

Fractal Neurodynamics and Quantum Chaos : Resolving the Mind-Brain Paradox Through Novel Biophysics

Chris King
Mathematics and Statistics Department
University of Auckland

Abstract: A model of the mind-brain relationship is developed in which novel biophysical principles in brain function generate a dynamic possessing attributes consistent with consciousness and free-will. The model invokes a fractal link between neurodynamical chaos and quantum uncertainty. Transactional wave collapse allows this link to be utilized predictively by the excitable cell, in a way which bypasses and complements formal computation. The formal unpredictability of the model allows mind to interact upon the brain, the predictivity of consciousness in survival strategies being selected as a trait by organismic evolution.

1 Mind and Brain, Chaos and Quantum Mechanics.

1.1 Paradigms in Scientific Discovery and The Enigma of Consciousness The twentieth century has seen the unification of the microscopic and cosmic realms of physics in theories such as inflation, in which symmetry-breaking of the fundamental forces is linked to cosmic expansion. Molecular biology has had equally epoch-making successes unravelling the intricate molecular mechanisms underlying living systems, from the genetic code through to developmental structures such as homeotic genes. Despite these conceptual advances, the principles by which the brain generates mind remain mysterious. The intractability of this central unresolved problem in science suggests its principles run deeper than the conventional biochemical description, requiring novel biophysical principles. This paper develops such a model based on linkage between the fractal aspect of chaotic neurodynamics and quantum non-locality, giving brain science a cosmological status at the foundations of physical description.

1.2 Chaos and Quantum Mechanics : Unpredictability as a Basis for Mind Although mechanists tolerate mind as a passive shadow representation of physical causality in such theories as epiphenomenalism and brain-mind identity, *free-will* conjures up the spectre of active causal interference. To quote Sir John Eccles : *'It is a psychological fact that we believe we have the ability to control and modify our actions by the exercise of "will", and in practical life all sane men will assume they have this ability'*. Nevertheless free will has a very unpopular history in science because of the paradox of mind acting on a supposedly deterministic physical system. The controversiality of *consciousness* and *free-will* in science stems from their supposed inconsistency with causal scientific description - but is this so? Chaotic dynamical systems and quantum mechanics both share attributes which are more consistent with these two features than biochemical reductionism would suggest:

1.2.1 *Chaotic dynamics* possess both *sensitivity to initial conditions* and *computational unpredictability*, fig 1(a) (Schuster 1986, Stewart 1989) because exponential spreading of adjacent trajectories with increasing time occurs with a positive Liapunov exponent $L > 1$ fig 1(a). Similar considerations apply to complex systems in transition in and out of chaotic regimes, where L crosses 1 . Arbitrarily small fluctuations are thus inflated into global instabilities by the "butterfly effect", in which a perturbation such as a butterfly can become the source of a subsequent tropical cyclone. A chaotic system is arbitrarily sensitive to perturbation and hence responsive. Sensitivity also prevents a chaotic system from being precisely modelled. It is thus unpredictable, though it may be deterministic. Such systems behave in a way which makes it impossible for an observer outside the system to describe it precisely enough to determine its outcome and hence test its causal nature.

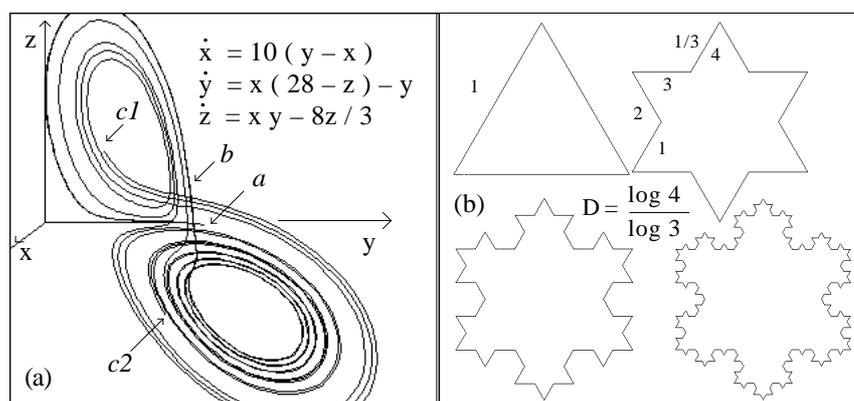


Fig 1: (a) Positive Liapunov exponent causing sensitive dependence on initial conditions is illustrated by the Lorenz flow. Trajectories starting -close at *a* have exponentially separated by *b* and are in distinct parts of the flow by *c1,2*.

Computational unpredictability follows from the incapacity of any approximation to model the flow over increasing time.

(b) Non-integer fractal dimension D of the Koch flake. Each side is repeatedly replaced by 4 sides of length $1/3$.

The Lorentz flow has a strange attractor which has a correlation dimension of 2.06 (Grassberger & Procaccia 1983).

1.2.2 *Quanta* possess a *global internal model* of their environment in the form of the wave function and violate causality through *uncertainty* during *reduction of the wave packet*. These attributes, although somewhat different in nature from sensitivity and unpredictability, cap off the causality of chaotic physical systems at the microscopic level and have parallels to consciousness and free-will. Although a quantum behaves like a particle in terms of its emission and absorption, its wave function extends throughout space-time, forming a global representation of its environment. Subsequent absorption of the particle appears to collapse the wave function into only one of its superposition of possible states. Thus although averaged ensembles of events conform to the probability distribution of the wave, the absorption foci of individual quanta cannot be predicted. The stochastic nature of the theory makes it possible in effect for each quantum to both be *conscious* of the universe through the extended wave function and to exercise *free-will* in its demise in wave packet reduction, while conforming to the principles of quantum mechanics.

1.2.3 *Fractal linkage*. These two levels of physics have a natural link of scale through the *fractal* nature of chaotic dynamics. Many chaotic systems display conserved sets such as attractors and basins which are *fractal* in the sense that they are replicatively self-similar on descending microscopic scales, resulting in a non-integer dimensionality (Peitgen & Richter 1986). In fig 1(b) the Koch flake illustrates a simple geometrical fractal in which each side is repeatedly replaced by 4 sides of $1/3$ the length l . The number of units thus scales as $l^{-\log 4 / \log 3}$, giving a fractal dimension $D = \log 4 / \log 3$. The correlation dimension is a similar measure (Grassberger & Procaccia 1983).

The term *quantum chaos* has been used to describe a variety of quantum systems which have analogous dynamics to classically chaotic systems. Electrons, atoms and small molecules traversing a molecular *milieu*, have dynamics well approximated by a chaotic system. Complementing this frontier is the link between quantum uncertainty and sensitive dependence. In a chaotic physical system, quantum fluctuations will become amplified into global instabilities by the butterfly effect - *quantum inflation*. The *fractal* nature of chaotic dynamics results in a disseminated set of increasingly unstable regimes which can serve as nuclei for global fluctuation (King 1991). Complex systems in the chaotic transition region may also enter a state of self-organized criticality in which a local perturbation leads to global bifurcation.

Although our sensory experiences, particularly visual representations of the physical world, have obvious stability properties, the necessity of sensitive dependence on the external world guarantees that the internal model must include unstable dynamics, as is confirmed by study of optical illusions, hallucinations and dreams. Recent studies of the chaotic dynamics of a variety of neurophysiological processes support such attractor-bifurcation models at both the cellular and neurosystems level.

1.2.4 *The Mind of the Uncertain Brain* Such a linkage could be used by the brain to allow *mind* states to critically perturb *brain* states through quantum non-locality. Such an interaction is possible only if the time evolution of the brain is formally unpredictable when observed externally as a physical system. This unpredictability must also be advantageous in evolutionary terms, and hence must assist the brain in the computationally intractable task of survival in the open environment. In this sense, mind may be an extra-physical dual aspect of reality, corresponding to unpredictabilities and uncertainties in a physical brain. Such an interpretation is a *dual model of reality* in which mental and physical are fundamental components of the universe. The physical world is manifest only indirectly as a set of stability properties of mind. From the physical perspective the same mental experiences correspond to stability structures in an internal model of reality.

2 Conceptual Problems in the Mind-Brain Relationship

2.1 Defining Mind and Consciousness

2.1.1 *Mind* and *Consciousness* remain so different from the usual objects of scientific inquiry that it is unclear they conform to the objective criteria usually applied to scientific description. The terms are the subject of such ambiguity that it is essential to review their semantic variations:

Mind is often referred to as the sum of our intellectual faculties, our capacity to think or reason, the *rational mind*, as distinct from sensation. Being *out of one's mind* in a complementary way suggests escape from rational controls into insanity. *Mindless* activity similarly implies unreflecting action. *Minding* carries different emphases of attending - "Mind that step!" or caring - "I don't mind if I do!". Being *mindful* again implies attentiveness. Having *something on one's mind* that of preoccupied thought. *Making up one's mind* that of deciding. *Being of one mind* having the same opinion or intent. Nevertheless, mind as the dual of body embraces the diversity of subjective experience. To avoid such semantic confusion, I will inclusively define *mind* as: *the envelope of all subjective manifestations of brain-related activity*, including sensation, thought, feeling and states such as dreaming. The essential feature of the *mental* is its *fundamentality*, the fact that all our access to the physical world occurs via the conduit of subjective experience, the one undeniable reality of existence.

Two scientifically controversial attributes of mind are likely to be pivotal to a successful description :

2.1.1.1 *Consciousness* : subjective manifestation of attentive brain function.

2.1.1.2 *Free-will* : mental action upon brain function, violating physical determinism.

At a primary level, our *conscious* experiences are our only access to the nature of physical reality. Although we become firmly convinced of the existence of the real world, our access to this world is only by inference from our subjective, conscious experience as observers. The physical universe is manifest entirely as structural stabilities of conscious experience, or as conceptual descriptions we develop from analysis of other forms of conscious observation, such as particle tracks, spectrographs etc. The physical world is thus accessed indirectly as an inferential structure linking our own conscious experiences and those of others into a single stable description. Thus despite believing in the primacy of the world we live in, all of us derive all our knowledge of the universe from our subjective representations of reality (Eccles 1966, Blakemore & Greenfield, 1987, Rose 1973, Margenau 1984). Without the direct avenue of subjective awareness, it is unclear that a physical universe would even exist.

This basic and undeniable manifestation of *subjective consciousness* has again a backdrop of other more restrictive concepts. One can refer to another person as *conscious* or *unconscious* depending on whether they appear to be responding to stimuli, or in a state of coma. One can also compare the conscious with the *subconscious* or the *collective unconscious* of Jung, allowing for some attributes of mind to pass subliminally into existence or represent archetypes lying below the level of attentive awareness. Cognitive scientists may dismiss many peripheral aspects of brain processing as being *pre-conscious*, leaving only the major orienting focus of attention as reaching the conscious level. Finally consciousness is viewed as a reflective type of attention process, exemplified by *self-consciousness* in which a person in addition to perceiving is aware of themselves as a subject. As described by Rosenthal (1986) “a conscious state is one which has a higher-order accompanying thought which is *about* the state in question”. Ironically such self-consciousness has been claimed by Jaynes (1976) to be a very recent and culture-born imposition, however to the contrary, it may be an evolutionary feature of mammalian or even metazoan brains, because distinction of self from world is the fundamental distinction for survival. A central feature of consciousness research is how perception and attention combine to result in action in the brain (and mind).

I will thus inclusively define *consciousness* as: *the envelope of capacities of the brain to form subjective representations of reality*. In this sense, the *brain* is *conscious* of *mind*. This is consistent with one of the most popular modern conceptions of the mind as an internal model of reality constructed by the brain, a view consistent with a variety of lines of evidence spanning normal cognition, the nature of optical illusions, dreaming and many pathological states of the brain. *Free-will* on the other hand is the reciprocal action of *mind* on brain.

2.1.2 *The Menagerie of the Mind* The scope of subjective experience can be outlined through a combination of introspection and study of traditional concepts in language. The most undeniable mental experiences are our sensory experiences of the world around us, and physical sensations in our bodies from touch and pain through to the manifestations of emotions such as fear and anger. Along with these come less clearly defined inner images provided by memorization, imagination and thought. While these are less rich than direct sensory experience in usual waking life, probably as a result of competition with direct sensory stimuli accessing the same processing modules, in states of relaxation, sensory-deprivation, dreaming, or meditation, internal imagery becomes clearer and less distinguishable in intensity from sensory experience, and may take on a life of its own. Study of the properties of such alternative states has immense potential for consciousness research, because the properties of consciousness are not sensorily tied to the physical world description, thus providing a unique opportunity to test its internal dynamical qualities.

Many mental features, being processes rather than states, cannot be subjected to stable scrutiny without changing their characteristics. While it is easy to understand the meaning of this sentence, it is vastly more difficult to simultaneously perceive the details of how you are able to understand its meaning, and more difficult still to decide to what extent the semantic background of the words is consciously perceived or merely subconsciously controlling the conceptual process. Nevertheless it is accepted English usage that we can choose to *think* and that *thinking* is a structured conscious process, in which a sequence of semantic concepts emerge as a product of directed voluntary attention, a sequential process with semantic direction, which may take the form of narrative, rehearsal or have sensory or abstract properties. To *imagine* is again a voluntary process but dealing with imagery generation. By contrast, to have an *idea* is a spontaneous and possibly novel product of the thought process. Such terminology is consistent with a dynamical model in which the attention process generates structural bifurcations, some of which spontaneously generate novel features or concepts. The difficulty of attending to two things at once and the singularity of the stream of consciousness suggests that it represents a global dynamic in the brain. It may be more accurately described as a bundle of related awarenesses, dynamically coupled, but capable of further bifurcation.

Central to our subjective consciousness is the notion of an observer, or self, witnessing a theatre of conscious experience through the attention process, having the capacity by an act of will, or intent, to alter the circumstances occurring in the perceived world. Dennet (1991), based on the dictates of a parallel processing model, and various perceptual illusions, asserts that such a “Cartesian Theatre” is non-existent. “What would make this sequence the stream of consciousness? There is no one inside, looking at the wide screen show displayed all over the cortex, even if such a show is discernible by outside observers”. Nevertheless the construction of the physical world model is derived from our conscious experiences. While there may not be a localized and distinct representation of the stream of consciousness in the brain, and consciousness, including time-perception, may present as an internal model of reality, the self and its intentional relation to the stream of consciousness remains our fundamental arena of experiential reality.

2.1.3 *Observer Problems in Consciousness* Several features make consciousness uniquely difficult to observe:

- 2.1.3.1 Mental observation [introspection] involves a whole-systems observer problem in which the system being observed is also the system doing the observing. “Introspection is one of the many forms consciousness itself can assume, so that it represents a significant part of what we are trying to explain” (Miller 1992). The attempt to examine conscious states thus globally alters their phenomenology.
- 2.1.3.2 Mental constructs do not satisfy the criteria of objectivity possessed by physical objects and processes, so most aspects objective observation are rendered invalid. “Although consciousness exists by virtue of some physical property of the brain, just as bioluminescence exists by virtue of some chemical property of specialized cells, it is *not* as bioluminescence is an observable property of living matter. Nor is it an invisible property... It is detectible to anyone who has it. The difficulty is the method by which consciousness is detected is logically different from ... bioluminescence” (Miller 1992). Thus *qualia* such as redness remain ill-defined.
- 2.1.3.3 As William James originally pointed out “consciousness is not a thing, but a process”. Conscious features may thus be rapidly transformed by the very act of observation, leaving only the sensoria as stable observables. *Thought* is an example of such dynamically unstable observation, because the act of thinking results in an evolution of the experience. An *idea* is an unstable bifurcation to a novel thought state.
- 2.1.3.4 The boundary between subconscious processing and conscious experience is ill-defined. Consciousness may thus be incomplete as a process. The hidden background of conscious experience, which Dreyfus and Searle call “intrinsic intentionality” may contain some of the highest computations.
- 2.1.3.5 Crick & Koch (1992) note that the problem of consciousness is ill posed, because it is a constructive process, requiring further constraints to provide a unique solution.
- 2.1.3.6 The subjective experience of free-will is inconsistent with causal description.

