has addressed this issue of unity. In discussing aspects of conscious experience, he pointedly down-plays the unity of experience: "Like the sense of self, this unity sometimes seems illusory -- it is certainly harder to pin down than any specific experiences -- but there is a strong intuition that unity is there." (pp. 10-11) And he addresses it later when listing six basic "open questions" that any theory of consciousness must answer:

> [W]hat makes my visual experiences, auditory experiences, and so on, all experiences of the same subject? I suspect that the answer involves the way that the relevant information is processed, so that the unity of consciousness corresponds to the fact that relevant information is available to be integrated in a certain way. But just how to cash this out is unclear. (p. 309)

Like Churchland (1998), I propose that the "relevant information" is the synaptic voltage, and that this information is "integrated" by virtue of that fact that the brain is a highly interconnected feedback network which exhibits a strong sense of unity, a fact reflected in the singular point in phase space.

The equating of mind with the point in phase space is a very simple conjecture – some might say, audaciously simple. Obviously such a simple picture cannot account for all the complexities of mind, nor can it answer every conceivable metaphysical query. Be that as it may, I believe that it has much to offer in the way of explanatory power, and points to larger issues of mind and participation. Like any theory, it is necessarily incomplete; it is only a step on the way to a deeper understanding of ourselves and our world.

Finally, let me note that my conjecture has a certain important connection to the 'identity theory' of mind. This theory, as traditionally presented, argues that mental states are not independent or merely correlated to the brain, but rather are literally identical with the physical states of the brain. The identity theory is typically portrayed as a materialist monism that denies all non-physical existence to mentality and mind. Standard identity theory is limited in that it only ascribes mind to neural states as opposed to physical states in general (though this is not a requirement), and in that it leaves unexplained certain central characteristics like 'unity of consciousness' and qualia. Hylonoism claims, along with the identity theory, that (human) mental states are uniquely given by neural states; but it differs in that the basis for this view is seen in the dynamics of mass/energy, and as such applies to all physical systems. Furthermore, hylonoism is monistic but *non-materialist* in that it views the unity of mind as an eminently real phenomenon that does not reside, properly speaking, in the material world.

4) Recent History of Mind in Phase Space

I must reemphasize that I am not the first to propose using phase space concepts to help understand the issue of mind and brain. I take this as an encouraging sign. There have been a number of related inquiries and studies in the past 25 years, and I want to take a moment to mention a few of the more relevant ones.

Perhaps the first indications came in 1977, when Edwin Land proposed a state-space theory of color perception, in the form of what may be called a 'color qualia cube' (Land, 1977) – something I address in more detail in the next section. Land did not refer to chaos theory, but he did make the first steps toward representing aspects of mind in *'state space'* (state space being a generalization of phase space). Not long thereafter, neuro-physiologists began to apply state space concepts directly to the brain. In the early 1980's Pellionisz and Llinas (1982) proposed state space models of sensory and motor function.

Then in an important 1986 article ("Some reductive strategies in cognitive neurobiology"), Paul Churchland elaborated on the philosophical implications of Pellionisz, Llinas, and Land's work, and articulated one of the first visions of mind in phase space. Churchland's central argument is that "the brain represents various aspects of reality by a *position* in a suitable *state space*" (1986: 280). By "position" he means the position of the single phase space point that I have been discussing. This main argument is an important development, and hints at a key element of hylonoism. Much of the article is taken in a discussion not of brain state spaces, but rather more abstract 'angular state spaces' that relate, in his example, visual input data to motor outputs. Churchland sees the brain as implementing a *transformation*, or mapping, between spaces – specific sensory inputs yielding specific motor outputs.

Near the end of the article, he addresses more directly a state space conception of the brain:

> The global state of any complex system composed of *n* distinct variables can be economically represented by a single point in an abstract *n*-dimensional state space. This state space as a whole can be neurally implemented…by a parallel set of only *n* distinct fibers. And a specific point within that space can be implemented by a specific distribution of *n* spiking frequencies… (p. 299)

This is very close to the basic view that I am arguing for. On the basis of this picture, Churchland suggests that Land's 'objective' color cube can be translated into an "internal qualia cube" (p. 301), with each axis of the 'mental state space' represented by "the instantaneous activity level or spiking frequency of one of the three [ocular] pathways" (ibid). He then cites examples that suggest that *all* sensory systems operate in a similar fashion, i.e. as a point in the appropriate state space.

Churchland is known for his defense of *materialist eliminativism* – that mind reduces to a material brain, and that folk notions of mental states are fundamentally mistaken. He takes his vision of mind in state space as a strong argument for this view. Thus one finds such materialist claims as: "the 'indescribable' olfactory sensation produced by a newly opened rose might be quite accurately described as a '95/33/10/80/60/55 chord' in some 6-D array within one's olfactory system." (p. 303) – where the numbers represent the coordinates of the point in state space (the 'rose scent point'). I interpret this state space vision of mind differently. To me, the unity of mind is an eminently real phenomenon, and the mental phase space is very much a part of reality. If this mental space (the Partimens) is real, then I conclude that materialism cannot be true. Material substance is not the basis of all reality, but only one aspect or dimension of it. This issue requires greater discussion, which I will give in subsequent chapters.

Furthermore, Churchland fails to explain what if anything is so unique about the *human* brain's state space that only it can experience qualia. In fact, he hints that other, non-human systems may experience qualitative, subjective, mind-like experience (see my comments below). But this is dangerously thin ice for a contemporary philosopher; the ever-present threat of panpsychism looms, which Churchland dodges and I embrace. He does, though, see great potential in the state space description of mind, suggesting even that "it [has] the resources to account for the so-called higher cognitive activities" (p. 305).

Notably, Churchland's 1986 article makes no mention of chaos theory. More surprisingly, he does not address it in *any* of his numerous discussions on neural state space since that time[8]. This is really quite astonishing, since chaos theory adds an important new dimension to the state space discussion.

Other thinkers advanced ideas surrounding mind and phase space. Lockwood (1989), for example, goes into the concept of phase space in some detail, but strangely drops the matter just as he is approaching the most important conclusions. He gets side-tracked on the issue of quantum mechanics and the related 'Hilbert space', and, like Churchland, fails to bring chaos theory into the discussion.

The early 1990's saw a significant expansion in the number of works on chaos and mind. Churchland and Churchland (1990) tackle the issue of artificial intelligence, this time using the techniques of neural networks. This leads them toward a more general conception of mind, including entertaining the possibilities that the 'Chinese nation' may actually function like a mind, and that there is "no principled reason" why intelligent machines could not be constructed. In the same year, Basar edited the book <u>Chaos in Brain Function</u> (1990) which included a number of important discussions. A year later, neurophysiologist Walter Freeman published an article in *Scientific American* (Freeman, 1991) giving clear evidence that the brain does in fact exhibit chaotic behavior. His 'phase portraits' of the olfactory system give an excellent picture of what one might envision as the movement of the point in phase space[9]. And he suggests that a kind of memory resides in the strange attractor patterns, allowing for rapid recall of previous sensory experiences. In 1992, Fodor and Lepore (1992) published one of the first philosophically critical works against Churchland's state space model; they focus more on the semantic and representational issues, asking how each individual (neural) axis in the state space gets its own semantic content from which to construct the larger content. They also argue that variations in structure of mapping and dimensionality between individuals should preclude any common understanding of the world. These are not insurmountable criticisms, and Churchland responds quite ably (see his 1998). Also in that year Churchland (1992) introduces the terminology of "activation space" for the state space of the brain, and of an "activation vector" that locates the point in that space. And as mentioned earlier, a number of other works were released (Kaufmann, 1993; Goertzel, 1993; Goerner, 1994), each elaborating on aspects of chaos and mind.