2.2 Concepts of the Brain-Mind Relationship

A diverse variety of views of the mind-brain relationship have been advanced, providing pointers to the basis of mind in brain function, while confirming the unresolved state of understanding in this area.

2.2.1 *Complexity* : Consciousness as a property of complex computational systems. One common idea about the emergence of mind is that it is somehow a product of the very complexity of the brain. However neither computer circuits nor artificial neural nets are ascribed to possess the attribute of mind in addition to their functioning at any given level of numerical complexity.

John Searle (1980) invented the Chinese room, in which [conscious] operators translate Chinese by symbolic constructs without the system being conscious of the meaning of the translation, to point out that strong AI cannot by itself explain consciousness. Dennett (1991) utters the ‘systems reply’ against this by saying that the brain *is* complex and *is* conscious so it is possible in principle for a parallel virtual machine to become conscious through it’s many parallel interactions - “this little bit of brain activity doesn’t understand Chinese, and neither does this bigger bit of which it is a part ... even the activity of the whole brain is insufficient to account for understanding Chinese”... of course the dualists would say “it takes an immaterial soul to pull off the miracle of understanding”. Dennet’s critical untested assumption is that the brain is simply a *classical virtual machine*.

Measures of complexity based only on neural net architecture neglect non-trivial properties of the individual neuron. The coelenterate *Hydra*, fig 2, displays complex behaviour involving a greater variety of locomotion types than the sea snail *Aplysia* and coordinated feeding, despite having an undifferentiated nerve net, which can withstand migratory reintegrations of the ectoderm and endoderm if the organism is turned inside out.

Certain non-linear systems near the chaotic boundary $L \sim 1$ or in chaotic transition do however display complex bifurcations and the development of novel structure within the system, and for this reason are termed *complex systems* by the Santa Fe school (Jen 1990). These form good models for neurophysiology, and have the potential when given an adequate quantum foundation also to explain consciousness.

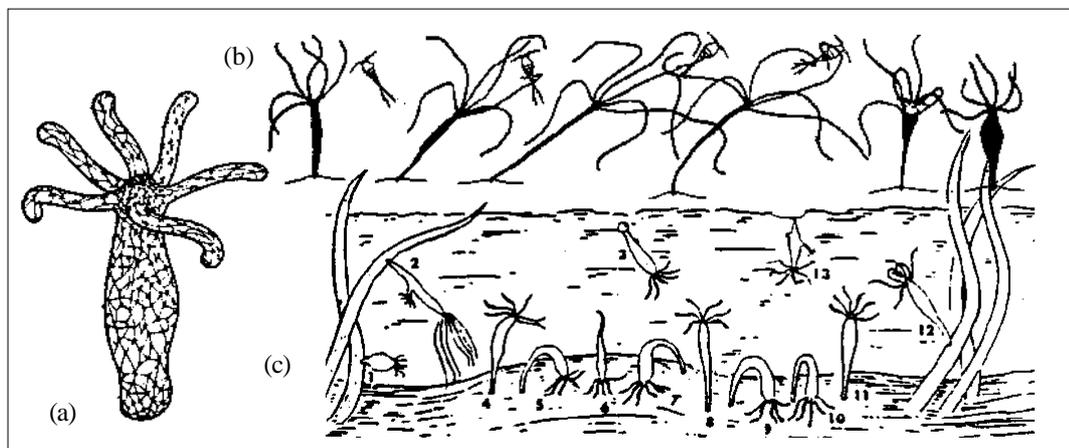


Fig 2: Hydra poses a dilemma for theories of neural net organization. It can reassemble ectoderm and endoderm if turned inside out and has a disseminated neural net (a) with no global structure, nevertheless it can coordinate eating (b) and possesses more diverse types of locomotion than animals such as molluscs and arthropods which have structured ganglia.

These include snail-like sliding, tumbling, inch-worm motion and use of bubbles and surface films.

2.2.2 *Emergence*: The idea that new properties emerge from the interaction of subsystems, not predicted by the subsystem architecture. In this sense *emergence*, which is a property of many digital and non-linear systems including molecular assemblies, applies to virtually every system with global feedback, from machines and organisms to the weather, all of which share system attributes which are disrupted by partitioning. Thus while the basis of mind is doubtless also emergent, this does not in itself explain how it 'emerges' from the brain. It is thus necessary to look in detail at the underlying mechanisms of mind for a substantive explanation.

2.2.3 *An internal model of reality* constructed by the brain. The idea of the mind as an internal model of reality has widespread support, both in the modular structures of sensory detectors which respond to features such as line orientation, thus synthesizing a model out of a combined set of features, and in various visual illusions in which these features lead to incomplete or contradictory results. The internal model is also consistent with a role for the mind as a monitoring system for attention. However the precise nature of the model and how the brain uses it to generate mind remain to be elucidated.

On a physiological level, research into modular sensory processing (see 3.3) and the distributed chaos models of Freeman's group (see 4.1.1) illustrate internal models of brain function which share distributed processing features. At an opposite extreme Blackmore's (1988) internal model unites a variety of modes of mental experience surrounding dreaming into a common description.

Somewhere in between stand the purely structural models of artificial intelligence (AI) and cognitive psychology, which draw from the studies of distributed processing in modern physiology (see 3.1) to present parallel cybernetic models which, although they have powerful features, explain consciousness away as an elaborate form of parallel computational control of the organism. Dennett's (1991) *multiple drafts* model is an example which denies our subjective view of a theatre of conscious experience with an attentive observer. "There is no single definitive "Stream of Consciousness" because there is no Central Headquarters, no Cartesian Theatre where "it all comes together", for the perusal of the Central Meaner. Instead of such a single stream (however wide), there are multiple channels in which specialist circuits try, in parallel pandemoniums, to do their various things, creating Multiple Drafts as they go. Most of these fragmentary drafts of "narrative" play short-lived roles in the modulation of current activity but some get promoted to further functional roles, in swift succession, by the activity of a virtual machine in the brain. The seriality of this machine (its 'von Neumanesque' character) is not a hard-wired design feature, but rather the upshot of a succession of coalitions of these specialists", (see also Marcel & Bisiach 1988, Baars 1988).

The multiple drafts model makes some physiological sense because an asynchronous parallel architecture allows the brain to make optimally rapid, but arbitrarily complex calculations. Such an architecture is consistent with cortical design in which the incoming afferents are associatively connected with the outgoing efferents with no intervening structures, leading to very short computational delays, while the timing delays across the cortex are non-zero. It is also consistent with the attractor dynamical model advanced in this paper in which multiple bifurcations can induce parallel structures in the same dynamic. The general nature of such a distributed internal model also has very interesting time properties (see 8.2), and allows for constructive filling in [blind spot and fig 5(c)], editing, and for gaps in the description, such as those caused by visual saccades to be smoothed out (Dennett 1991). "Nothing can seem jerky except what is represented as jerky" - Minsky.

However Dennett's description clearly leaves mind a role equivalent only to an abstract computational process. "The neuroscientists are right to insist that you don't really have a good model of consciousness until you solve the problem of where it fits in the brain, but the cognitive scientists, (the AIers and the cognitive psychologists, for instance) are right to insist that you don't really have a good model of consciousness until you solve the problem of what functions it performs and how it performs them - mechanically, without the benefit of Mind. ... Anyone or anything that has such a virtual machine as its control system is conscious in the fullest sense and conscious because it has such a virtual machine" (Dennett 1991). "Any scientific theory of mind has to treat it as an automaton" (Johnson-Laird 1983). These statements lose the subjective nature of mind completely.

This difficulty arises from dependence on abstract computational ideas as the basis for the models, reducing the functional implementation, and particularly its neurophysiological basis to subordinate roles as in Marr's (1982) three-level analysis of mental phenomena. If the brain uses unusual physical principles in its neurophysiology, such models will fail by the classical trap. Repeated objections have also been mounted on philosophical grounds. "No connectionist computer could exhibit real mentality" (Searle 1990a,b). "The subjective features of conscious mental processes - as opposed to their physical causes and effects - cannot be captured by the purified form of thought suitable for dealing with the physical world that underlies the appearances" (Nagel 1986). The current paper addresses this problem by presenting a model in which the biophysical principles are paramount and the computational features are a product of the biophysics.

2.2.4 *Duality* : Mind as a *dual phenomenon* to physical reality. The very great difference between mind and the diversity of physical phenomena suggests that although in a sense paralleling the physical brain, mind may not be a physical attribute as such but a complementary principle, making mind and universe dual aspects of totality.

Descartes' homunculus in the pineal and his "*cogito ergo sum*" illustrate two aspects of his dualism, expressed very eloquently in the following passage: "While I could pretend that I had no body, that there was no world ... I could not pretend that I was not ... from the fact that I thought of doubting the truth of other things ... it followed I existed ... from this I recognised that I was a substance whose whole essence or nature is to think and whose being requires no place and depends on no material things" - Descartes *Discourse on Method* 1637.

Dualism has been the subject of attack and counter-attack during the 20th century. Gilbert Ryle (1949) made a classic critique of dualism, describing it as the "ghost in the machine", and branding many aspects of mental description as *category mistakes*, promoting Koestler (1967) to mount a rebuttal by the same title. An outstanding feature of many of Ryle's descriptions, such as the lemon on the desk, is that they derive from everyday experiences in which the stable physical world model dominates other aspects of conscious perception.

Several researchers have proposed *dualistic* philosophies or even three-aspect brain-mind-knowledge models. Sir John Eccles wrote "we are a combination of two things or entities : our brains on the one hand; and our conscious selves on the other." The brain is a precious "instrument" a "lifelong servant and companion" providing "lines of communication from and to the material world," but we are not it. An act of will, as Eccles sees it is an everyday case of *psychokinesis* of mind moving bits of matter (Hooper & Teresi 1986). He has even gone as far as to propose structured entities *psychons* corresponding to ideas which interact with *dendrons* possibly in the pyramidal tracts. Vendler (1972, 1984) has also made a defence of dualism. *Epiphenomenalism* constitutes a weak one-sided form of duality in which world effects mind but not vice versa.

Critics of the artificial intelligence and cognitive psychology schools such as Dennet (1991) describe dualism as *forlorn* because it undermines the agenda of materialist or operationalist description of both the brain and mind in abstract computational terms ... "If mind and body are distinct things or substances, they nevertheless must interact; the bodily sense organs via the brain must inform the mind, ... and then the mind, having thought things over must direct the body in appropriate action. ... Cartesian interactionism". "How can mind stuff both elude all physical measurement and control the body?". Such criticisms depend on outmoded classical reasoning ... "It is [the] principle of conservation of energy that accounts for the physical impossibility of perpetual motion machines, and the same principle is apparently violated by dualism. This confrontation between quite standard physics and dualism has been endlessly discussed since Descartes's own day, and is widely regarded as the inescapable and fatal flaw of dualism". This statement displays a startling lack of understanding of a variety of physical processes from the weather to the behaviour of quanta, in which instability and uncertainty fragment classical causality and provide room for a logical loop connecting mind and brain - a central theme of the current paper.

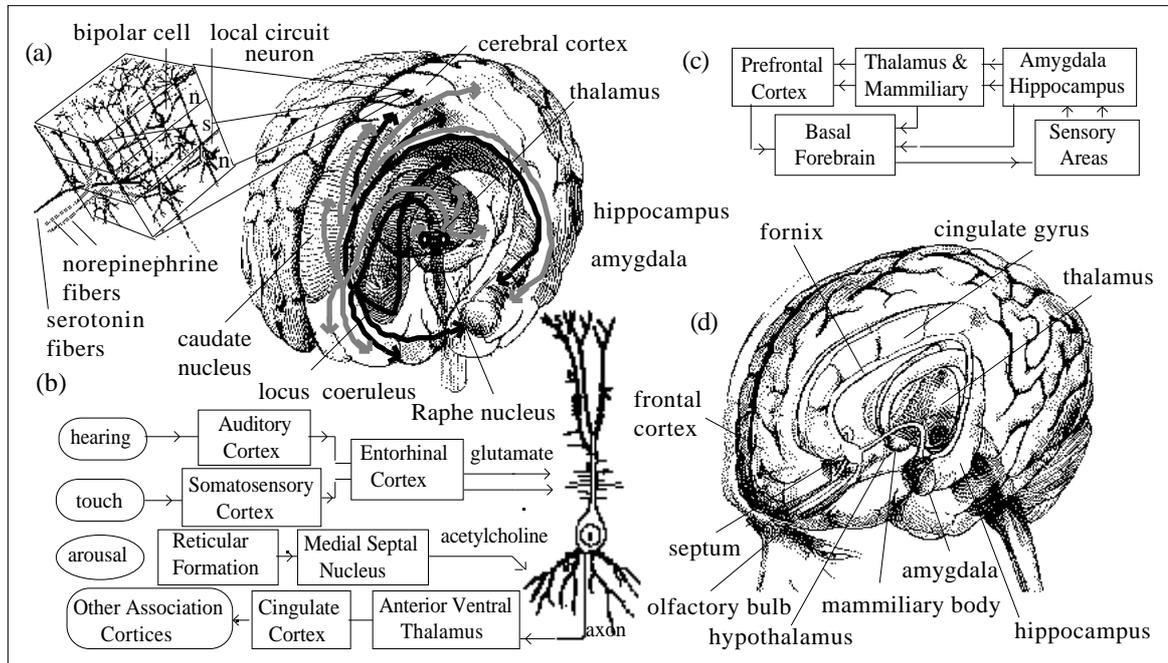


Fig 3: (a) Nor-epinephrine and serotonin pathways originating from mid-brain centres modulating light and dreaming sleep are distributed across wide areas of the cortex (Bloom et. al. 1985). (b) Inputs from different areas impinge on a single hippocampal CA1 neuron via distinct neurotransmitters, thus mapping neurosystems architecture on to single cells (Alkon 1989). (c) Looping circuits of the limbic system are involved in both affect and memory. (d) Limbic structures and the thalamus in brain section (Bloom et. al. 1985).

2.2.5 *Sensitive instability.* The internal model is non-linear, dynamically unstable and undergoes transitions to and from chaos. While some aspects of mind, such as visual processing, have structural stability in their representation of most objects, optical illusions and a variety of mental phenomena from hallucinations to the bizarre subjective realities of dreaming sleep demonstrate that the mind is capable of unstable self-generative behavior. Dynamical arguments dictate that a nervous system which is optimally responsive to sensory conditions must

undergo transitions into chaos to provide arbitrary sensitivity and ensure it does not become locked in any stability state or periodic oscillation. Thus while philosophers such as Gilbert Ryle, who rely on stable mental representations of objects, may conclude that mind is not even a well formulated concept, the unstable aspects may be essential to the internal model of reality.