In 1993 I first publicly presented my own vision of chaos and mind, an early articulation of hylonoism. This occurred at the 13th World Conference of the World Futures Studies Federation (Turku, Finland), with the topic 'chaos and convergence'. Though philosophically undeveloped, my theory of *participatory chaos* captured for the first time several key elements, including (1) the first clear articulation of a neural phase space, (2) a new interpretation of attractors, (3) the identification of the phase point with the unity of mind, and (4) the panpsychic implications. See my (1994) for details.

The broader discussion continued with vigor into the latter half of the 1990's. Kelso and Fuchs (1995) consider chaos in brain activity as centrally important, but neglect to connect the phase space point itself with any real phenomena. Goertzel (1994) and Combs (1995) draw out some psychological implications of chaos and mind, and highlight some important connections between mind and attractors (more on this shortly). MacLennan (1996) touches on all the relevant issues, including reference to the synapses as determining brain state, non-deterministic behavior, and synapse action as 'protophenomenal', i.e. as something mental-like in itself – but again, he fails to pull the points together and draw a cohesive picture.

The Chuchlands return to the subject in 1997 and 1998. In their (1997) they continue the discussion of activation space (phase space of the brain) and argue (as I do) that this makes for a relatively straightforward explanation of the 'hard problem' of qualia. Interestingly, they cite "unity of consciousness" as one of the "much harder" problems – which overlooks the unity of the phase space point itself as an obvious candidate. As such, they are left without much of an answer to the unity problem; they conclude that the brain "can integrate information from different sensory modalities by delivering such information, directly or indirectly, back to a common cell population" (1997: 175-6). One might have hoped for a more clearly articulated conclusion.

Paul Churchland (1997) at the same time argues for a new conception of neural space, one very close to what I am presenting here. He proposes to use the *synapse* as the state variable. In doing so he replaces the terminology of an activation space with a "*synaptic weight space*". But again he stops short of the larger implications. Lastly, his (1998) responds to the on-going criticisms of Fodor and Lepore. Here he returns to the activation space concept, and drops all reference to the synapses. He also explicitly speaks of a space with 'one dimension per neuron' – identical to my 1993 articulation of 'participatory chaos'. Chuchland spends much time discussing how to measure distances in state space. He cites research from the late 80's and late 90's, although similar calculations have been performed for decades in the field of information theory, where the 'Hamming distance' has long been used as a metric between points in state space. His lengthy analysis of simplistic feed-forward neural networks finally gives way to mention of more realistic "recurrent" (feedback) models; here we find "a new universe of subtleties". In these feedback models, he notes just in passing some important aspects of state space:

> [a feedback] network's primary unit of [semantic] representation is not the *point* in activation space, but rather the *trajectory* in activation space."
> (1998: 27)

He seems to sense some importance in this idea, but leaves much unsaid. As I see it, the notion of the trajectory is captured in the dynamics of a quasi-attractor pattern, as I explain in the next section. This is the closest Churchland comes to acknowledging the role that chaos theory can play in the understanding of mind.

Thus it is clear that many writers have explored the application of phase space and chaos theory to the problem of mind, with varying degrees of success. The link is undeniable to many, and I find it encouraging that a major philosophical figure like Churchland has found importance in it. But as much as has been offered, I believe there is much more to the story. As I have mentioned, no one yet seems to have made either the connection between 'point in phase space' and 'unity of mind', or drawn out the panpsychist implications that I first proposed in August of 1993. And one finds only the most fleeting glimpses of a connection to the ideas of participatory philosophy.

As I have noted, the unity of mind is a central philosophical issue. Dualists have (ostensibly) no problem with it, and monists have a big problem. The standard materialist monism has no satisfactory answer. Phase space approaches offer the most promising resolution, but it implies (at least) a dual-aspect ontology. Actually, I am skirting around some essential points here, and I will address these later. But I do want to briefly acknowledge Chalmers' point that a unitary consciousness sometimes seems illusory. In fact, I think there is good reason for this (as suggested in the preceding paragraph), and it follows from a fuller reading of my hylonoism theory. The essence of my view is that, from the perspective of the individual, the most complete unity of consciousness is that of the *entire body*, not just the brain. The brain is a dominating consciousness, but it is only one part of the whole. This discussion, however, breaks into new ground. It argues that something like 'consciousness' results not only from the brain, but also from all other *biological* systems, and even all other *physical* systems. This is contained in my theory of hylonoism, and I discuss it at length below.

5) Characteristics of the Point of Consciousness

The point in phase space clearly addresses the issue of unity. I take the unity of human experience as a reality, and the phase space model gives a simple and elegant account of why it exists. But we should be able to say more. If the model is a valid account of reality, it must demonstrate explanatory power in a number of areas, not just on the issue of unity. Let me mention here four important implications.

One, we may note that, as the brain moves through a succession of 'brain states', the point correspondingly moves through regions of phase space. Since the brain is a nonlinear feedback system, it likely exhibits chaos, and thus, *the path traveled by the point will be chaotic*. This means that its precise change through time is unpredictable in principle. No knowledge of neuron states, no information about sensory inputs or outputs, is sufficiently accurate to predict the brain's progression and overall state. Infinite accuracy would be required, and this is clearly impossible. The brain is like all dynamic systems -- chaotic and unpredictable in detail. This is, at least, consistent with our common sense view of human thought, and of human action. Thoughts and actions are not predictable in detail.

Two: However, we know that *there is a sense* in which thoughts and behavior are predictable, and this is through the concept of human *personality*. A personality is a quasi-stable entity. In people, it represents the range of typical and expected behavior. For most people, barring injury or severe disruption, it tends to be consistent over time, usually from childhood through old age.

The concept of personality corresponds very closely with the concept of the strange attractor. Recall the Lorenz attractor: a consistent, recognizable, semi-stable pattern, which, in a fuzzy sense, identifies the bounds of the possible states of the system. If the brain is seen as a chaotic system, accompanied by a quasi-attractor pattern in phase space, then a personality can be seen as a logical and necessary consequence.

This connection between mental states and strange attractors was first addressed independently by myself, Goertzel, and Combs; all emerged around 1993. In his (1994), Goertzel writes:

> The brain, like other extremely complex systems, is unpredictable in the level of detail but roughly predictable on the level of structure. This means that the dynamics of its physical variables display a strange attractor with a complex structure…" (p. 157)

In the same work Goertzel identifies a 'cognitive equation' as defining a grand attractor which encompasses a person's entire mental life. This is very close in spirit to my description in 1993. Combs develops this idea from a psychological standpoint. He writes, "Rather than viewing a state of consciousness simply as a system, let us also view it as an attractor. … [S]tructures and states of consciousness are strange (chaotic) or chaotic-like attractors." (1995: 59, 61). For him, *each different state of consciousness is a different strange attractor*. This is an intriguing idea; it views the personality as a collection of strange attractors rather than (as I do) a single attractor entity. These are not incompatible views, and Combs' approach has the added benefit of suggesting a research program that may attempt to map out the various attractor patterns.

So: why do people have personalities? The answer seems the same as: why do real chaotic systems follow quasi-attractor patterns in phase space? The reason is related to the stability of the interconnected network over time. In the Lorenz model, the three equations are stable, even though the variables take on many different values. In the brain, the neurons generally establish long-term connections with their neighbors. The total number of neurons is maximal at birth, and they slowly die out as we age. The interconnections also appear to be near maximal at birth, although recent evidence indicates that new connections can occur under certain circumstances[10]. These two factors – the number of neural nodes, and the pattern of interconnections – are central to defining the nature of the quasi-attractor pattern, and hence, presumably, to personality.

What *does* change, as I have mentioned, is the 'weighting' of the synapses. This weighting acts as a barrier, a resistance, to the passage of energy through the brain. Frequent use reduces the resistance along certain paths, thus strengthening the interaction. It is reasonable to assume that the synaptic values at birth (i.e. those of the newly-developed neuron cells) are in some neutral, or perhaps even uniform, state – this owing to the similarity in human genetic processes that give rise to the neurons in the first place. In this sense, the infant brain is 'unprogrammed', or better, programmed genetically only for a few very specific tasks, such as maternal voice recognition, sucking instinct, and fear of falling. An empiricist could argue that this is the genetic *tabula rasa*, the 'blank slate' that infants can appear to be.

It is reasonable to claim that the variation in the weighting, then, changes not the overall personality pattern (which is determined by number of neurons and pattern of interconnection) but rather the path of movement within the fuzzy confines of the quasi-attractor. A change in the overall personality pattern would require either significant change to the structure of the neural interconnections, such as a loss of neurons or a severing of their connections, or the interruption of the communication flow in a significant way, such as through alterations in the neurotransmitter chemicals.

Let me emphasize: it can thus be seen that there are in fact *two unities* associated with a given chaotic system: the *focused unity of the instantaneous point in phase space*, and the *larger-scale, fuzzy unity of the quasi-attractor pattern*. We see strong first-hand evidence, namely, our own personal experience, of these unities in human beings. I believe we have good reason to seek them in all physical systems.

Three, this approach to mind and consciousness is clearly dependent on the connectionist structure of the brain. Connectionism, in the philosophy of mind, is generally seen as a functionalist account of mind, seeking to explain aspects of behavior and learning; it is also usually seen as opposed to the standard 'language-of-thought' model. Discussion of connectionist approaches to understanding the mind are often attacked as being 'merely functional', and as being unable to account for the deeper aspects of consciousness. Chalmers (1996) again provides a case in point:

> Even such "revolutionary" developments as the invocation of connectionist networks, [and] nonlinear dynamics...will provide only more powerful functional explanations. This may make for some very interesting cognitive science, but the mystery of consciousness will not be removed. ... Any account given in purely physical terms will suffer from

> the same problem. ... [I]t will yield only more structure and dynamics. (p. 121)

I have argued that at least *one* of the major mysteries, that of unity (in both aspects), can be accounted for. Churchland argues (and I concur) that *another* major mystery, that of qualia, can be resolved (see below). Furthermore, my approach offers new ways of addressing the issue of *causality* between mind and matter[11]. Chalmers' main concern with connectionism is that it is a reductionist/materialist approach to consciousness, and for a number of reasons he is convinced that any reductionist approach must fail. I think that his sense is right – materialist reductionism fails – but his fear is misplaced. A connectionist-based approach can yield a non-reductionist, non-materialist ontology. Let me note once again that the first piece of evidence for this is in the dual unities of phase space point and quasi-attractor -- they are real, yet non-physical. They reside nowhere in space-time, yet they exist. This fact points toward a variation of non-reductive monism – what I earlier referred to as a naturalistic dual-aspect view.

Four: The chief mystery that Chalmers is referring to above is that of *qualia*, or the qualitative feel of different mental states. This is his "hard problem" of consciousness -- why does a given mental state feel the way it does, or feel like anything at all? This is certainly a valid complaint; most every theory of mind offered up so far fails to explain why an 'inner experience' must exist, not to mention how and why it feels as it does.

My account above offers some new approaches to qualia. The point of consciousness reflects the instantaneous state of every synapse. In the brain's phase space, every synapse is associated with one dimension, which can be thought of as one 'axis' in a 100-trillion-axis space. When confronted with, say, a field of red, certain (thousands) of neurons in the primary visual projection area are stimulated in a specific and unique way. This stimulation results in the point of consciousness moving into a certain specific region of phase space, one that we might call the 'red region'. When in this region, we 'feel redness'. A red 'quale' is, *by definition*, the state of being one finds oneself in when in the red region of phase space. It 'feels' unique only because we are able to distinguish it from other regions, such blue, green, and so on.

In one sense, this is very close to the 'retinex' theory of color perception proposed by Land (see his 1977). The various colors are assigned unique points in a state space, based not on brain parameters like synaptic potential, but on the 'brightness' of each of three wavelength responses that the cells in the eye are tuned to. This model results in a 'color qualia cube' – see Figure 1.

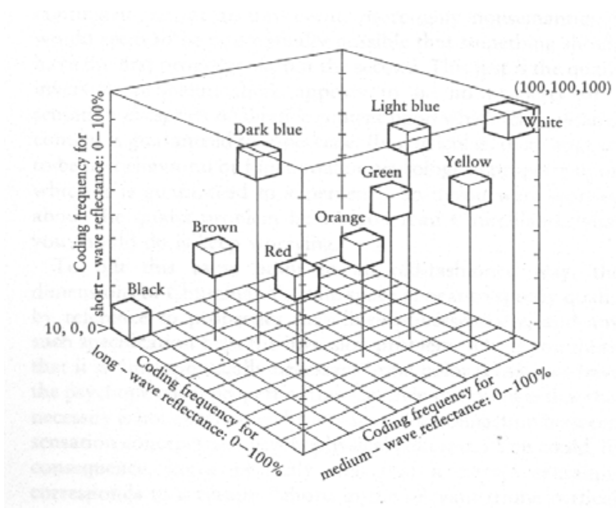

Figure 1 – Edwin Land's 'color qualia cube'

But Land focuses on external, measurable quantities (for good reasons), rather than the more inaccessible state variables of the brain. A more general theory of mind would argue that (a) we cannot describe the complexity of color perception with only three variables, and (b) color is not unique, but rather *all* perceptions might fit into a similar phase space description, with the appropriate state variables.

Because all the dimensions of phase space are mutually orthogonal (perpendicular), other feelings, sensory or otherwise, may co-exist with our feeling of redness. The tactile projection neurons may indicate ‘pain in left elbow’ at the same time that the visual neurons are indicating ‘red’. The phase space point then moves to a different region of ‘red’, a region that intersects with the ‘pain in left elbow’ region. Thus both are ‘felt’ at once. Phase space of the brain is almost unimaginably vast, and can reflect all different combinations of sensory perceptions that we may experience.