Sensitive dependence is consistent both with representation of the mind as an internal model and with a dualistic interpretation of reality. The form of stability sets such as attractors and their evolution through bifurcation provides the basis for an internal model. The unpredictability of the chaotic regime and its ramifications in terms of quantum uncertainty provide a causal loophole within which to discuss principles complementary to physical processes occurring above the quantum level, which would support the dualistic perspective without contradiction.

3 The Neurophysiological Basis of Mind

It is obvious that the manifestation of consciousness in the forms we are used to experiencing requires interactive dynamics of the sensitively dependent active brain. What remains more elusive, like the engram of memory, is the neurophysiological basis for conscious states.

3.1 Local versus distributed generation of mind.

The hypothesis that mind is a consequence of the nature of distributed brain processing has a variety of support, based on the modular architecture of the cortex, modal arousal of the ascending distributed pathways and the impact of limbic circuits which we will investigate below. As all these systems are required for conscious attentiveness, the conclusion that consciousness is a global manifestation of attentive brain function is strongly supported.

An alternative strategy for the brain to generate the mind would be to have specialized areas dedicated to the generation of the internal model of reality. Sir John Eccles suggested that the mind is generated by the supplementary motor cortex, which is almost universally active (Popper & Eccles 1977). However damage to a variety of cortical areas reveals only "graceful degradation" of both function and subjective awareness, rather than 'mind loss' (Blakemore 1991).

Disagreement over the source of major oscillations in the brain such as the alpha and theta rhythms has led to ideas that specific sub-cortical structures such as the thalamus may play a principal role in generating mind, acting as a gating mechanism between the cortex and subcortical sensory centres (Crick 1984, Taylor 1992). It has topographical representations of many cortical modalities and forms an intermediate position between the cortex and the sensoria, thus having the potential to act as a filter releasing only the most relevant stimuli into conscious attention, coinciding with Huxley's (1954) filter theory of consciousness. These roles remain to be proven because the thalamus is difficult to access and the evidence from accidental lesions in humans is not clear. Similarly the ascending pathways of the basal brain are essential to maintain active consciousness, but this appears to be by diffusely activating the entire cortex.

Consciousness could nevertheless involve only a subset of cortical neurons. "Consciousness corresponds to coalitions of cortical neurons dynamically modulated by attention and higher-level expectations ... We would expect that only some of the cells in the cortex would be expressing what we see, while others are carrying out unconscious computations, but which cells correspond to consciousness?" (Crick & Koch 1992). At an extreme, identifying mind with distributed processing becomes *mind-brain identity* in which all mental states are considered the subjective equivalent of particular brain states. Mind-brain identity has two difficulties. Firstly the structural basis of mind is eliminated rather than explained by identity. Any responsive physical system, such as a computer could equally possess mind by the identity principle. Secondly identity prevents any *causal* link between the mind and brain, reducing consciousness and free-will to the status of delusions of the internal model, eliminating any role for the subjective aspect of reality in evolution and hence the need for an 'identity' mind.

3.2 Ascending distributed pathways. A very important contribution to the modal nature of conscious activity comes from the distributed pathways ascending from the midbrain centres, fig 3(a) responsible for general arousal in the reticular activating system [RES], and in regulating the major modality shifts of consciousness, light and dreaming sleep. Two pathways lead from the Raphe Nuclei and the Locus Coeruleus to diverse cortical areas and involve the modulating neurotransmitters, serotonin and nor-epinephrine, fig 11. The onset of dreaming sleep is heralded by activity of cells in the Pons and silencing of cells in the Raphe Nuclei and Locus Coeruleus (Bloom et. al. 1986). The latter also show bursts during orientation to novel stimuli. Similar dopamine paths spread out from the Substantia Nigra selectively into the frontal lobes and motor centres. The ascending pathways have been implicated in mental illness, addiction and motor syndromes such as Parkinson's disease (Gilling & Brightwell 1982). Dopamine is sometimes associated with pleasure and nor-adrenaline with anxiety.

Dreaming or REM sleep is both one of the most singular phases of conscious activity in which feedback appears to be accentuated at the expense of external input, generating complete subjective realities or 'worlds within'. The nature and function of dreaming consciousness and its wealth of detail remains obscure. The principal hallucinogens are also serotonin and catecholamine analogues, fig 11. In addition to cerebral arousal and sleep loss, their action probably triggers fractal waves of cortical excitation through the diffuse connections into interleaved cortical layers shown in fig 3(a) inset. Such connectivity gives the hallucinogens the capacity to modulate reflex modular excitability across the entire cortex, giving rise to patterned visions and cross-sensory synesthesias. They have earned a controversial

reputation by provoking, alongside dreaming, some of the most remarkable changes in the nature of consciousness discovered by man. For the same reason they represent a key tool for consciousness research.

3.3 Cortical modularity. A variety of experiments support the modular (Fodor 1983, Mountcastle 1978) involvement of cortical centres, both in various sensory-cognitive tasks and their correlates in mental activity. These illustrate how modular cortical processing can be associated with different aspects of conscious experience.

Visual processing is clearly modular, with parallel processing of colour and movement in distinct areas (Zeki 1992). The primary visual area V1 has 'discrete and segregated' connections through more structured sensors in V2 to V3, V4 and V5 responsible for dynamic form, colour form and motion. These areas are each associated with their own lesion syndromes such as achromatopsia [no colour], akinetopsia [no movement]. Zeki's studies raise fascinating questions concerning how subjective visual awareness is generated from these modular aspects. Although they have direct reciprocal connections and diffuse connections back to V2 and V1, there is no central arena where their output is sent, suggesting visual awareness is generated either by their modulation back on V1, or somehow by the entire distributed dynamic. Face and mood recognition, written and spoken speech, and music, are all modular features.

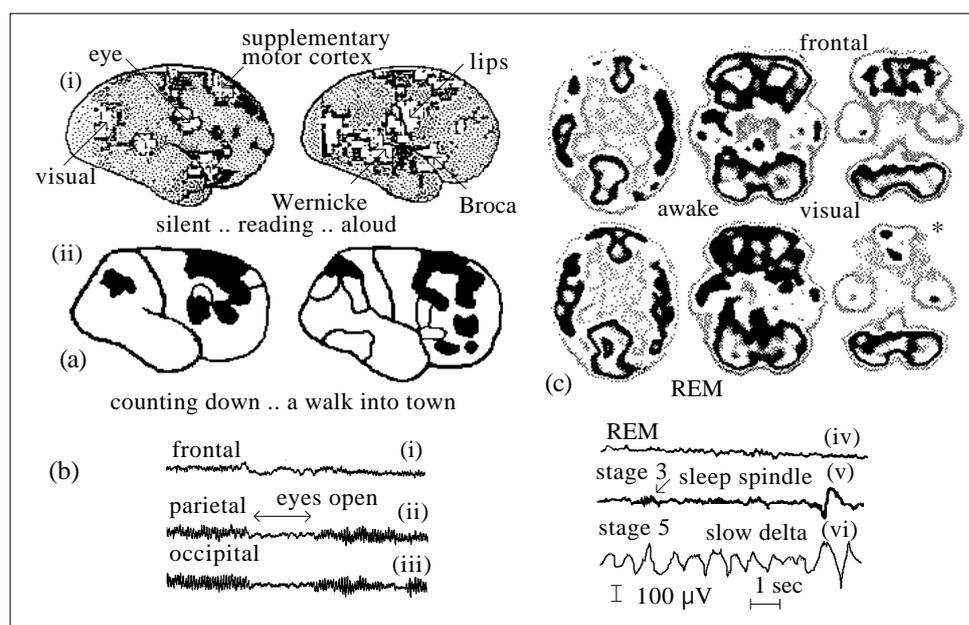


Fig 4: (a) Cortical modularity in PET scans. (i) Silent reading is contrasted with reading aloud, in which there is wider cortical involvement, including motor and somatosensory lips areas. (ii) Counting down is contrasted with visualizing a walk into town, stimulating a variety of frontal areas as well as the parietal cortex (P. Roland ex Blakemore 1991). The supplementary motor cortex is activated in all four views. (b) Similarity of the REM sleep EEG (iv) to the alert state [(i)-(iii) eyes open]. (c) REM sleep PET scan parallels the awake brain in activation of visual cortex and frontal lobes [dark], except for reduced REM inferior frontal activity (*), consistent with the lack of control in dream sequences.

The PET scans in fig 4(a) illustrate the correspondence between different conscious activities and the activation of specific modular regions of the cortex, including well-known areas such as Wernicke's and Broca's areas of linguistic interpretation and articulation and the supplementary motor cortex, as well as highlighting less well understood areas in the frontal lobes. Listening to ambiguous structured signals [time reversed recordings] can activate just about the entire cortex (Friberg 1992) suggesting that activation is at least partially a product of chaotic instabilities in the process of forming a stable representation. Dreaming states provide interesting PET scans in which the cortex is perceptually activated in a manner consistent with the similar EEG to the waking state, fig 4(b,c), and the intensity of dream experiences. One feature different in dreams is the lower activity of the inferior frontal cortex, which may reflect the uncontrolled nature of dreams (Madsen et.al. 1991).

Such studies support a modular distributed internal model, which may also be *holographic* in its use of distributed phase fronts and wave transforms. The holographic aspect, popularized by Pribram, arises naturally from the many to many nature of synaptic connections, the simultaneity of Hebbian synaptic response and from the decomposition of sensoria into features such as line orientation and ocular dominance, forming a parallel representation in which each memory or experience is registered across the cortex as in terms of its attributes. What is less clear is how attributes such as colour motion, edges and filled regions coordinate with the primary sensory areas to resynthesize the complete conscious view.

3.4 The Split-brain and sex. Study of split-brain patients reveals how difficult it is to pinpoint the structures supporting sentient consciousness. When the left and right cerebral hemispheres are severed by cutting the corpus callosum, replies to experimental questions centre around the content of the dominant hemisphere, because it is uniquely able to articulate verbal responses. If a composite image is shown separately to the left and right half eye

fields of the split-brain subject, they will describe the image their dominant hemisphere sees, and will be unable to refer descriptively to stimuli presented exclusively to their recessive hemisphere, unless it also retains linguistic ability. For example a nude in the left field will elicit a laugh and the indirect comment "That funny machine". The person thus behaves verbally, but not emotionally, as if the experiences of the non-dominant hemisphere are unavailable. However if asked merely to point to the picture seen, the recessive hemisphere, which is specialized at non-verbal pattern recognition, can assume control. The subject appears to retain an integrated personality and displays only minor conflicts of behavior, because the midbrain structures involving emotion and arousal are still intact, although the hemispheres appear a little like Siamese twin minds which can express distinct desires and aims. One patient's hemispheres for instance had the distinct aims of being draftsman and racing driver (Gazzaniga in Bloom et. al. 1985). Consciousness, even in the intact brain, may be a bundle of coupled awarenesses (Gazzaniga 1985, Parfitt 1987, Dennett 1991) rather than a single dynamical entity.

Sexual differences in the brain provide a further intriguing dimension of variation in human consciousness (Kimura 1992). At least three types of difference have been noted, enlargement of a specific hypothalamic nucleus in men, and differences both in lateralization and relative function of frontal and parietal areas. Women appear to have less linguistic lateralization, despite displaying superior verbal abilities (McGlone in Bloom et. al. 1985), and are several times more likely to have aphasia or apraxia from frontal than parietal strokes. Men have corresponding parietal and lateral dominance, leading to the possibility that male and female brains have global differences of organization similar to the plasticity seen in sensory processing.

3.5 Attention and Memory : The Limbic System and Frontal Areas.

The limbic system fig 3(e), (Mishkin et.al.1988, Alkon 1989) also forms a particularly interesting set of looping pathways combining sensoria, emotional states and episodic long-term memory, (c,d). The hippocampus, which has an older three-layered structure than the six-layer neocortex has a pivotal role in establishing long-term memory, possibly by transferring experiences into associative memory over a matter of weeks. It has projections from diverse sensory areas via the entorhinal cortex and feeds back into the thalamus and subsequently to cortical areas including prefrontal, cingulate gyrus, and basal forebrain. The amygdala has similar looping circuits linking diverse sense modes and connecting to the thalamus and deeper emotional centres in the hypothalamus. Phase decoherence occurs in the hippocampus during orientation to unfamiliar stimuli. The limbic system thus forms a bridge between emotion, memory and a distributed representation of time action and self in the frontal lobes. This is consistent with the emotional and motivational side-effects of frontal lobotomy and with studies on time-delayed learning in damaged hippocampi. It also gives a graphic portrayal of the link between extremes of emotional experience from fear to exaltation, the central themes of survival, attention, and the establishment of long-term memory.

The limbic system may also be linked to both the ascending pathways and the cortex in processing waking memories in the REM phase of sleep (Winsen 1990). In several mammalian species, theta rhythms, which are generated in the brain stem and pass both to the Septum in the forebrain and to synchronous generators in the hippocampus, can act as phase locking signals for long-term potentiation, in association with orientation to key survival activities. Spatially selective CA1 cells, which signal an animal's location in the waking state, are selectively active in subsequent REM phases, suggesting REM functions in memory processing in the sleep cycle. The role of emotion in the limbic system as a monitor of and driving force for survival, may thus underlie the archetypal intensity of dream content. However, because we dream about past experiences, it is also likely that hippocampal cells will revisit locational states. Notably, we can also remember our dreams. It is difficult to see how this is possible at the same time as memory reconsolidation.

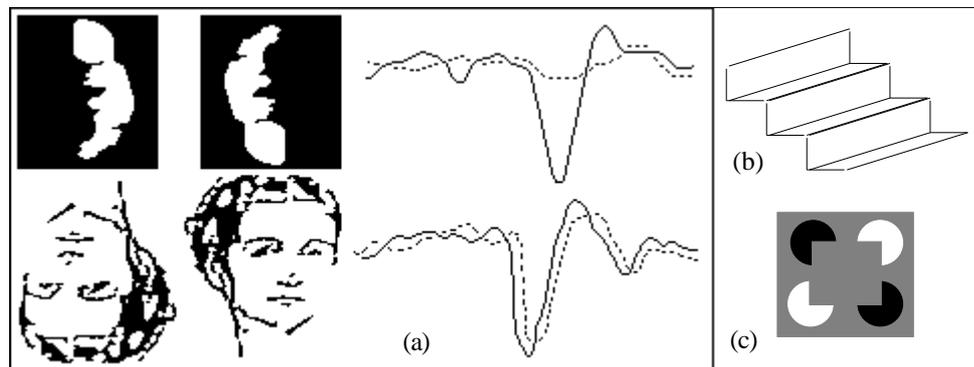


Fig 5: Optical illusions illustrate the close linkage between mind state and brain state, and support a dynamical bifurcation model of conscious imaging. (a) The lower face, which is easy to recognise in either orientation gives similar evoked potentials, while the upper one which is difficult to recognise inverted does not (Jeffreys ex Blakemore 1991). Optical illusions illustrate two features of visual processing consistent with attractor dynamics: (b) alternating percepts of a diagram which is ambiguous in 3-D, (c) construction of a geometrical figure from incomplete information.

A second active type of short-term memory often called *working memory* (Goldman-Rakic 1992) complements [long-term] associative memory by providing short-term storage of symbolic information as well as permitting the manipulation of that information. It appears to be centred on the prefrontal cortex with reciprocal connections with both the parietal cortex and the limbic system. Prefrontal damage effects use of knowledge to guide behaviour in

everyday situations, including predictive tracking e.g. of projectile movements. When a monkey is trained to look at where a target has disappeared after a delay selected cells in the prefrontal cortex fire, on target disappearing, others fire during the delay and others on the motor act. Such eye movement also involves feedback loops to the basal brain [from pyramidal cells to the striatum, the substantia nigra, mediodorsal thalamus and back to pyramidal cells]. Prefrontal action is modular with spatial and compound attributes active in different loci. A model linking the frontal and limbic structures in a representation of space-time is developed in 8.2.

3.6 Global Dynamics : Mind States and Brain states.

Examination of the contributions to consciousness by the major dynamical structures of the brain confirms that consciousness is a collective product of the ascending pathways, the cortex and limbic system. The dynamical activation of the cortex by ascending distributed pathways appears essential for consciousness, while all sensory areas and most of the associative areas of the cortex can be seen to contribute in a modular manner to the envelope of conscious experience, dynamically modified by the looping circuits of the limbic system.

Conscious experience is thus subject to much of the global dynamical variation for which the brain is capable, from anaesthesia, through waking, resting, dreaming, and hallucination. Only in deep sleep, seizure and coma when the global dynamics are profoundly altered do we see a loss of conscious function. In fig 5(a) the close correspondence between conscious recognition and brain states is illustrated. In (b) two optical illusions illustrate the way in which perception displays both oscillatory compensations in the presence of ambiguous 3-D information, and attractor-like constructs which complete partial visual information with perceived lines and regions. This can be seen as a possible example of linkages between edge detectors in V2 and higher areas and is also consistent with an attractor-bifurcation basis for the internal model of reality.

Crick and Koch (1990,1992) have explored a variety of hypotheses as to where and how consciousness might be generated in the cortex. One structured hypothesis is that it is associated with a specific frequency mode. "We have suggested that one of the functions of consciousness is to present the result of various underlying computations and that this involves an attentional mechanism that temporarily binds the relevant neurons together by synchronising their spikes in 40Hz [35-70Hz] oscillations". They point out that distinct images could excite the same modules without confusion if they had synchronous oscillations. This would explain, for example, how you can briefly imagine something while looking at the world around you. They also speculate that the top layers of the cortex could be unconscious and layers 5 & 6 which output to other areas might be conscious. A minimum processing time of 60-70ms for a conscious percept can be deduced from the display of rapid images [20ms red + 20ms green = yellow] or tones.

4 Non-linear Dynamics in the Central Nervous System

Physical evidence for attractor dynamics in a variety of aspects of central nervous system function and development has become abundant in recent years. Chaotic regimes have been demonstrated, both at the neurosystems level and in the dynamics of single excitable cells, and fractal dynamics has been proposed for ion channels (King 1991).

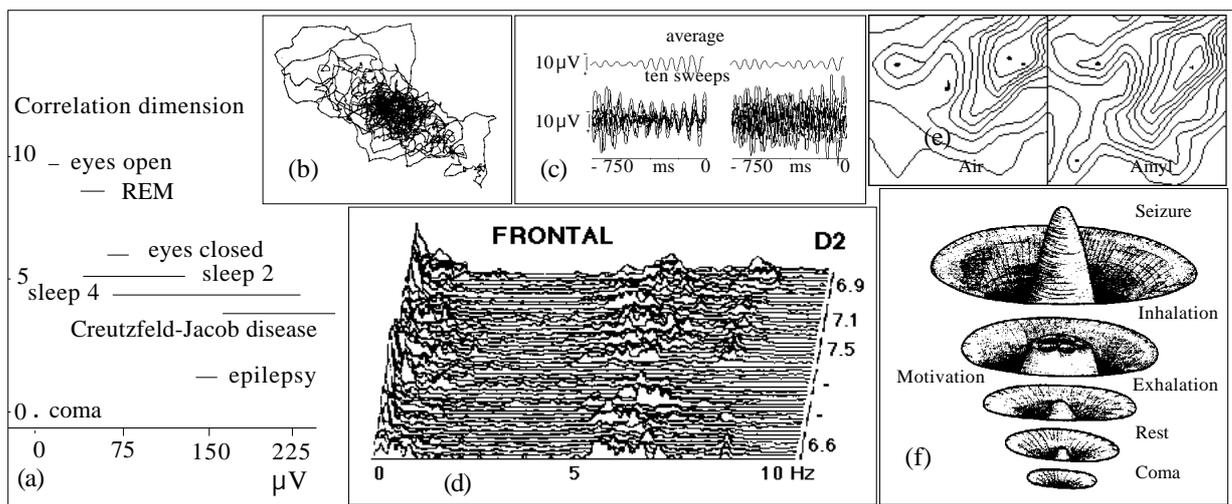


Fig 6: Chaotic neurosystem dynamics are illustrated (a) By the low correlation dimensions of a variety of brain states, (b) phase portrait of an EEG recording (Babloyantz & Salazar 1985), (d) time evolving Fourier spectrum and associated correlation dimensions. (c) Phase decoherence in novel or unexpected stimuli is consistent with a distributed model of processing based on oscillatory phase, similar to a hologram. (e,f) Chaotic and distributed processing is combined in Walter Freeman's model of olfactory bulb processing. Recognition of a given odour by the bulb arises from the distributed pattern of activity, occurring in bursts phased with inhalation. The time-dependent dynamics supporting this consists of bifurcation from low-level chaos to higher level activity which settles into an existing attractor [recognition] or develops a new one [learning] after exploring phase space in higher level chaos. Chaotic neural nets based on neuroanatomy can perform pattern discrimination tasks competitively with other neural net designs (Skarda & Freeman 1987).

4.1 Electrodynamics.

4.1.1 *Neurosystems Dynamics*: At the neurosystems level, experimental evidence has accumulated for chaos in the EEG's of at least some phases of cortical activity, including sleep, resting wakefulness and pathological states such as epilepsy (Babloyantz 1985, 1989, Basar 1990). The low correlation dimensions of several of these states is consistent with collective chaotic dynamics in neuron populations, rather than stochastic or independently programmed behaviour. Evoked potentials also show desynchronizations during orientation, consistent with phase relations being pivotal in recognition and orientation (Basar et.al. 1989, Hoke 1989), supporting a holographic model. The model of burst dynamics in the olfactory bulb advanced by Walter Freeman fig 6(e,f) combines these two aspects into a model with bifurcations of spatially distributed waves into chaotic temporal dynamics which both follow the neurophysiology and also permit real tests of pattern discrimination of neural nets displaying comparable dynamics (Freeman & Baird 1987, Skarda & Freeman 1987, Freeman 1991, Yao et.al. 1991).

In this model, low level chaos is lifted into a higher energy state by olfactory input. Chaos in this state enables the system to explore its phase space, falling into an existing attractor in the case of a recognised odour, but bifurcating to form a new attractor in the case of a newly learned stimulus. The transition into chaos thus provides sensitive dependence on input, ergodic 'randomizing' phase space exploration, parametric bifurcation to form new symbols, and possible quantum amplification. Return from chaos in turn fixes stability structures from the fractal dynamics.

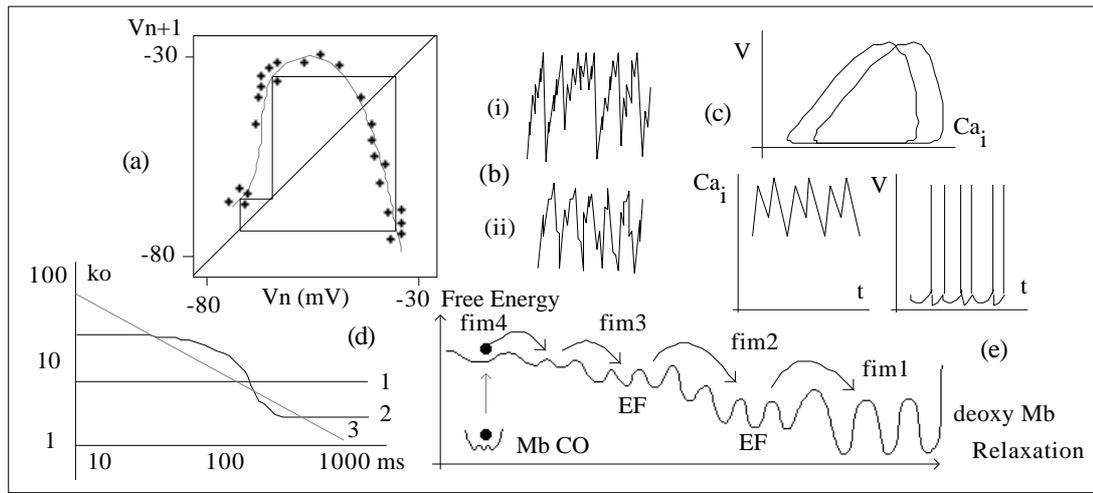


Fig 7: (a) Period 3 oscillations in *Nitella* indicate dynamics within the chaotic regime. Chay-Rinzel model (1985), (b) output is comparable with experimental recordings, (c) period doubling bifurcation in model. (d) Experimental behaviour of voltage gated K^+ -channel is consistent with a fractal model (3) rather than a one, or two step Markov chain (1,2) (Liebovitch et. al. 1987a,b). (e) Fractal dynamics in relation of excited myoglobin is illustrated in terms of functionally important movements and equilibrium fluctuations involving a variety of quantum transitions on differing scales.

4.1.2 *Single Cell Dynamics*: Similar experimental evidence has accumulated for chaos in a variety of excitable cell types, supported by the chaotic models of Chay and Rinzel (1985), fig 7(a,b,c). These extend the Hodgkin-Huxley equations (1952) to take account of calcium ion pumping, thus displaying a variety of dynamical features, including period doubling bifurcations, chaotic regimes and period three oscillations characteristic of the chaotic regime. These dynamics model well the chaotic excitations of *Nitella* pancreas cells, and similar models have been advanced for excitations in neurons and heart pacemaker cells. The irregular behaviour of controlling cells in small ganglia such as in *Aplysia* studies is also consistent with sensitive dependence and chaos, by contrast with the more regular beating of subordinate neurons.

4.1.3 *Fractal Ion-Channel Kinetics*: A Markov model is commonly used for ion channel kinetics, in which an open state is linked to one or more closed states. However the likelihood that a closed channel will open behaves fractally with increasing time scales according to fig 7(d) (Liebovitch et. al. 1987a,b, 1991). This is consistent with biomolecular structures behaving fractally, not only in a geometrical sense, but also dynamically as shown for myoglobin in (e) (Ansari et. al. 1985). The dynamics of many important biological molecules may be fractal in this way, which involves the linkage between a variety of quantum excitations of differing energies, and feedback between tertiary structures and active sites.

4.2 Long-term adaption. Many aspects of the long-term structure of sensory areas of the cortex are consistent with their inheriting an attractor structure derived from particular sensory innervation and stimulation patterns. On a short time scale are the reported spatial distributions corresponding to olfactory stimuli, fig 6(e) which on a longer time scale adopt new forms on relearning the same stimulus a second time, and phase desynchronization of cortical evoked potentials. On a longer time scale plasticity of sensory structure fig 7 from the somatosensory barrels of the rodent (b), through to visual ocular dominance and orientation patterns induced by training regimes (a) indicate major sensory structures arise as a dynamical system induced through bifurcation.

4.3 Neurogenesis. The raw numbers game of neurogenesis suggests attractor dynamics may form an essential bridge between central nervous genotype and phenotype. The 5×10^4 genes governing central nervous system

development [around 60% of human genes] cannot informationally specify the connections for 10^{11} neurons and 10^{15} synapses. Generalizing principles are thus required to complement the informational specificity of developmental genes such as the homeotic genes, thus providing both genetic efficiency and plasticity. The form of early embryogenesis is a series of bifurcations induced by morphogen gradients leading to the differentiation of major brain structures, fig 9(a). Further general principles playing a dynamical role in central nervous organization include cell surface interactions enabling migration up the glial scaffold (b), selection of tissue layer, or target cell synapse type, and parallel growth (Blakemore 1991). The neurogenic picture is thus consistent with genetic selection up to target cell type but the development of specific synaptic connections and the organization of thalamic and cortical layers, ocular dominance columns, barrels etc. through dynamical excitation driven by the afferent sense organs, culminating in the sensory experiences of the newborn (Kalil 1989). This is consistent with the plasticity of sensory structures already described, with tissue culture experiments (c), and with the waves of excitation seen on the prenatal retina [1/10-1/100 action potential speed], which stop just before the onset of visual activity. These waves appear to result in both geniculate layering and subsequent organization in the visual cortex (Shats 1992), by competitive input, in which synchronous inputs cause Hebbian enhancement, while asynchronous inputs from distinct eyes cause synaptic separation, consistent with the sequential organization of (1) the retina via early firing in ganglion cells, (2) subsequent layering of the geniculate after retinal wave input, and finally (3) organization of ocular dominance and other features in the visual cortex.

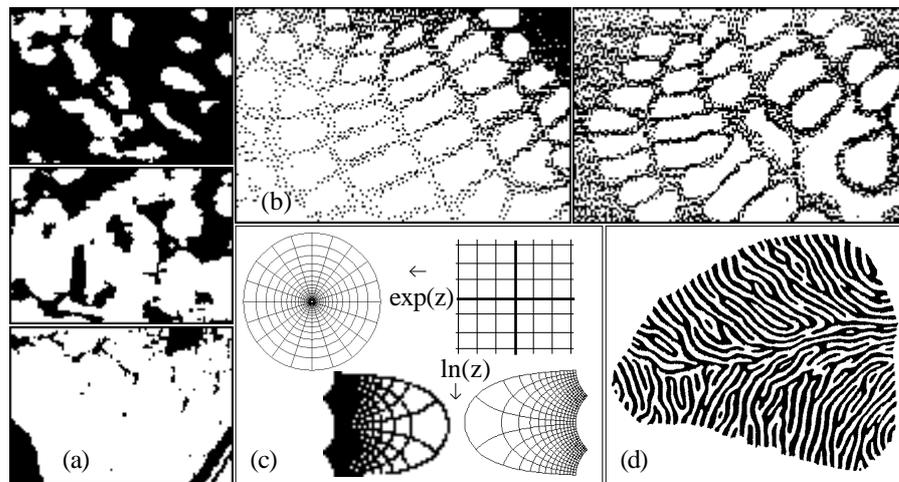


Fig 8: Plasticity consistent with attractor dynamics is illustrated (Blakemore 1991) (a) by field patterns of reversal of imbalanced ocular dominance caused by covering the dominant eye in a cat, and (b) somatosensory barrels in the mouse showing invasion by neighbouring nuclei on removal of a whisker. (c) The visual field on the cortex is distorted by a non area-conserving map similar to a complex logarithm, which gives greater sensitivity to the centre but does not match the geometry of the perceived world (Cowan & Sharp 1988). (d) Ocular dominance displays a bifurcation of the 2D field in terms of the 1D parameter of dominance (Hubel & Wiesel 1989).