As to why there is a 'feeling' associated with different regions of phase space, I would suggest that this is a result of our evolutionary heritage. As the point of consciousness moves through different regions of phase space, the human organism distinguishes different states of being, and the mode through which we distinguish this difference is what we call 'feeling'. We humans notice different (phenomenal) feelings for two reasons: one, because of the varied nature of our sensory organs, and two, because different perceptions have different levels of meaning and urgency. The difference, and the quality of the difference, has been honed over millions of years -- the smell of ripe fruit, the sight of a tiger, the feeling of pain, the sound of a baby's cry, all have varying levels of meaning and importance with respect to one's propensity for survival and well-being. The range and sensitivity of our eyes, ears, skin, and so on have increased over the eons of time, and varying levels of sensitivity are reflected in our ability to detect increasingly subtle variation within the brain's phase space. And of course, the phase space itself has grown in dimensionality as the brain has increased its neuronal count. But the main point is that the human organism has found it necessary to detect ever more subtle inputs from the environment, and this is ability is made manifest in what we call a qualitative 'feeling'.

If the existence of qualia is an evolutionary fact of human nature, then this offers a resolution to the philosophical arguments surrounding 'zombies'. A philosophical zombie is a being who is exactly like us in every way except that he lacks 'inner experience', i.e. qualia. Functionally a zombie would supposedly walk and talk just like a real person, but all his activity would be unaccompanied by subjective experience. In my conception, the philosophical zombie is both naturally and logically *impossible*: human physical make-up, and in particular a brain composed of human neurons, necessarily implies human-like qualia.

6) Hylonoism, Information, and Mind-Brain

Let me reiterate: I believe that the picture given to us by phase space analysis is essentially correct, and that it has significant philosophical implications. Classically, this analysis was performed on moving masses. More generally, it applies to the movement of mass-energy. Dynamic systems of mass-energy are describable by the trajectory of a single point in phase space. For the human brain I have argued that this corresponds to our unity of consciousness. Let me now begin to further develop this theory, which has as a logical consequence the feature that all dynamic systems of matter co-exist with mind.

All physical systems are describable in terms of a single point moving in phase space. This much is clear, and is widely accepted. Hylonoism is the conjecture that this point can be identified with a noetic unity of the system. Certain characteristics of this point are completely general, and apply equally well to the human brain as to any physical system – including chaotic behavior, personality, qualia, and so on. This idea of 'phase space point as noetic unity' requires a new, less cumbersome name; following the terminology of hylonoism, I will refer to the point in phase space as the *hylon.* As for phase space itself, I consider it not merely a theoretical 'space' but rather a very real aspect of the world; I will refer to this space as the *hylosphere*[12]. Thus, the hylosphere becomes the realm of mind for a given system. Each physical system maps out its own particular hylosphere as a subspace of the larger realm of the Partimens. The hylon — the unity point of mind — moves within the hylosphere, in a manner described by chaos[13]. For persistent dynamic systems, the hylon traces out a fuzzy, semi-stable pattern in the hylosphere; this pattern takes the form of a quasi-attractor, and represents the 'personality' of the system.

Earlier I looked at the dynamics of the brain. With the new terminology I can state that the hylon moves continuously in the trillion-dimensional hylosphere, yielding different 'feelings' or 'moods' or 'impressions' corresponding to which region it is in. The hylosphere is as vast and wide as the complexity of the corresponding physical system. Qualia can be defined as 'region of the hylosphere'. Each region represents a different set of neural states, and hence will 'feel' different to the subject. Not every region, or every possible state, can necessarily be uniquely felt. But I submit that most of the vast number of regions of the hylosphere have a distinctive, 'subjective' feel to them. Evolution has ensured that living organisms are quite capable of distinguishing 'hot' physical states from 'cold', 'hungry' from 'satiated', or 'face of a stranger' from 'face of a friend'. Such a concept of 'hylonoetic qualia' can perhaps serve as the first step toward a noetic 'science of quality' (cf. Goodwin, 1999a, 1999b, 2000).

Of course, energy flow occurs not only *within* the brain, but between the brain (and body) and the external world. The energy exchange between the brain and the external environment has an intimate relationship to the concept of *information*. Energy exchanged is used and interpreted in a particular way. Depending on the nature and magnitude of the energy coming in, the brain reacts in a specific physiological manner, which in turn results in the hylon moving to a specific region of the hylosphere. Photons of a certain frequency hitting the rods and cones of the eye cause very specific neurons in the brain to fire, putting it in a unique region of the hylosphere; the effect is that the person 'feels' the impression of that particular input, which he associates with the concept of 'color'. (Recall that the 'color' region of the hylosphere is independent of all the other sensory regions, so that one can be simultaneously in the 'red', 'loud', 'itching', 'hungry', and 'smells like a rose' regions; these are independent, because certain unique groups of cells input cells are firing in each case. But the feeling is integrated into a single unity, because these cells are ultimately all interconnected.)

Thus described, *information consists of a particular reaction to received input of energy*. Depending on how the energy enters my brain, I react or interpret the energy in a unique way. A laser beam directed at my hand has a much different effect than one directed at my eye. Thus, the information content differs. My brain, being a highly-chaotic system, is very sensitive to inputs of energy. My brain-hylon (brain state) rapidly reacts to all inputs in my sensory field. The feeling that results varies depending how poised I am to a particular input. The total sensory input, combined with the effect on the total synaptic memory, determines how I feel and react; this is the definition of information as *interpretation of received energy.*

Such a definition is similar in spirit to Bateson's definition of information as "the difference that makes a difference" (Bateson, 1972: 453). He uses the phrase somewhat whimsically and imprecisely, whereas I have attempted a very specific and well-defined meaning.

7) Cell-Based, Biological Mind

The overall picture of the brain, then, is one in which a vast network of interconnected cells exchanges mass-energy, both amongst themselves and with the outside world. Neural cells are unique in that they exchange energy primarily (for functional purposes) in the form of electricity. Other cells of the body are less specialized. They exchange energy, but mostly in the usual metabolic form of nutrients and wastes. Clearly, for example, skin cells must exchange *something*, or else they could not cohere. A tension or pressure on one cell gets passed along to all surrounding cells, which in turn pass it on to their neighbors. Energy, in the form of 'force', is transferred from cell to cell. In addition to forces, chemicals continually move in and out of cells. Different cells react differently to forces, and exchange different types of chemicals. The brain is unique in the type and speed of energy exchange, but not different from the other organs in that it is a system of interconnected cells that continually exchange mass and energy.

The concept of the hylon applies to any and all systems of mass-energy. The classical picture of a cluster of moving masses is easily generalized to cover the movement of particles of mass-energy. In one sense, the brain is unique because of its high-speed, highly interconnected, highly chaotic system nature; in another sense, it is like all other organs — they all are networks of cells exchanging energy. Their dynamics may be different, but they share in the ability to be fully described by a point in phase space.

Each organ, then, maps out its own hylosphere in which moves a hylon point representing the noetic unity of that organ. Every organ 'feels', experiences qualia, and possesses a personality.

The hylons of the other organs react in their own way, dependent upon their structure of interconnection, speed of exchange, and form of exchange. They receive energy directly from the external world, or via nerves connecting to the brain or other organs. The flow of energy through each organ leaves it mark; there is an element of memory to every organ. Professional athletes know this well: the body remembers its blows, stresses, pains, and bruises. Memories are stored not in synapses, but, in an analogous way, in the physiological structure of the organ (as well as, of course, in the synapses of the brain — if for example one experiences a memorable injury). *Every material object notes the passage of time, each in its own unique way*. Organs are no exception. This is confirmed by our knowledge of the hylon, which alters its path through the hylosphere based on each and every quanta of energy that it experiences.