5 The Fractal Link between Chaos and Quantum Mechanics.

5.1 The Scale Link between Neurosystems and Cellular Dynamics. The occurrence of chaos in neurosystem dynamics suggests that the brain may also utilize the fractal aspect of chaos as an intrinsic aspect of its processing, in combination with the natural scale transformations from organism to cell to molecule. The architecture of the central nervous system includes specific linkages between the level of whole neurosystems and the single cell. One is illustrated in fig 3(d) where a single hippocampal CA1 pyramidal cell has inputs from distinct brain regions, the sensoria and the reticular activating system via distinct neurotransmitters and distinct anatomical regions of the cell.

Such architecture permits a two-way relation between large-scale neurosystems dynamics and that of single cells, which both enables large-scale bifurcations to alter the stability of single cells and for single cells to precipitate bifurcations at the neurosystems level. The utilization of instability to provide responsiveness pinpoints the unstable aspects of the dynamics at the centre of processing demands, because these are the unresolved aspects of the internal model. The occurrence of either chaotic sensitivity or self-organized criticality at the neurosystems level could then enable a small subpopulation or even a single critical cell to precipitate global bifurcation.

The brain may utilize sensitive instability to deal with computationally difficult situations by mapping parallel representations on a fractal basis similar to Penrose's (1989) fractal algorithms for parallel computation (Dewdney 1989), with the added feature that continuous dynamical instability is used in addition to resolve ambiguous situations which remain intractable digitally.

5.2 The Complexity of Form of the Eucaryote Excitable Cell. Such reasoning places an additional emphasis on the neuron (Stevens 1989) as an integrated field processing unit, thus replacing the trivial formal neurons of McCulloch-Pitts, or optimizing analogue models such as the Hopfield net (Tank & Hopfield 1987) with a sophisticated integrated unit capable of chaos and unstable bifurcations. This is supported by the obvious complexity

of typical central nervous neurons, with up to 100,000 synaptic junctions having a variety of anatomical forms fig 10(c), unstable bifurcations across threshold, and other non-linear features, (a). On a descending series of scales, the cell is itself a physical fractal both structurally and functionally in terms of its dendritic and axonic trees, (b) and in terms of subcellular processing both across dendrites (d) and synapto-synaptic junctions (e). Despite the approximate conformity to linearity of neuronal conduction over a restricted range above threshold (a), the neuron also has pivotal features of self-organized criticality in the form of tuning to its threshold, sigmoid limit-cycle bifurcation at threshold, and chaotic dynamics as depicted by the Chay-Rinzel model. The sensitivity of sensory modules such as pressure organelles also displays non-linear [quadratic] dynamics.

The fractal nature of dendritic and axonal trees provides the neuron with its second outstanding complex systems feature, which is that of a *fractal integral transform*. The capacity of the neuron to use its fractal structure to form many-to-many synaptic contacts lies at the foundation of its traditional role as a summation module. When organized in layers this permits a global integral transform, leading to the formation of complex fields from simple ones in sensory processing. The combination of this architecture with oscillatory signals could generate a Fourier-type invertible transform which would permit the retrieval of previous structures in a form comparable to a hologram, consistent with phase decoherence dynamics in experimental studies of the cortex and hippocampus.

Two characteristics of the neuron pivotal to a reassessment of its function are thus:

5.2.1 chaos and threshold self-organized criticality in non-linear dynamics.

5.2.2 the *fractal integral transform*.

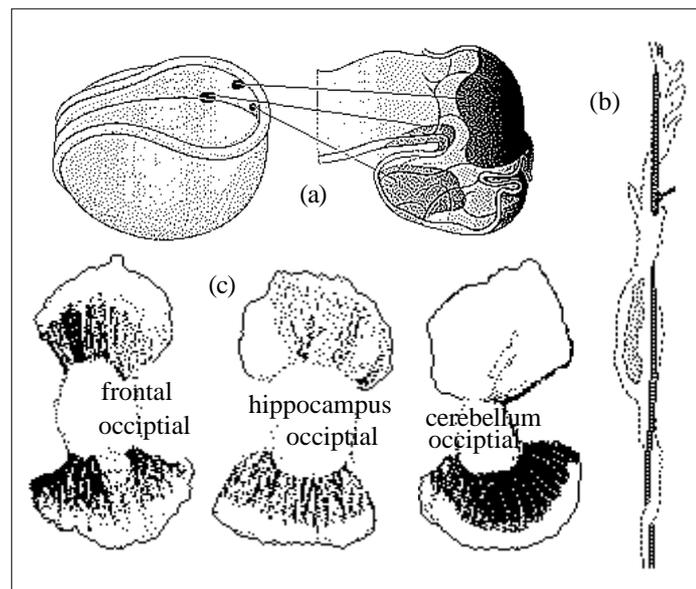


Fig 9: Morphogenic and contact fields and bifurcations: (a) impact of position within primary morphogenic tissue bifurcations on the development of brain regions, (b) cell-adhesion properties of proteins such as CAMs enable migration of specific neuron types, both along the glial scaffold and to specific cell layers or target types, (c) Specificity of ascending optic fibres may be limited to a general affinity for cortex suggesting the form of cortical sensory architecture may be organized by input from sense organs and stimulation in early life, rather than genetic specificity alone (Blakemore 1991).

5.3 The Non-linear Synapse. The fractal geometry of the neuron leads to an examination of the way cell organelles can provide a similar bridge between cellular and molecular dynamics. A variety of cell organelles provide a non-linear basis for sub-cellular dynamics. The concentration dynamics of the synapse fig 10(e) involves a rich diversity of feedbacks with non-linear characteristics. Concentration dynamics is linear only for single molecule interactions, but critical ion channels such as the acetyl-choline channel require two molecules for activation, thus having quadratic dynamics. Synapto-synaptic junctions display bilinear dynamics. Both of these can lead to chaos. Membrane dynamics also involve piezo-electric interactions. Microtubules have also been proposed as functional cellular automata (Hameroff 1987).

Such non-linearities make it possible for unstable fluctuation at the synaptic vesicle or ion channel level, within a critically poised neuron, to precipitate cellular instability and subsequent global neurosystem bifurcation. In cortical synapses, there is no need for the large number of vesicles seen in the neuro-muscular junction, and it has been proposed that in some synapses, the release of contents of a single vesicle is sufficient to traverse the threshold and elicit a post-synaptic response. A single vesicle, releases around 10,000 acetyl-choline molecules, activating 2000 ion channels, causing discrete micro-potentials even at the neuro-muscular junction, which depolarize the membrane by about 1 mV, sufficient to result in an action potential if a cell is already at threshold.

Eddington (1935) and Eccles (1970) discussed the possibility of quantum-mechanical action of the vesicle and pointed out that the uncertainty of position of a vesicle of 400 \AA diameter and mass $3 \times 10^{-17} \text{ g}$ is about 30 \AA , comparable with the thickness of the membrane. Because of this, the vesicle can be regarded as a quantum object, which is at

the same time capable of triggering cellular and hence global instability. The topological closure of the vesicle membrane results in the amplification of quantal instabilities from the level of the molecule to the larger level of the vesicle. The kinetics of vesicle association with the pre-synaptic membrane is determined by binding to one, or a few proteins, making vesicle release a function of the kinetics of one or a few molecules. The precise mechanism of vesicle exocytosis is not yet elucidated, but may involve the vesicle membrane protein synapsin I.

5.4 The Molecular Level. Activation of a single ion channel requires one or two neurotransmitter molecules. While the ion flux resulting from a single open ion channel will not generally elicit an action potential, if the channel happens to command a critical site on the two-dimensional dendritic surface, for example close to the cell body where the action potential begins, and the cell is at or near threshold, then the single quantal encounter of a neurotransmitter binding to an ion channel could be capable of evoking an action potential. The fractal nature of ion channel kinetics finally allows for the interaction of molecular quantum excitations on a variety of fractal scales, constituting the quantum chaotic level of expression. Long-term potentiation associated with a receptor-kinase-membrane feedback (Alkon 1989, Winson 1990) is another kinetic process at the molecular level which permits a molecular change to trigger a distinct global history, however the determinate nature of memory makes it one of the less likely aspects of brain function to be subject to quantum instability.

The four levels of instability link in stages, making it possible for the fractal aspect of chaotic dynamics at the global, cellular, synaptic and molecular levels to combine to provide a fractal model in which global and quantum instabilities are linked by mutual interactions of scale. Global instabilities in brain dynamics may be dynamically-linked to fluctuation of a critical neuron. Threshold instability similarly makes the neuron a potentially unstable dynamical system which is open to synaptic perturbations. Quantization at the level of the synaptic vesicle allows for amplification of quantum fluctuations in binding proteins into vesicle rupture that is capable of eliciting micropotentials at the neuronal level. Sensitive dependence and quantum amplification thus give the brain the capacity to detect fluctuation at the quantum level. This is consistent with the sensitivity of sensory apparati which are all capable of detections at or close to the level of single quanta [see 7.1].

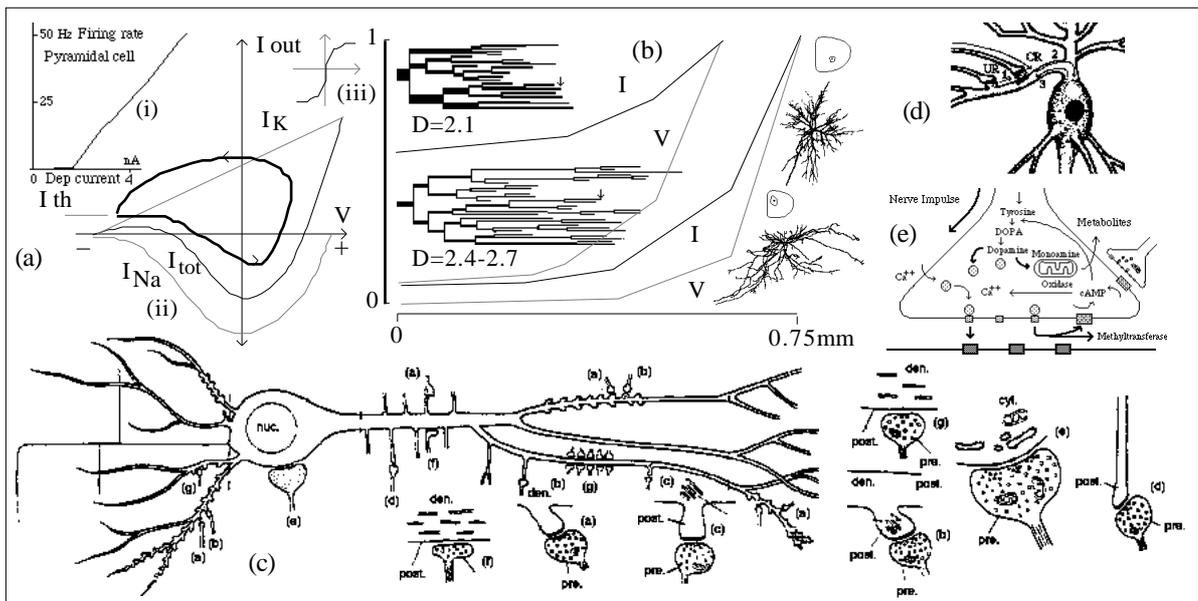


Fig 10: Non-linear and fractal aspects of the neuron. (a) Non-linearities occur in formation of a limit cycle and excitation threshold (ii), despite approximate linear relation between depolarization current and firing rate in a limited range (i). Sigmoid transmission curve (iii) and mechanoreceptive bulbs also have a non-linear response. (b) Fractal structures of dendrites of two cell types and their electrodynamics (Schierwagen 1986). (c) The anatomical complexity of the neuron is illustrated by the structural variety of synaptic junctions, which also utilize distinct neurotransmitters. (d) Dendritic microcircuits and synapto-synaptic junctions (e) place the level of net organization one or two levels below the neuron. Synaptic conduction involves many feedbacks (e), some of which, including the two-molecule activation of the acetylcholine ion channel have quadratic rather than linear concentration dynamics.

6 The Evolutionary Origins of Fractal Processing

It is one thing to establish the possibility that fluctuations at the quantum level could in principle become amplified into global instabilities in the brain, but quite another thing to explain why the brain should find it advantageous to allow such disordered processes to intervene in its functioning. Normally noise in a system is regarded as the anathema of computational precision, so an explanation is in order.

6.1 The Computational Intractability of Survival in the Open Environment. The principal task of the brain of is to compute the survival strategy most likely to enable the organism to evade death and produce viable offspring. A computational problem is intractable if the number of computational steps required grows super-exponentially with the complexity of the problem. The *travelling salesman* problem (Bern & Graham 1989), finding the shortest route round n cities illustrates this, growing with $(n-1)!$ A problem may also be formally undecidable

in the sense of Gödel. Many adaption-survival problems in the open environment share the characteristics of intractable problems, because each strategy tends to be matched by a competing strategy in another organism and the number of options rapidly exponentiates. An active organism must also complete a processing task within 0.1-1 second if it is going to have survival utility, regardless of its complexity. Such arguments make it clear why parallel processing is an integral feature of vertebrate nervous systems.

The fractal algorithm (Penrose 1989, Dewdney 1989), which in addition to parallelism, features fractal task assignment, shares significant features with biological processing. Including attractor dynamics with chaotic regimes in such a scheme provides additional features of sensitive dependence, phase space exploration, continuous resolution of instabilities, and the capacity to form new symbolic structures through bifurcation. It also provides a dynamic model for cognition in which bifurcation generates a series of symbolic structures, which become stable representations forming the successfully-modelled aspects of a problem. The complementary unstable component may continue to hunt through chaotic states, either bifurcating to stability, or forming a fractal instability which could in turn be perturbed by quantum instabilities.

6.2 Chaotic Excitability as a founding Eucaryote Characteristic. Chaotic excitability may originate deeper in evolutionary history, representing one of the oldest features of eucaryote cells (King 1978, 1990). The Piezo-electric nature and high voltage gradient of the excitable membrane provides an excitable single cell with a generalized sense organ. Sensitive dependence would enable such a cell to gain feedback about the external environment, rather than becoming locked in a particular oscillatory mode. Excitation could be perturbed mechanically and chemically through acoustic or molecular interaction, and electromagnetically through photon absorption and the perturbations of the fluctuating fields generated by the excitations themselves. Such excitability would predate the computational role of neural nets, making chaos fundamental to the evolution of neuronal computing rather than vice versa. The chemical modifiers may have been precursors of the amine-based neurotransmitters which span acetyl-choline, serotonin, catecholamines and the amino acids such as glutamate and GABA, several of which have a primal status chemically. The use of positive amines may have chemically complemented the negatively charged phosphate-based lipids, fig 11, in modulating membrane excitability without requiring complex proteins. It is thus possible that chaotic excitation dates from as early a period as the genetic code itself and that the first eucaryote cells may have been excitable via direct electrochemical transfer from light energy, before enzyme-based metabolic pathways had developed.