A given organ consists of several types of cells, reflecting the different tissues; these may include epithelial, connective, muscular, or nerve cells. And the various tissue cells merge into other organs, forming a fuzzy boundary that delineates the organ. Nonetheless, we can identify a variety of structures within the body. Most cells clearly belong to a given organ or structure, and hence contribute strongly to that particular hylon. Many cells exist on the fuzzy boundary between structures of the body, and these, therefore, participate strongly in *multiple* hylons.

It could be argued that because cells are not always clearly assigned to a given organ, this implies that the concept of a hylon is ill-defined. On the contrary, this is an essential aspect of the theory. Sub-structures such as cells are not rigidly assigned to particular systems but participate in varying degrees with a variety of structures within the body. It is typical that one particular system dominates a cell's interactions, and thus we say that the neuron 'belongs' to the brain. But if a neuron releases peptide neurotransmitters that act on another organ of the body, then it clearly has an element of participation in that organ as well. And every cell interacts via the bloodstream with all parts of the body.

Each organ has a unique personality, the pattern of its quasi-attractor, which we can sense when we interact with it, consciously or unconsciously. Yet clearly the brain *is* different. The brain excels over the other organs in at least five ways: First, there is the *speed* of communication. The electrical signal moves at up to 100 m/s along the axon, versus the slow rate of chemical exchange that occurs between non-neural cells. Neurons have a highly-articulated *memory*, in the way the synapses elastically change over time, recording the patterns of energy flow. Also, the *degree of interconnection* is significantly higher for brain cells that for other cells. Neurons interact with up to 10,000 other cells; non-neural cells have perhaps 5-10 neighboring cells with whom they communicate directly. And, neurons perform a simple but crucial act of *processing* when they integrate (i.e. sum up) the incoming voltage pulses. Fifth, one form of energy — the electrical pulse — dominates its energy dynamics, versus a typical cell that may exchange many forms of energy.

In concluding this section, let me add that it is not only an organ that possesses its own hylon, but also *every part* of the body that exists as a subsystem of the whole. Consider an arm or a leg. Each is composed of a variety of sub-structures: organs, bones, cells, fluids, and so on. These sub-structures, each possessing their own hylons, jointly participate to form higher-order hylons. This inter-structure exchange forms the basis for higher-level hylon of the whole limb. Corresponding with this limb-hylon and its quasi-attractor pattern in the hylosphere, we have the 'personality' of the limb, comprising all of its visible and felt characteristics — appearance, strength, sensitivity, size, etc.

All this perhaps seems implausible at first glance. Historically, though, other thinkers have come to a similar conclusion. Leibniz saw the changes and movement of the individual organs as contributing to the overall condition of the soul: "I even maintain that something happens in the soul corresponding to the circulation of the blood and to every internal movement of the viscera, although one is unaware of such happenings..." (1704: 116). Denis Diderot put forth the idea that each organ experiences 'sensations'; "In all seriousness, [I] believe that the foot, the hand, the thigh, the belly, the stomach, the chest, the lungs, the heart, have their own particular sensations…" (1769: 85). William James observed and noted this same fact about the human body. In the midst of developing his panpsychist theory of reality, James recognized that the parts of the body have experiences "for themselves". To use his example: instead of speaking of an arm-hylon, he referred to "arm-feelings". He wrote, "My arm-feelings can be, though unnoticed [by me]. They can also be noticed, and cooperate with my eye-feelings in a total consciousness of 'my arm'." (Perry, 1935: 765, vol. 2). This is exactly my point — that the singular experiences of each limb or each organ (A) exist for themselves, and (B) interact to form a higher-order mind.

8) Layers of Mind

So what of the body as a whole? The only logical and consistent conclusion is that the total mind of the body consists of *layers of mind*, represented by the various levels of organization within the body. The body can be considered as organized on differing levels, and correspondingly*, mind is also organized on different levels*. Nietzsche (1886) expressed this insight; he said, "*unser Leib ist ja nur ein Gesellschaftsbau vieler Seelen*" – "our body is only a social structure composed of many minds" (sec. 19, my translation).

Let us begin at the bottom. Consider the atoms within the body. These atoms consist of protons, neutrons, and electrons, and their corresponding field particles. The protons, neutrons, and electrons form quasi-stable patterns that we call atoms, and they do this by exchanging particles of energy (the field particles). The atom thus consists of a swarm of particles — mass-type and force-type — in a dynamic relation. The energies of theses particles form the basis for a *hylon of the atom*, a single point in phase space that represents the current total energy state of the atom. The hylon is a singularity, corresponding to the fact that the atom is, in some sense, a singular thing whose existence stands out against the background 'noise' of the surrounding flux of mass-energy. If the particles of energy that composed the atom did not stand out, did not make themselves known as a unity, it would not be a single 'thing'. The interaction among the atom's particles of energy are clearly stronger than their interaction with other neighboring particles of energy, and this gives the atom its existence.

Atoms interact to form molecules. They 'stick together', either by sharing an electron (covalent bonding) or by strength of electrical attraction (ionic bonding). In either case, energy is exchanged. The fact that molecules exist and persist is evidence of a strength and durability of interaction among the atoms, a unique pattern of energy exchange. The exchange of energy between atoms forms the basis for a *hylon of the molecule*.

The molecular structure has alternate expressions. We could consider it only a collection of protons, neutrons, and electrons, and leave the atoms out of the picture. Thus the molecular hylon has both a single sub-atomic hylon (based on the protons, neutrons, electrons, and force particles), and simultaneously, and some discrete number of atomic hylons.

Consider a salt molecule, for example. It consists of one atom of chlorine, and one atom of sodium. The chlorine atom has 17 protons, 17 electrons, and 18 neutrons. The sodium atom is 11 protons, 11 electrons, and 12 neutrons. There exists a 'chlorine hylon', based on its 52 sub-atomic particles (plus corresponding force particles), and likewise there exists a 'sodium hylon' based on its 34 particles. The salt molecule has a total hylon composed of both its sub-structures: as '86 sub-atomic particles' and as 'two atoms'. We may say that it is the simultaneous superposition of lower-level hylons that compose the high-level molecular hylon.

Why make a distinction? Why regard this as a two-level hylon? Why not ignore the atomic structure, and just consider salt as composed of 86 sub-particles? Because the pattern of interaction requires it. Compare a molecule of salt to an atom of nickel isotope[14]. Nickel has 28 protons, 28 electrons, and 30 neutrons — 86 particles, identical to that of a salt molecule. But clearly salt is different than nickel. It interacts differently, it exchanges energy differently with surrounding atoms. In the presence of water, for example, salt dissociates into a sodium ion plus a chlorine ion; nickel does nothing like this. The reason for this is clear: the atomic sub-structure of salt, i.e. the fact that the 86 particles are in one configuration (namely, two discrete atoms) rather than another. Salt is a 'pattern of patterns', whereas nickel is merely a 'pattern'.

This line of reasoning may be extended upward to the higher levels of complexity. Molecules interact to form compounds, or solutions, or even simple organisms. Molecules can only interact by exchanging particles of force/energy. A compound may therefore have a 3-tier hylon: one from the molecules interacting, a second from the numerous atoms, and a third from the sub-atomic particles[15].