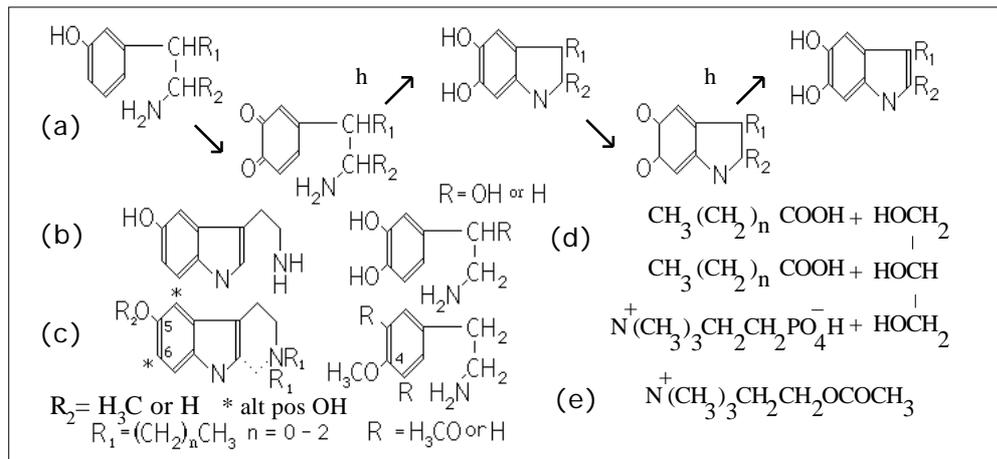


Fig 11 : Primal chemical aspects of neurotransmitters. (a) Primal uv-bridge between catecholamines and indoles. (b) Serotonin, Nor-adrenalin ($\text{R}=\text{OH}$) & Dopamine ($\text{R}=\text{H}$) and (c) their psychoactive variants are monoamines. (d) Acetyl-choline and (e) Phosphatidyl-choline demonstrate a common tertiary amine involvement.

6.3 Consciousness as an Evolutionary Manifestation of Chaotic Neurodynamics. From this perspective it is natural to postulate that, far from being an epiphenomenon, consciousness is a feature which has been elaborated and conserved by nervous systems because it has had unique survival value for the organism. We are thus led to an examination of how chaotic excitation may have evolved from single-celled animals through the early stages represented by *Hydra* to the complex nervous systems of metazoa. We have seen how chaotic excitation provides for exploration of phase space and sensitivity to internal and external fluctuations. However the conservation of consciousness may also involve features expressed only by chaotic systems which are fractal to the quantum level.

It is a logical conclusion that the conscious brain has been selected by evolution because its biophysical properties provide access to an additional principle of predictivity not possessed by formal computational systems. One of the key strategies of survival is *anticipation* and *prediction* of events (King 1978, Llinás (1987)). Computational systems achieve this by a combination of deductive logic and heuristic calculation of contingent probabilities. However quantum non-locality may also provide another avenue for anticipation which might be effective even across the membrane of a single cell, if wave reductions are correlated in a non-local manner in space-time.

7 Quantum Models in the Central Nervous System

7.1 Quantum Sensitivity in the Senses. The limits to the sensitivity of nervous systems are constrained

only by the physics of quanta rather than biological limits. This is exemplified in fig 1(a) by the capacity of retinal cells to record single quanta, and by the fact that membranes of cochlear cells oscillate by only about one H atom radius at the threshold of hearing, far below the level of thermodynamic fluctuations. Moth pheromones are similarly effective at concentrations consistent with one molecule being active, as are the sensitivities of some olfactory mammals. The quantum uncertainty of the vesicle in relation to the membrane has also been noted above as a source of sensitivity of the synapse to quantum fluctuation.

7.2 Sense Modes as Quantum Modes. The very distinct qualitative differences between vision, hearing, touch and smell do not appear to be paralleled in the similar patterns of electrical excitation evoked in their cortical areas. It is thus hard to see how the internal model of reality generates such different subjective modalities as the experiences of vision smell and hearing from common electrochemical dynamics. One possibility is the senses are generated in the internal model by the same quantum modes of sensory excitation, namely photons, phonons, membrane solitons and weak bonding interactions. If all these excitations can occur simultaneously in the membrane, its quantum-chaotic excitation could represent a form of cellular *synesthesia*, which is subsequently specialized in representing each individual sense mode.

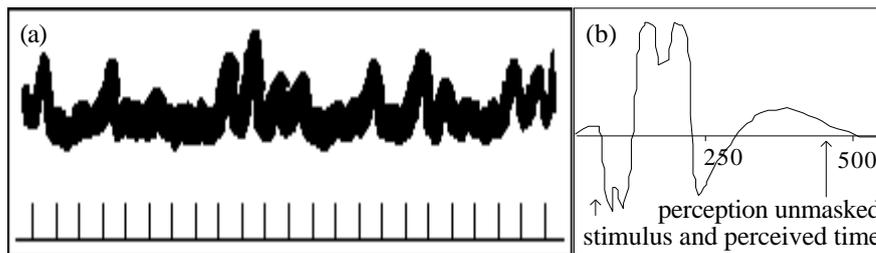


Fig 12: (a) Excitations of single rod cells shows peaks with 0, 1, or 2 photons being registered, consistent with quantum statistics of photons being released very slowly at a rate corresponding to the marks below (Bailer & Lamb ex Blakemore 1991). Derefencing of a perceived stimulus back to the original time (Libet et.al. 1979).

7.3 Quantum Mechanics and Wave Packet Reduction. Quantum systems differ fundamentally from the classical case, in which in principle conforms to a deterministic description. While the evolution of the system proceeds according to a deterministic Hamiltonian equation :

$$(\nabla^2 + \psi^2 - 2 + m^2) = 0 \tag{7.3.1}$$

the measurement process, results in causality violations in which the probability interpretation

$$P = * \tag{7.3.2}$$

constitutes the limits on our knowledge of the system, resulting in a **stochastic-causal** model, in which measurement collapses the wave function from a superposition of possible states into one of these states. While quantum-mechanics predicts each event only as a probability, the universe appears to have a means to resolve each reduction of the wave-packet uniquely, which I will call the *principle of choice*, the subject of Schrödinger's famous cat paradox, in which quantum mechanics predicts a cat killed as a result of a quantum fluctuation is both alive and dead with certain probabilities, while we find it is only one : alive, or dead! The **stochastic-causal** processes of quantum mechanics violate causality because Heisenberg uncertainty

$$E . \quad t \sim \frac{h}{2} \quad p_x . \quad x \sim \frac{h}{2} \tag{7.3.3}$$

prevents a complete causal description of quantum dynamics, which can predict future [or past] states only as probabilities in each instance of *reduction of the wave packet*.

It is one thing to suggest that quantum fluctuations could in principle evoke global bifurcations of brain function, but quite another to determine what advantage might accrue from such seemingly stochastic activity. The possibility of a connection between quantum mechanics and brain function has been a source of interest since the discovery of the uncertainty principle, because of its implications for consciousness & free-will, and several interesting models have been developed. The connection between the observer's mind and quantum mechanics is pivotal in some interpretations of wave function collapse.

7.4 Quantum Chaos versus Uncertainty as Substrates for Classical Chaos. Repeated attempts to model a variety of quantum analogues of classical chaotic systems have revealed significant differences which may prevent the full display of chaotic dynamics in the quantum analogues. Two theoretical approaches have been mounted on a variety of transition systems. In the semi-classical approach, fig 13(b) point particles are replaced by wave packets whose trajectories are calculated to provide a simulation of the wave function (Tomsovic & Heller 1991). Complementing this are quantum wave function approaches, such as quenched quantum mechanics, and studies of the so-called *scarring* of some chaotic wave functions around the periodic orbits (Gutzwiller 1992), which are necessarily embedded in any chaotic system (a). A variety of systems have been explored experimentally from hydrogen atom in a magnetic field to particles such as electrons traversing a molecule or molecular medium (c).

The spreading of wave fronts results in some smoothing of the classical picture of chaotic mixing, including tunnelling between trajectories, non-diffusive or time reversible dynamics, and the level repulsion between eigenvalues characteristic of the many-body dynamics of atomic nuclei. At the time of writing, verdicts on the capacity of quantum systems to fully exhibit chaos is still in flux, with some quantum systems, including magnetically excited atoms and electrons traversing molecular media appearing to display key features of chaos (Schuster 1986, Casati 1986, Giesel 1989, Wintgen & Honig 1989, Zhang et. al. 1990, Berry 1991, Peterson 1991, Uzer 1991). The electron traversing a molecule (Gutzwiller 1992) gives a simplified picture of chaos in molecular dynamics displaying chaotic variation in transition time [phase]. Sensitive dependence of molecular kinetics follows.

However it is the stochastic wave-reduction aspect of quantum mechanics which ultimately underpins the unpredictabilities found in chaotic physical systems. Statistical mechanics ultimately derives its random variation from Heisenberg uncertainty [7.3.3] in the form of wave-packet reduction. For example the positional statistics of molecular kinetics is made uncertain through diffraction of the wave aspect of a molecule by other molecules. An amino acid at room temperature has a self-diffraction angle of about 5° (King 1989), contributing initial condition uncertainty to each successive chaotic encounter, fig 13(c) when traversing a molecular medium. One of the important roles of classical chaos may thus be the amplification of quantum uncertainty into macroscopic indeterminacy. Sensitive-dependence in physical systems may thus result in *quantum inflation*, the amplification of quantum fluctuation into global perturbations of the dynamic. The distributed nature of wave reduction over the eigenspace may thus link to the ergodicity of chaotic systems.

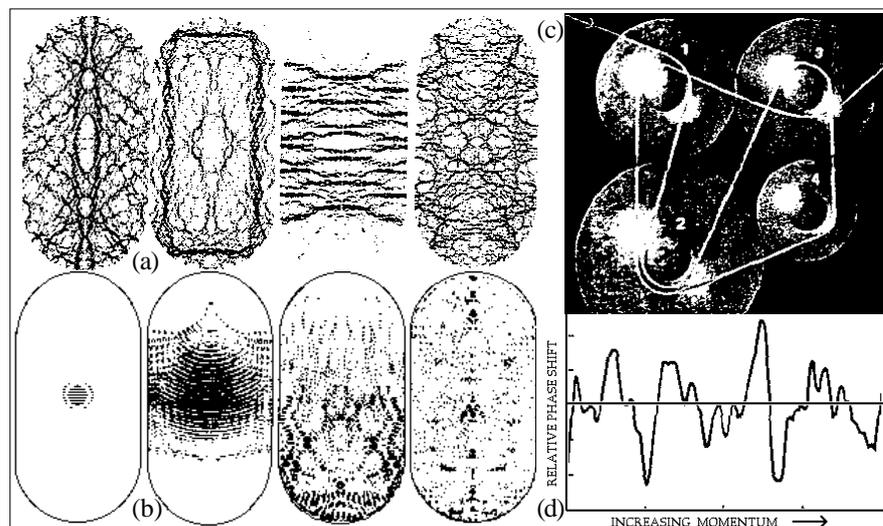


Fig 13: The quantum stadium represented (a) by quantum wave functions displays scarring of several wave functions around embedded periodic solutions (Gutzwiller 1992), (b) semi-classical approach provides a close approximation using a finite number of periodic solutions at least for some stages (Tomsovic & Heller 1991), (c) electron traversing a molecule has continuous variation of time [phase] with chaotic irregularity (Gutzwiller 1992).

7.5 Quantum Concepts in Brain Function. Bohm's work on the Einstein-Podolsky-Rosen conjecture, Bell's theorem and the Aspect experiments (Clauser & Shimony 1978, Aspect et. al. 1982) which display spin-correlations between a split photon pair over space-like intervals have demonstrated that hidden variable theories cannot be locally causal, leading several researchers to postulate the idea of non-local states correlating the activity of various parts of the brain (Penrose 1987).

Interest in quantum concepts in brain function has had a considerable history starting from Eddington (1935), and continuing with Eccles (1970). Basar (1983) has suggested matrix theory and Feynman diagram approaches (Stowell et. al. 1989) to resonances at the neurosystems level. Popper and Eccles (1977) and Margenau (1984) have also discussed the possibility of quantum reduction being dependent on the mind of the observer, leading to the paradox of Wigner's friend in which an observer's friend splits the wave function, and reports on the result. Multiple minds thus lead to ambiguities of splitting. One way around this paradox is to require mind to be a unity rather than a multiplicity removing the ambiguity of the reduction point, another is that the first conscious observer in the chain collapses the wave function. Recent studies using down-converters demonstrate that the possibility of gaining information about a photon's path collapses the wave function and that such knowledge can be erased to regenerate a coherent wave (Horgan 1992). Although such distinctions ultimate reach the conscious observer, collapse appears to occur with the loss of ambiguity, whether or not immediately manifest in conscious experience.

Deutch (1985) has analysed the potentialities of a quantum computer, which has a fuzzy logic representing quantum superposition of states to form a probability function in the interval $[0,1]$ in place of the usual $\{0,1\} = \{T,F\}$ of formal logic. Although the algorithmic capacity of such a quantum computer does not extend the class of functions computable by a conventional Turing machine, several specific instances have been given in which a quantum computer might solve special tasks more efficiently, (Lockwood 1989). These do not appear to provide significant advantages over parallel distributed processing. Both these authors adhere to the Everett many-worlds interpretation

of quantum mechanics in which the collapse of the wave function never occurs, and all histories having a non-zero probability under the quantum prediction are presumed to co-exist as parallel aspects of a cosmic wave function. This bypasses the Schrödinger cat paradox, however it contradicts the evidence of our conscious sensory processes, which in common with physical measuring apparatus, experience a single historical process. Collapse of the wave function also appears to be the aspect of quantum mechanics which underlies the indeterminacy of chaotic systems.

The mathematician Roger Penrose (1986,1989) has also studied the relation between the conscious brain and quantum physics and attempted to combine quantum theoretic and relativistic ideas. He has suggested that collapse of the wave function may be a deterministic process based on the interaction of the superimposed wave function with the gravitational field at the level of one graviton, thus having parallels to decoherence theories (Zurek 1991).

7.6 The Supercausal Model. A final model (King 1989), which also combines quantum theory and relativity, develops a supercausal hidden-variable theory which is consistent with conventional quantum mechanics, but allows for correlations between quantum events over both space and time, replacing the stochasticity of the quantum model with a transcausal description, which is non-local in space-time. The temporal ordering of causal events is thus violated below the quantum level by space-time symmetric interactions. This description prevents determination of a system from initial conditions, because the non-local correlations include future states of the system. It is based on the transactional interpretation of special-relativistic quantum mechanics.

The relativistic energy-momentum equation $E^2 = \mathbf{p}^2 + m^2$ [7.6.1]
 has dual energy solutions $E = \pm \sqrt{\mathbf{p}^2 + m^2}$ [7.6.2]

in which the negative energy solution has reversed temporal behaviour in space-time.

This is consistent with Feynman diagrams in which a particle travelling in the usual (*retarded*) direction can be equated with its anti-particle in the time-reversed (*advanced*) state. This fact allowed Dirac to predict the existence of the positron from the negative energy solutions to the electron wave equation.