Consider a single-celled organism. It consists of a number of sub-structures in the cell body, surrounded by some enclosing membrane (also a sub-structure). These sub-structures have their own identities and hence their own hylons (otherwise, we would not recognize them as independently-existing structures). At the highest level, the cell has a hylon based on the exchanges between these sub-structures, but it also has one based on the molecular, atomic, and sub-atomic interactions. The top level hylon is a function of the *total mass-energy configuration* within it.

Organs composed of a variety of cell types have a yet higher-level hylon, with the highest level a function of the interaction between cells. The total hylon of the organ is determined by all the sub-structures, plus all mass-energy that enters its realm of influence. Invading microbes, food particles, bits of waste, all become elements of the total hylon. An obvious question arises: At what point does something 'enter the realm of influence' and become integrated into the total hylon? The answer: *degree of integration depends upon the degree of participation*. The degree of participation is a function of the level of exchange; high levels of exchange = strong participation = high integration into the hylon. At the atomic level, atoms exchange either photons (of electric force) or electrons, and thus 'participate' in a very restricted sense; many photons/electrons means strong participation, few photons/electrons means weak participation. More complex structures can exchange more complex forms of mass and energy, and thus have more complex levels of participation.

Degree of participation is a relative concept. The sodium atom in a molecule of salt exchanges many photons of electrical force with its partner chlorine atom, but it also exchanges force particles with other nearby chlorine atoms. To the degree that it does exchange with other chlorine atoms, it does in fact enter into the total hylon of other nearby molecules. But of course, this is much weaker than the participation with its immediate partner.

Consider a large-scale system, like the sun and its nine planets. We know that the solar system has a phase space description (many, actually) that describes its changing state with the trajectory of a single point. As before, I suggest that we correlate this theoretical unity with a real, noetic unity. I thus claim that the solar system as a whole has noetic singularity, a total mind, given by the instantaneous energy state of its constituents. Each planet exchanges gravitons with each other and with the sun, and this is the dominant mode of interaction. (Though of course not the *only* mode of interaction. The sun gives off photons and other high-energy particles that contribute to its total being. But the dominant force, from a 'universal perspective', is that of gravitation.)

Then step down to the planetary level. Each planetary subsystem – defined as 'planet plus its moons' – has its own hylon, based again primarily on their mutual exchange of gravitons. Step down one more level. Each planet individually, and each moon individually, have their own hylons; these are based on the movement of mass-energy in the realm of influence of the planet or moon — primarily, the structures and movements of mass-energy on and within the planet.

The hylon of the solar system is determined by the relative amounts and distribution of mass-energy within it. Obviously the sun is the most massive, contains the most energy, and thus dominates the hylon. In one sense, 'from afar', the sun virtually *is* the solar system. From our local perspective, the planets contribute somewhat more strongly, more so for the largest planets, less so for the minor ones. The 'earth-moon' subsystem hylon is naturally dominated by the earth, the moon, and the gravitons they exchange; but gravitons from the sun and other planets, and photons as well, impinge on the system, contributing energy and thus to a degree affecting the total hylon.

Since all possible configurations of physical structures have a phase-space description, this implies that *all possible configurations of bodies possess their own hylon*. It is not just the 'solar system', or 'planetary subsystem' that are described this way, but every relationship individually as well. The *'earth-sun system'* has a unique hylon, given primarily by the exchange of gravitons between the two bodies. That the earth and the sun possess a collective hylon is merely to say that they stand in a relationship to one another, they interact, and they participate. This hylon, this relationship, is also affected by the moon and the other planets. The moon's orbit around the earth causes the earth to sweep out a wobbly path through space, thus affecting the gravitational force between earth and sun. The other planets participate weakly, but could conceivably interact strongly if their path was altered. We saw earlier that chaotic motion of the planets could (and may actually have) caused planets to go into highly eccentric orbits around the sun, and perhaps even being ejected out of the solar system. Such a strong input of energy, a strong form of participation, would clearly alter the entire structure of the sun-planet hylon. Rather than simply altering the path of the hylon through the hylosphere (the ordinary case), a strong interaction/exchange could cause fundamental restructuring. The quasi-attractor pattern in the hylosphere may change radically; it may become a 'new personality', perhaps one that fades into virtual nonexistence.

* * * * *

This discussion relates to the notion of *emergence of mind*. I have argued that degree of participation is determined by degree of interaction, and furthermore that intensity of mind depends on degree of participation. As intensity of interaction varies, so does intensity of mind. Mind thus is seen as 'emerging' from a system as participation increases, and 'de-emerging' as it subsides. This concept addresses the important philosophical problem of how, and in what sense, mind came to exist in the universe.

A hylonoetic interpretation of chaos theory thus implies two senses of emergence: *qualitative*, and *participatory*. 'Qualitative emergence' arises from the nature of chaotic systems. The nature of a strange attractor is such that it passes through an infinitely large number of states, never exactly repeating itself. As the hylon point moves through phase space, it likewise follows a non-repeating trajectory, never passing through identical mental states. In this sense, *mind is always new*. Mind is always in the process of change-without-repetition, i.e. in the process of *becoming*. It continually achieves new states, new experiences, new 'feelings'.

'Participatory emergence' is a recognition that the various types of physical being have passed from a state of non-existence into existence over some given period of time. At one point in the distant past neither people, oak trees, rocks, nor the Earth existed per se, and now they do; they represented new forms of participations between the energy quanta that was present in the universe. Correspondingly, their noetic systems grew in intensity and distinctness as they evolved.

As quanta of energy, or any system of objects, come to interact more strongly, the corresponding system of mind grows in intensity. This change is reflected in the phase space picture by the fact that more particles of exchange are represented in the system.

Consider a simple example. A pile of sand on the table in front of me is a 'unity'. Its grains interact strongly, exchanging electromagnetic photons of force, particularly between grains that are in direct contact. The system is definable by the state of every quanta of energy in some very high dimensional phase space. At the 'top level', it can be described by a space with one dimension per grain -- this is the level that is immediately apparent to us.

The pile of sand can be represented by a hylon, a noetic unity. The point in phase space moves as the energy state of the pile changes. A 'stationary' pile would have a distinctive attractor personality. At the 'top level', all the grain velocities would be essentially zero, resulting in a nearly stable point. At the 'total level', though, forces are continually interchanged, and hence the total hylon moves with a distinctive pattern.

If we add grains to the pile, the phase space expands in dimensionality, and the personality pattern responds accordingly. Under certain conditions, a growing sand pile can reach a 'critical' state (cf. Bak and Chen, 1991), poised on the edge of a series of mini-avalanches. One can imagine a gradual change in the total attractor pattern, as forces build up to a critical configuration (recall my discussion of the pendulum with energy added to it -- Chapter 2). As an avalanche occurs, forces are realigned, ending in a new and more stable configuration, both physically and in phase space.

Now if we vibrate the table and cause the pile to disperse, both the 'top level' and the 'total' phase space patterns respond accordingly. If we stop vibrating momentarily at the point just when the grains cease to physically touch, we no longer have a 'pile', but we still certainly have a 'system of grains'. The 'top level' pattern again would be a mere stationary point -- *indistinguishable from the 'pile'*. The 'total level' pattern, though, would be clearly different: relatively very little force exchanged, low dimensional phase space, low intensity mind -- clearly different than the pile. Mind has devolved, or 'de-emerged'.