As a simple example, the Hamiltonian equation [5.3.1] for a zero spin particle with mass m has elementary solutions:

$$+,k = (2)^{-3/2} e^{-i(\mathbf{k}\cdot\mathbf{x} - t)} \quad [7.6.3a]$$

$$-,k = (2)^{-3/2} e^{-i(\mathbf{k}\cdot\mathbf{x} - t)} \quad [7.6.3b]$$

where

$$= (k^2 + m^2)^{1/2} \quad [7.6.4]$$

One solution travels in each direction in space-time, forming distinct *retarded* and *advanced* solutions. For a photon which is its own anti-particle, these reduce to the offer and confirmation waves of the emission and absorption foci.

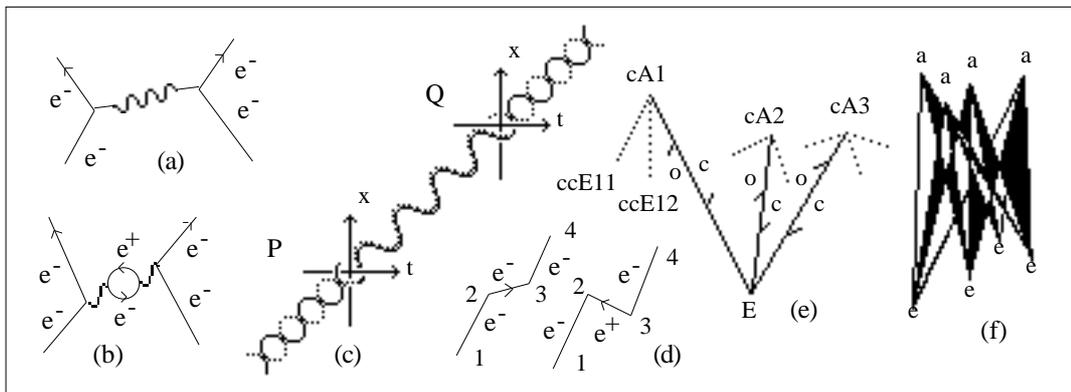


Fig 14: (a) Feynman diagram of exchange of a photon, (b) higher-order diagram. (c) One-photon transaction involves interfering offer and confirmation waves. (d) Electron deflection and positron creation and annihilation. The time-reversed electron is a positron. (e) contingent emitters and absorbers as boundary of collapse. (f) Spliced reduction interactions.

In the Feynman diagram Fig 14(a), the force between electrons is determined by integrating all possible virtual photon and higher-order interactions (b). The photon is virtual because it exists only for an interval consistent with the uncertainty relations [7.3.3], and is detected only by its secondary effects in the electric field. While in virtual exchange, all possible exchanged photons are summed, in the case of a real exchanged photon, the boundary condition that only one real photon is exchanged, forces reduction of the packet of all possible such exchanges to one real exchange. Time reversal is standard in Feynman diagrams, a time-reversed electron being equivalent to a positron (d).

Such time-reversal is used in the transactional interpretation of quantum mechanics (Cramer 1986) fig 14(c), a mutual encounter between emitter and absorber is modelled by the release of crossed-phase advanced and retarded waves, each having zero-energy, the *offer* wave of the emitter and the *confirmation* wave of the absorber. While the retarded offer wave travels with elapsing time in the usual manner, the advanced confirmation wave, back-propagates in a

time-reversing manner from the absorber to the earlier emission event. The mutual interference of these advanced and retarded waves produces a real superposition (the photon) between the emission and absorption events in space-time.

Modelling reduction of the wave packet now depends on the mutual interaction of all contingent emitters and absorbers as in (e), on the basis that a photon can only be created linking the two events and cannot simply disappear into space, following Feynman's absorber theory (Davies 1974). This means that the probability distribution is determined by boundary conditions which include all contingent absorbers which could have alternatively participated in the emission event (f). However, because these include future states which have not been causally determined, a logical regress results, leading to paradox in terms of temporal determinism. Transactions can also link contingent foci across both time-like and space-like intervals by linking confirmation waves at any particular emission vertex, regardless of the proper time interval to the contingent absorbers, e.g. cA1 and cA2 in fig 14(e), explaining the pair-splitting experiments of Aspect et. al. (1982).

One way of modelling transactional collapse is via a bifurcation of a non-linear interaction between all contingent foci, however the time parameter in any such bifurcation has to be handled very carefully. Whether or not collapse results from a non-linearity in gravitation as suggested by Penrose (1989), the space-time boundary constraints are inconsistent with the usual idea of temporal causality defined by initial conditions and Laplacian determinism.

Transactional collapse is also consistent with quantum decoherence models, which include incidental collapse caused by field and thermal excitations (Zurek 1991). Although decoherence has the effect of breaking a transactional contingent set into a class of smaller sets linked by emission and absorption foci, similar to higher-order Feynman diagrams, it does not alter the supercausal properties of transactional reduction, enfolding the implicate order of quantum non-locality without disruption. Thus similar space-time properties apply to kinetic molecular systems with many thermodynamic and other quantum interactions between production of an intermediate and its reaction.

8 Supercausality and the Conscious Brain

8.1 Superset Correlations and the Evolution of Chaotic Neurosystems Dual-time supercausality results in *pseudorandom* behaviour consistent with the probability interpretation, which is non-local not only in space, but also in time. This could enable a neural net to become internally interconnected through sub-quantum effects which were non-local in time, and hence enable a form of predictivity unavailable through classical computation. The mutual exchange of quanta between such units would make them a contingent transactional set of emitters and absorbers. Such linkage could arise via excitons, or photon or phonon exchange. The cell membrane topology forms a global link between its quanta of excitability, making such linkages possible also in the single cell. A variety of excitons, including the major oscillations of the EEG could also form a basis for neurosystems linkage in the brain. The many-to-many transform nature of the neuron may provide a basis for this effect through the connection of any given state to a large population of neurons in the cortex.

An excitable cell or neurosystem which evolved initially to achieve constrained optimization through chaotic fluctuation, could thus also display a new type of predictive modelling through non-local quantum interactions. Predictive optimization may thus have driven the evolution of the excitable cell and subsequently a structurally-unstable chaotic brain in which consciousness and free-will become direct manifestations of the quantum non-locality underlying membrane and brain-function.

This view combines a *reductionist* approach, in which biological phenomena are reduced to chemical and finally physical models (Skinner et.al. 1989), with a new emphasis on quantum physics as the limit of a fractal process. A component of *panpsychism* is included in the physical description, in which consciousness can be associated with a real quantum by virtue of the uncertainty arising from its wave-particle duality. *Sentience* is the capacity of the emitter to utilize the confirmation waves of contingent absorbers in wave-packet reduction, while *free-will* or *intent* is the uniqueness implied by the *principle of choice*. *Emergentism*, the capacity of a system to be more than the sum of its parts, is also present, because the time-symmetric subquantum associations in the model are developed as a result of the large number of units in a parallel net which can become transactionally related as mutual conditional emitters and absorbers. This gives the brain a degree of cooperative uncertainty which is lacking in a single quantum. *Free-will* raises possibilities that the mind can at least in some ways alter the future states of the universe. The limits of such possibilities remain to be established.

8.2 Anomalies of Time Perception Since Grey-Walter first made subjects witness movement of slide show via a motor cortex probe and found they witnessed the slide change *before* they pressed a dummy button, the time properties of conscious experience have remained a conceptual challenge.

Two experiments outline some of the puzzling temporal properties of consciousness. In the first, (Kolars & von Grunau 1976) alternate lights of different colour flash for 150 ms with an intervening gap of 50 ms. Subjects report a single moving light which changes colour at the mid point, even on a first exposure, or random colour change. This creates an apparent paradox because the colour change apparently occurs *before* the second light has come on.

In a second class of experiment (Libet et. al. 1979), which has been the subject of repeated discussion (Libet 1985a,b,1987,1989, Churchland 1981 a,b, Honderich 1984, Snyder 1988) involves the subjective timing of stimulation of one hand [say the left, which excites the right somatosensory area] at the same time as direct

stimulation of the opposite [left] finger somatosensory area. The genuine hand-tingle is perceived *before* the cortically induced one even if it actually occurred afterwards. Because of the considerable delay for the development of neuronal adequacy for the conscious experience [200 - 500ms] the time of the experience appears to be referred back to the primary evoked potential [10-20ms after stimulus], fig 12(b).

Although this referral can be explained as a construct of the internal model, similar to spatial representations which are subjectively “out there”, temporal projection comes close to causal paradox. Libet suggests “a dissociation between the timings of the corresponding mental’ and ‘physical’ events would seem to raise serious though not insurmountable difficulties for the ... theory of psychoneural identity”. Penrose (1989) “suggested that a materialistic explanation of Libet’s phenomena would require a revolution in fundamental physics” (Dennett 1991). “This antedating procedure does not seem to be explicable by any neurophysiological process... [but is] attributable to the ability of the self-conscious mind to make slight temporal adjustments, i.e. to play tricks with time.” (Popper & Eccles 1977).

Dennett (1991) explains such features by looping of the subjective time sequence out of the physical sequence. The order of consciously perceived events does not have to be coincident with the physical or apparent physiological order when parallel processing builds up a global model of a time sequence. The order in which constructs become established may be arbitrary, within the space-time constraints of a large parallel device, but the completed construct will nevertheless represent the sequence of the original, perhaps modified by simplifying assumptions of the internal model. This approach suggests however that the completed representation cannot be formed until *after* the sequence ends, [e.g. until both the red and green lights have flashed and not half-way across], and may require editing of the partial constructs of the model either prior or subsequently to their registration.

Further experiments are required. The supercausal model was constructed to deal with the causal paradox of free-will but could apply also to these examples. Observational difficulties make the issue similar to the problems of quantum measurement. One difficulty is pinpointing the time of subconscious origin of a response which results in a button press or a verbal signal. Another is that comparing the absolute times of stimuli and neurophysiological events with those of perceived conscious events [‘it happened when the hand was at 2’] involves comparing the ‘representing and represented’ states (Dennett 1991).

8.3 Supercausality and the Representation of Time in the Cortex

One particularly interesting idea is that time is represented in the same distributed and holographic manner that other modalities are. The relationship between the frontal lobes and the rest of the cortex appears to involve representations of activities integrating future states [intentions] into time-directed actions based on past experiences [memories]. The frontal lobes generalize motor acts into associations in a similar manner to the sensory association areas in the rest of the cortex. Thus the frontal cortex may generate a spatially distributed representation of time in terms of the organization of both remembered and planned actions spanning the past and future, utilizing oscillatory phase relations as seen in EEG and evoked potential studies, possibly in the 40Hz mode suggested by Crick & Koch (1990). Coherent oscillations would link by Hebbian coincidentalness. Both short-term working memory and the long-term consolidation of the limbic system may thus form part of a transform representation of time.

Subjective time may thus be an internal model whose basis is quite different from mechanical notions of linear time, partly because it requires integrated representation of past memorizations and learning with future plans and survival strategies. It is easy to see that visual perception constructs an external spatial reality but more difficult to accept the possibility that time is similarly an internal construct. What may be even more difficult to accept is that the subjective notion of free-will or intent arises because the function of consciousness is to *anticipate*, forming an “ill posed” problem in time.

A holographic representation of time generated by the frontal cortex and limbic system thus provides a possible realization of the supercausal model. The central task of the brain is the representation of the activity of the organism in terms of both past and future temporal dynamics. While the past is based predominantly on memory, the future, representing the organism's survival strategy, may be based on complementary principles of computation and predictivity, utilizing both attractor-based computation and access to quantum non-locality. The modal oscillations in such a holographic representation are time-symmetric in the sense that the beats of phase coherence measure only a circular phase-shift and not a direction. This is exactly the same act that is required in quantum measurement to determine the uncertainty relations, since counting beats to determine frequency and wavelength requires a time or distance determined by the uncertainty relations [5.3.3]. It thus raises the rather odd spectre that cortical oscillations and their corresponding mental states may be inflated quanta reverberating through the brain. It also suggests that the subjective notion of the present may be an extended *quantum of the present*, forming a reverberating envelope of past and future states.

Solving the problem of temporal representation is central to understanding the nature of attention, consciousness, and will, both because of the causal paradox implied by will, and because the problem of the ‘ghost in the machine’ is essentially a problem of how the temporal dynamics of attention are organised. Enclosing this ghost of attention within the quantum of the present carries the paradox into the causality-violating arena of sub-quantum physics.

8.4 The Experiencing Totality

Although normal waking experience has a reasonable correspondence to our concept of physical reality, the experiences of dreaming and other reflexive states such as hypnogogic and meditative trance, psychotropic hallucinations and near-death experiences, which transcend correspondence to the physical world, raise fundamental questions concerning the relation between the mind and the physical world. Dreaming is one of the most outstanding of these non-collective conscious states. It is one which we are all aware of, and one whose intensity, in cases of good recollection, parallels, or even exceeds that of sense experience of the 'real world'. Dreaming has definite correlates in central nervous activity in the REM phases of sleep, originally called *paradoxical* because of the appearance of internal waking arousal, illustrated in the EEG's and PET scans of fig 4, contrasting with the slow wave activity of deep sleep. The unusual properties of such states suggest that the more esoteric aspects of mind, which I will term *dreaming*, may contain deeper clues to its underlying nature beyond physical correspondence. In such a dual model, mind is more fundamental to reality than merely a physical internal model, a complementary principle to physical reality, emerging physically through indeterminacy.

The concept of a dual totality in which mind and universe are primary components raises further deep issues. While it may not be possible to describe mind from the point of view of physical world constructs alone, it *is* possible to describe the physical world as stability properties of conscious experience. Similarly, although our model of the physical world is inferential, our conscious experience from birth to death is direct and undeniable. It is thus possible to mount an alternative description of reality in which mind is primary and fundamental and the physical world is merely a stability structure of mind, as is central to the Indian philosophy of mind. The link between chance, living organisms and consciousness is also central to the Chinese oracle *I Ching* (Wilhelm 1951) in which these three are regarded as joint manifestations of a unifying predictive cosmic principle.

The status of such reflexive conscious states as dreaming may thus represent one of the greatest enigmas of scientific enquiry, because it is here that the temporal paradoxes described enter into unstable self-feedback without direct input from the external world. Dreaming is traditionally viewed as an illusory or hallucinatory invention of the mind, functioning either in the release of psychological tensions, or as a subjective manifestation of neural processing during sleep, possibly in the consolidation of long-term memories (Koukkou & Lehmann 1983, Winson 1990), or even to forget as Francis Crick has suggested. Although true REM sleep appears to be a mammalian trait, there is evidence for a paralysis phase of sleep in animals spanning the arthropods and vertebrates. Although dreams presumably do serve a physiological function, as evidenced by metabolic compensation after periods of deprivation, the origin of the content of dreaming remains obscure.

Complementing physiological studies of dreaming is a parallel stream of literature addressing the possibility that dreaming has unusual space-time properties, associated as much with future as with past experiences (Dunne c1935). Although the significance of dreaming in western culture has concentrated on the symbolism of dreaming as an expression of fears and aspirations in daily life and its analysis as a means of therapy, reference to dreaming in other cultures, such as Australian aborigines, and the *Senoi* of Malaysia includes the use of dreams to anticipate future problems and events, and is based on the concept that the dreaming state is another level of conscious reality, which is not an illusory representation of the 'real world', but is rather a mode of conscious existence in its own right. I have had many personal dreaming experiences with attest to such temporal properties of dreaming, including having a double dream of being stung, reporting the dream to my wife and an hour later being stung wide awake in bed.