Finally, scatter the grains across the room. Mind diffuses to an extremely low level, completely imperceptible to us. We no longer see a 'system of grains', perhaps we don't see even a single grain. Yet the phase space description persists. The inter-grain exchanges are almost, but not completely, zero. The mind of the collective still exists, but has been totally subsumed by the background configurations of other pieces of matter.

Emergence of mind, in the participatory sense, is thus not a question of ‘coming into being’, but rather of ‘growing intensity’, of becoming apparent, perceptible. Such emergence occurs both in strength of interaction, and complexity of interaction. Intensity relates to the concept of *potenza* that I will describe in Chapter 8; greater interactions among greater numbers yields something of relatively great *potenza*, or intensity. As the *potenza* waxes and wanes, the corresponding mind emerges or devolves.

* * * * *

Let me close this section by returning to the world of ordinary objects. All objects around us — a pencil, a cup, a table, a house, a cat, a person — possess their own unique and individual hylons. Each hylon is a complex superposition of sub-hylons, based on the sub-structures of mass and energy that exist within the object. These are the 'layers of mind' that all things possess.

A human being consists of total hylon organized at several levels: the level of organ-interaction, of each organ in itself, of the cells of the body collectively, of the molecules of the body collectively, of the atoms of the body collectively, and of the sub-atomic particles of the body collectively. The body as whole has this total 'mind', this noetic unity. Again, this is not an entirely new position. Recall Leibniz's quote in the preceding section, that every change in the organs contributes something to the total soul of the body. Merleau-Ponty developed a phenomenology of the body that incorporated a similar insight: "[P]erceiving as we do with our body, the body is a *natural self* and, as it were, the *subject of perception*." (1945: 206; my italics).

We can sense this, intuitively, when we interact with another person. When we meet someone, especially for the first time, I claim that this total mind is in fact what appears to us as our 'immediate impression'. We see, hear, smell this person in front of us. We notice his or her size, shape, color, stance. But we know it *as a whole*, as a unified person. Only when we begin to interact, to participate with this person do we focus on the details, on the particular elements and subtleties of his or her persona. We begin to know their 'brain-mind', acting as it does as the coordinating center of interaction. Or, perhaps we interact 'physically' (as in sport), thus coming to know their 'body-mind'.

But our first impression, I claim, prior to all intellectualization, is a comprehension of the total hylon. It is not something known empirically. It is a kind of direct intuition, of one mind encountering another, and perhaps more: of two participating in a temporal unity, of an act of union resulting in the creation of a newly-intense system of participation, with its own noetic unity. A coming-together of minds results in each knowing the other directly and intuitive, non-empirically, through a form of mental unification and emergence. Hylonoism supplements this intuitive mode of knowledge by providing a rational foundation. Knowledge of other minds is thus both rational and intuitive, but not empirical.

This concept of grasping initially the total hylon is very near to something that Heidegger has discussed and analyzed. In <u>Being and Time</u> (1953), he attempts a fundamental examination of the nature of 'being'. In Chapter 3 of Division I ("The Worldliness of the World"), Heidegger is exploring the ontological meaning of value, which, for material objects, he discusses in terms of 'usefulness' (*verwendenheit*) and 'handiness' (*zuhandenheit*). He notes that useful things are not useful in themselves, but only in respect to other things -- as a nail is useful only in respect to a hammer: "[U]seful things are always *in terms of* their belonging to other useful things: writing materials [to] pen, [to] ink, [to] paper, ..." and so on. (p. 64). What is important is the *relationship* between such objects, and the fact that this relationship is of a *unity*. He continues:

> These "things" never show themselves initially by themselves, in order then to fill out a room as a sum of real things. What we encounter as nearest to us, although we do not grasp it thematically, is *the room*, not as what is "between four walls" in a geometrical, spatial sense, but rather as material for living. ... A *totality* of useful things is always already discovered *before* the individual useful thing. (ibid, first two italics mine)

Thus, when one enters a room, one grasps initially, intuitively, the room as a whole, and only then do we intellectually dissect it into a collection of objects. The web of relationships of the objects in it form the total unity of the room. The physical placement of objects, and their relative location to the floors and walls, is determined by exchanges of energy between these objects, and the mass/energy of the objects themselves. This total energy state of a room, for example, is given by the total hylon. Whether the objects are stationary or moving, their weight, color, shape, and so on are all elements of the total configuration of energy that makes the room a unique and singular entity.

Returning finally to the brain: The brain, as I have argued, is unique among the bodily organs, for at least five reasons stated previously — speed, memory, degree of internal interconnection, neural processing ability, and predominant exchange of electricity. This makes the 'mind' of the brain — its hylon — unique among all organs. It is more dynamic, more complex, than any other sub-structure of the body. The brain hylon dominates the total body hylon, but does not uniquely comprise it. In other words, brain is not equal to (total) mind, but is a dominating aspect of it.

The ancient Stoics had a term for the 'dominating part' of someone's soul; they called it the *hegemonikon*. It was the central point of interaction, the coordinator of activity. In the human body, they believed that the heart was the *hegemonikon*. Cleanthes claimed that the sun was the *hegemonikon* of the cosmos — very close in spirit to my depiction of the sun as leading element of the solar-system-hylon. I claim that the brain is the *hegemonikon* of the total mind of the body, and is a mind in itself.

The human body is, in a very real sense, a singularity. There is a oneness about it, a oneness we can feel but yet not point to. But the oneness is not absolute. Elements of our surroundings affect us in varying ways, blurring the boundary of ourselves, causing that which we call our mind to have fuzzy edges that blend into the world around us. We each are one, and simultaneously we are part of the whole environment. As we interact and participate, we become more integrated into the larger hylons that exist around us — whether it is that of our family, our circle of friends, the natural world, or even the universe. Endless layers of mind exist around us. Thus we have a new way of conceiving mind as permeating the universe.

9) Explanation versus Description

I have outlined a theory of mind based on the energy dynamics of the human brain, one that I have called the hylonoetic model of mind. I claim that this model, in which a point of consciousness moves continuously within the phase space of the brain, offers a major new approach to issues of mind and consciousness. But what is the deeper significance of this approach? Does it ‘explain’ mind, does it ‘describe’ mind, or does it rather do something else altogether?

First, let me again make clear some points about what is being offered here. The method of analyzing physical systems with phase space techniques is indisputable. As Penrose informs us, this approach applies to any and all systems in the universe, including the human brain, a star, or the cosmos as a whole. In his 1995 book Dynamic Patterns, Kelso has already applied such techniques to the brain, and has found various modes of chaos in brain activity. This chaos, he argues, serves the human organism in its need to interact with a complex environment. He writes:

> [T]he brain is intrinsically chaotic, possessing, by definition, an infinite number of unstable periodic orbits. ... [W]hen a cognitive, emotional, or environmental demand is made on the organism, an appropriate orbit or sequence of orbits is selected and then stabilized through a kind of chaotic synchronization mechanism. (1995: 284)

Kelso has included simple EEG sketches of the brain’s movement through phase space[16]. Cognizant of this radically new approach to understanding the brain, he is adamant that his technique is on solid scientific footing; “the facts presented here cannot be denied” (p. 285). He does not, however, identify the point in phase space with the unity of consciousness, nor does he develop the philosophical implications.

With respect to the usage of phase space as an analytic tool, I suggest that it can be viewed as a mathematical description of a physical process, one that I would liken to

Newton's equation of gravitational force ($F=GmM/R^2$). Newton, of course, did not 'discover' gravity, but he did articulate its nature in quantitative form. His equation describes the gravitational force, and when combined with modern vector notation, describes the 'gravitational field'. But Newton did nothing to 'explain' gravity. He proposed that certain phenomena (falling objects, tides, planetary motion) could best be generalized and described by presuming the existence of a certain universal entity called 'gravity' that acted according to a certain regularity of strength (proportional to 'mass') and of distance (inverse-square law). In hylonoism I am proposing that a certain phenomena, mind, can be generalized and described by presuming the existence of a universal entity called 'mind' that acts according to a certain regularity described by nonlinear dynamics. Gravity theory had certain implications – all mass 'has' gravity – and hylonoism too has certain implications – all systems 'have' mind. I am not offering to explain why this is so, just as Newton did not explain why gravity exists, other than naming it as a subtle fact about matter.

Later developments have made progress in understanding gravity, including the concepts of gravitational radiation (gravitons), and gravity as curvature in space-time. Still, these things only offer better descriptions; the 'why' of gravity's existence remains as mysterious as in the time of Galileo, or Plato.

Thus I offer up my hylonoetic theory as a *description* of mind, but one that allows us to make important new inferences about systems in general. And I take the existence of the point in phase space, and its identification with the unity of consciousness, as core facts of nature. That this unity is accompanied by human-like qualia I take as an evolutionary fact of the human species; the specific qualia we feel are related to both the type of sensory input and to the significance of that input.

I have pointed to the many correspondences between what phase space analysis has to say about dynamic systems, and what I take as core facts of human experience. With some qualifications, I take the unity of consciousness to be a real and central phenomena; as such, it is imperative that any model of mind account for it. I take the quasi-unity of the 'personality' to be a real phenomena, also in need of adequate explanation. I take the brain as deterministic, wholly physical system, one that defies detailed theoretical or practical predictability. I take the indisputable connectionist structure of the physical brain as being central to its operation, thus demanding a connectionist theory of mind (under the assumption that brain activity plays a central role in the process of mind).

It seems to me that these correlations between the properties of the point in phase and the unity of consciousness are too strong to disregard. But neither can I prove that they are equivalent, or that they must be equivalent. *This equivalency I take as an irreducible yet subtle fact of nature*. Those who might dismiss it as 'coincidental' overlook a promising and potentially revolutionary new approach to mind.

The hylonoetic theory offers a rational, naturalistic account of all these issues. Simply consider the parallels between the point in phase space and the ‘point-like’ unity of our own consciousness; between ‘personality’ and the quasi-stable form of a virtual attractor. *These parallels are too striking not to be taken seriously as indicative of something important*. It cannot be purely coincidental. There must a deeper connection – a deep description of consciousness that is found in this analysis.

I suspect that some philosophers and other thinkers must have come to this point of understanding, but when looking ahead to the implications they saw the fearsome abyss of panpsychism, and retreated. My hylonoetic view of mind has some radical and far-reaching consequences, and it is entirely possible that a conventional philosopher would recoil at the thought of them. Taking as I am the ‘unconventional’ path, I will attempt to follow through on these implications to the fullest limit.

NOTES:

[1] See Kolb and Whishaw (1990: 15).

[2] See Kolb and Whishaw (1990: 22).

[3] The axon releases a small amount of a given neurotransmitter chemical, which acts as a ‘key’ to unlock a small opening in the dendrite. Upon opening, ions (positively or

negatively charged atoms) in the surrounding fluid rush in. If the neurotransmitter is of a certain type, positively-charged sodium atoms rush in, and the effect is excitatory, increasing the likelihood of the recipient neuron firing. Other types of neurotransmitters allow negatively-charged chlorine atoms to enter, and the effect is inhibitory, decreasing the likelihood of firing. After completing its task, the neurotransmitter is either released into the bloodstream or reabsorbed by the axonal bouton. This, in brief, describes how the electrical signal traveling down the axon is passed over to a recipient neuron, in the form of a small incremental electrical charge, either positive or negative. For a good basic overview see Bloom and Lazerson (1988: 30-40).

[4] A similar figure is given by MacLennan (1996: 414).

[5] A similar estimate for the number of states per synapse was given to me by Leslie Smith (personal communication, 1998). However there is clearly wide disagreement regarding the number of bits that each synapse represents. Walker (1970: 173) gives an estimate of 10^7 bits per synapse, resulting in an astounding figure of 10^{27} bits per brain.

[6] And in some cases into the bloodstream; see Pert, et al (1985).

[7] This same phenomenon, of missing the complexities of chaos by viewing it under digitized conditions, occurs as well in digital computers that model or simulate chaos. There is a strong sense in which *digitization destroys chaos*; I must defer this discussion to a later date.

[8] See for example the book, On the Contrary (Churchland and Churchland, 1998); in several articles on state space, one finds not a single mention of chaos theory.

[9] Freeman used EEG tracings rather than individual neurons or synapses. EEG's track large groups of neurons and so are not as precise, but give the same intuitive picture.

[10] See D. Smith, et al (1999) for a detailed and technical discussion.

[11] My theory of hylonoism sees mind as intimately bound with the structure of matter. The dynamics of matter possess a concurrent dynamics of mind. Both occur simultaneously -- in this sense, it is a kind of parallelism, but not of the mystically-correlated kind that Leibniz envisioned. Following Spinoza, it sees mind and matter as 'of the same order': more complex structures of matter correspond with more complex spaces of mind. But it is incorrect, on my view, to say *either* that 'mind is causal on matter' or 'matter is causal on mind'. If both are simultaneous aspects of an underlying monism, then the term 'causal' is simply not valid for discussions of the relationship between mind and matter, or in the human case, between mind and body.

Recent philosophical analysis of causation deals primarily with intra-physical causation, via such approaches as a Humean nomological analysis, counterfactual analysis, or probabilistic analysis. Mental-physical causation is rarely discussed, in part due to difficulties in achieving a technical definition of the mental realm. In contemporary terms, my approach may be seen on the one hand as a kind of '*dual concurrent causation'* between mind and matter, each simultaneously causing the other. Others may describe such a view as a variation of causal nihilism, as I claim that traditional notions of causality are inappropriate and inapplicable.

[12] The term 'sphere' is appropriate here, as the imagery is based on the phase space of the brain. The hylon of the brain moves within a 100-trillion-dimensional sphere, due to the fact that the synapse potentials are both of comparable magnitude and finite for all neurons.

[13] My term 'hylon' has no connection with Koestler's word 'holon', as he describes it in his (1967). But there are some important similarities between his general philosophical system and the approach I am advocating. I discuss his ideas further in Part III.

[14] Standard nickel has 31 neutrons, but I use an isotope of 30 here for purposes of comparison.

[15] The hierarchy could as well be extended 'below' – yielding a level of structure at that of the quark-lepton level. This added level of structure does not affect the basic argument.

[16] See pages 278 and 282.