Similar accounts occur in societies, such as the *Huichols and Mazatecs* of Mexico and the Amazonian *Cashinahua, Shipibo, Jivaro*, etc. where plants or fungi are taken to induce hallucinatory trance states during shamanic rites. Five aspects of these states have been noted by anthropologists; geometrical illusions, visions of animals and demons, the separation of the mind from the physical body, clairvoyant visions of distant places, and divination of past or future events (Harner 1973). "*On the day following one ayahuasca party, six of nine men informed me of seeing the death of my 'chai', my mother's father. This occurred two days before I was informed by radio of his death*".

The apparent capacity of people, in near-death experiences to have perceptions of their surroundings from another physical position [out of their body] invites further questions concerning the physical location of consciousness, particularly when they [occasionally] report accurate details they could not have witnessed from their physical position, such as the patient who correctly perceived a discarded shoe on a ledge three floors above the room where she had cardiac arrest (Groff S. 1988).

In what I would loosely describe *the Sorcerer's Explanation*, the *dreaming* aspect of reality underlies the physical so that the waking experience of the physical world is just one manifestation of a wider *dreaming totality*, rather than vice versa. Castenada (1976) in his many allegories, discusses the *technique of dreaming* in which the dreaming and waking state are connected by *intent* so that dreamer can gain control. The technique involves picking some simple action that the dreamer will perform as an act of volition to assume temporary command of their will, and check the onrush of dreaming attention. For example the act of looking at the backs of one's hands while in the dream. This technique is paralleled in Stephen LaBerge's (1985,1990) research into *lucid dreaming* (Blackmore 1990), in which the subject learns to make a variety of reality tests of the dreaming state by combining waking practice tests with setting intent during the sleep phase. These are complemented by waking techniques such as looking for the gaps (see 1.4.3) in conscious experience, *stopping the internal dialogue* and *stalking* (Abelar 1992).

The empirical investigation of such reflexive conscious states constitutes the best hope we have for discovering the foundations of the mind-brain relationship. While research is dominated by clinical tinkering with the brain from

outside, a comprehensive description will continue to elude society. Thus balancing the pictures gained by brain lesions, EEG studies and PET scans should be an emphasis on pure consciousness research, combining scientific techniques with the traditional means used by societies throughout history, namely meditative and shamanic trance, the use of power plants and dreaming techniques. Several of these have been largely ignored as unscientific, or prohibited as dangerous to consumer society because of their very capacity to induce fractal or chaotic conscious states, thus setting back by decades society's development of an understanding of the mind-brain relationship. Complementing such traditional techniques are new devices emerging from brain research laboratories. One valuable such device is the *Dream Light* developed by LaBerge (1990) from research studies on dreaming EEGs, which detects REM periods and alerts the subject by a flashing light or acoustic signal. Such devices can help to bring the relatively uncharted and inaccessible realms of consciousness into the scientific arena.

9 The Cosmological Perspective

The brain may be one of the few places where the *supercasual* aspect of wave-packet reduction can be clearly manifest, as a result of its unique capacity to utilize correlations in its dynamics. Although other unstable systems such as the weather may also display such features of non-locality, it is difficult to think of a physical experiment which could in any way match the brain as a detector of correlations within the stochastic model of quantum mechanics. In this respect it should be noted that cosmology is not simply a matter of vast energies, but also quantum rules. The diversity of wave-particles resulting from symmetry-breaking of the fundamental forces finds its final interactional complexity, in which all forces have a common asymmetric mode of expression, in complex molecular systems. It is thus natural that fundamental principles of their quantum interaction may be ultimately realized in the most delicate and complex molecular systems known - those of brain dynamics.

10 Conclusion

The importance of developing a model of brain function which gives a consistent description of mind, consciousness and free-will, is profound. The model described links the structural instability of brain dynamics, quantum uncertainty and the dual-time model. The quantum-physical brain may thus be more than just an interface between sensory input and decision-making. It may in fact be a doorway between complementary aspects of the physical universe, the time-directed nature of real-particle symmetry-breaking and the time-symmetric aspect of the sub-quantum domain (King 1989). If so, the role of consciousness and mind-brain duality may be central to cosmology.

REFERENCES

- Abelar Taisha (1992) *The Sorcerer's Crossing* Viking Arkana, Penguin U.S.A. 0-670-84272-9
- Alkon D.L., (1989), *Memory storage and neural systems*, Scientific American, **July**, 26-34.
- Ansari A, Berendzen J., Bowne S., Frauenfelder H., Iben I., Sauke T., Shyamsunder E., Young R., (1985), *Protein states and protein quakes*, Proc. Nat. Acad. Sci. **82** 5000-4.
- Aspect A., Dalibard J., Roger G., (1982), *Experimental tests of Bell's theorem using time-varying analysers*, Phys. Rev. Lett. **49**, 1804.
- Baars, Bernard 1988 *A cognitive theory of consciousness* Cambridge University Press.
- Babloyantz A. & Salazar J.M., (1985), *Evolution of chaotic dynamics of brain activity during the sleep cycle*, Phys. Lett. **111A**, 152 - 156.
- Babloyantz A., (1989), *Estimation of correlation dimensions from single and multichannel recordings*, in Basar E., Bullock T.H. eds. *Brain Dynamics* Springer-Verlag, 122-130.
- Basar E., (1983), *Towards a physical approach to integrative physiology I Brain dynamics and physical causality* Am. J. Physiol. **245**, R510-R533.
- Basar E., (1990), *Chaotic dynamics and resonance phenomena in brain function : Progress, perspectives and thoughts*, in Basar E. ed. *Chaos in Brain Function* Springer-Verlag, Heidelberg 1-30.
- Basar E., Basar-Eroglu J., Röschke J., Schütt A., (1989), *The EEG is a quasi-deterministic signal anticipating sensory-cognitive tasks*, in Basar E., Bullock T.H. eds. *Brain Dynamics* Springer-Verlag, 43-71.
- Bern M. & Graham R., (1989), *The shortest network problem*, Sci. Am. **Jan**, 66 - 71.
- Berry M. (1991) *some quantum-to-classical asymptotics* in *Chaos and Quantum Physics* (ed) Giannoni M. Voros A., Zinn-Justin Elsevier Science B.V.
- Blackmore S. (1988) *A theory of lucid dreams and OBEs* in Gackenbach J., S. LaBerge (1988) *Conscious Mind, Sleeping Brain* Plenum Press, NY.
- Blackmore S. (1990) *Dreams that do what they're told* New Scientist **6 Jan** 28-31.
- Blakemore C., Greenfield S., (1987), *Mindwaves*, Basil Blackwell, Oxford.
- Blakemore C. (1991) Sir Douglas Robb Lectures, Auckland N.Z.
- Bloom F., Lazerson A., Hofstadter L. (1985) *Mind, Brain and Behavior* Freeman NY
- Casati G. Chirikov B., Guarneri G., Shepelyanski D., (1986), *Dynamical stability of quantum chaotic motion in a hydrogen atom*, Phys. Rev. Lett., **56/23**, 2437-40.
- Chay T.R., Rinzel J. (1985), *Bursting, beating and chaos in an excitable membrane model*, Biophys. J. **47**, 357-366.
- Castenada C. (1976) *Tales of Power* Penguin Books.
- Churchland P. (1981) *On the alleged backward referral of experiences and its relevance for the mind-body problem* Philosophy of Science **48** 165-81,
- Churchland P. (1981) *The timing of sensations : Reply to Libet* Science **48** 492-7.
- Clauser J.F., Shimony A., (1978), *Bell's theorem : experimental tests and implications*, Rep. Prog. Phys. **41**, 1881 - 1927.
- Cooper J.R., Bloom F.E., Roth R.H. (1982) *The Biochemical Basis of Neuropharmacology* 4th ed. Oxford Univ. Pr.
- Cowan J.D., Sharp D.H. (1988) Quart. Rev. Biophys. **21** 365 - 427.
- Cramer J.G., (1986), *The transactional interpretation of quantum mechanics*, Rev. Mod. Phys. **58**, 647 - 687.

- Crick F. (1984) *Function of the thalamic reticular complex: The searchlight hypothesis* Proc. Nat. Acad. Sci. **81** 4586-90.
- Crick F., C. Koch (1990) *Towards a neurobiological theory of consciousness* Seminars in Neurosciences **2** 263-75.
- Crick Francis and Christopher Koch 1992 *The problem of consciousness* Sci. Am. **Sep** 111-7.
- Davies P.C.W. (1974), *The Physics of Time Asymmetry* Surrey Press.
- Dennett Daniell C. (1991) *Consciousness Explained* Little Brown & Co., Boston.
- Deutsch D., (1985), *Quantum theory, the Church-Turing principle and the universal quantum computer*, Proc. Roy. Soc. Lond. **A400**, 97-117.
- Dewdney, A.K. (1989) *Computer Recreations* Scientific American **Dec** 140-2.
- Dunne J. W. (c 1935) *An Experiment With Time* Faber, 1st ed.
- Eccles J.C. ed., (1966), *The Brain and Conscious Experience*, Springer-Verlag, Berlin.
- Eccles J.C., (1970), *Facing Reality*, Springer, New York, Heidelberg.
- Eddington A.S., (1935), *New Pathways in Science*, Cambridge Univ. Press, Cambridge.
- Fodor Jerry (1983) *The modularity of mind* MIT Press Bradford, Cambridge MA.
- Freeman W. (1991) *The physiology of perception* Scientific American **Feb** 35-41.
- Freeman W., B. Baird (1987) *Relation of olfactory EEG to behavior : Spatial analysis* Behavioral Neuroscience **101** 393-408.
- Friberg Lars, T. McLaughlin, B. Steinberg *Networks of activated cortical regions subserving language and attentional functions in the the normal human brain* Brain and Mind : Danish Royal Academy of Sciences Aug 1992.
- Gazzaniga M. (1985) *The social brain : discovering the networks of the mind* Basic Books N.Y.
- Giesel T., Radons G., Rubner J., (1989), *Kolmogorov, d'Arnold, Moser barriers in quantum dynamics of chaotic systems*, Phys. Rev. Lett. **57/23**, 2883.
- Gilling D., R. Brightwell (1982) *The Human Brain* Orbis, London BBC
- Goldman-Rakic P. (1992) *Working Memory and the Mind* Sci. Am. **Sep** 73-79.
- Grassberger P., Procaccia I., (1983), *Measuring the strangeness of strange attractors*, Physics **9D**, 189-208.
- Grof S. (1988) *The Adventure of Self-Discovery* State University of New York Press .
- Gutzwiller, M. (1992) *Quantum Chaos* Scientific American **Jan** 78-84.
- Hameroff Stuart (1987) *Ultimate Computing* North-Holland Amsterdam.
- Harner M.J. (1973) *Hallucinogens & Shamanism* Oxford University Press .
- Hodgkin A.L., Huxley A.F., (1952), *A quantitative description of membrane current and its application to conduction and excitation in nerve*, J. Physiol. **117**, 500-544.
- Hoke M., Lehnertz K., Pantev C., Lütkenhöner B., (1989), *Spatiotemporal aspects of synergetic processes in the auditory cortex as revealed by the magnetoencephalogram*, in Basar E., Bullock T.H. eds. *Brain Dynamics*, Springer-Verlag , 84-108.
- Honderich T. 1984 *The time of a conscious sensory experience in mind-brain theories* J. Th. Biol. **110** 115-29.
- Hooper J. & Teresi D., (1986), *The Three-Pound Universe*, MacMillan New York .
- Horgan J. (1992) *Quantum Philosophy* Sci. Am. **July** 94-104.
- Hubel D.H. & Wiesel T.N. (1979) in Flannagan D. ed., *The Brain* Scientific American Books, Freeman.
- Huxley Aldous (1954) *Doors of Perception* Chatto & Windus, 1959 Penguin Books London.
- Jaynes Julian (1976) *The origin of consciousness in the breakdown of the bicameral mind* Houghton:Mifflin, Boston.
- Jen Erica (1990) *1989 Lectures in Complex Systems : Santa Fe Inst Studies in the Science of Complexity* Addison-Wesley ISBN 0-201-50936-9 [Note: similar issues for other years]
- Johnson-Laird Phillip (1983) *Mental Models : Towards a cognitive science of language, inference and consciousness* Cambridge University Press.
- Kalil R.E., (1989), *Synapse formation in the developing brain*, Sci. Am. **Dec**. 76-85.
- Kimura Doreen 1992 *Sex differences in the brain* Sci. Am. **Sep** 80-87.
- King C.C., (1978), *Unified field theories and the origin of life*, Univ. Auck. Math. Rept. Ser. 134.
- King C.C., (1989), *Dual-time supercausality*, Phys. Essays **2**, 128 - 151.
- King C.C., (1990), *Did Membrane Electrochemistry Precede Translation?* Origins of Life & Evolution of the Biosphere **20**, 15 - 25.
- King C.C. (1991), *Fractal and Chaotic Dynamics in the Brain* **36** 279-308.
- Koestler Arthur 1967 *The Ghost in the Machine* New York McMillan.
- Kolers Paul, von Grunau Michael 1976 *Shape and Colour in apparent motion* Vision Res. **16** 329-35.
- Koukkou M. and D. Lehmann (1983) *Dreaming : The functional state shift hypothesis* Brit. J. Psychiat. **142** 221-231.
- LaBerge S., (1985), *Lucid Dreaming*, Ballantine Books, Random House, New York.
- LaBerge S., (1990), *Exploring the World of Lucid Dreaming*, Ballantine Books, Random House, New York. Lucidity Institute, Box 2364, Stanford CA 94309.
- Libet B., Wright E., Feinstein B., Pearl D., (1979), *Subjective referral of the time for a sensory conscious experience*, Brain **102**, 193 - 224.
- Libet B. (1985a) *Unconscious cerebral initiative and the control of conscious will in voluntary action* Behav. Br. Sci. **8** 529-566
- Libet B. (1985b) *Subjective antedating of a sensory experience and mind-brain theories* J. Th. Biol. **114** 563-70.
- Libet B. (1987) *Are mental experiences of will and self-control significant for the performance of a voluntary act?* Behav. Br. Sci. **10** 783-6.
- Libet B. (1989) *The timing of a subjective experience* Beh. Br. Sci. **12** 183-5.
- Liebovitch L.S., Fischbarg J., Konairek J.P., Todorova I., Wang Mei, (1987a), *Fractal model of ion-channel kinetics*, Biochim. Biophys. Acta **896**, 173-180.
- Liebovitch L.S., Sullivan J.M., (1987b), *Fractal analysis of a voltage-dependent potassium channel from cultured mouse hippocampal neurons*, Biophys. J. **52**, 979-988.
- Liebovitch L.S., T. Toth (1991) *A model of ion channel kinetics using deterministic chaotic rather than stochastic processes* J. Theor. Biol. **148**, 243-267.
- Llinás R., (1987) in Blakemore C., Greenfield S., *Mindwaves* Basil Blackwell, Oxford.
- Lockwood M., (1989), *Mind, Brain & the Quantum*, Basil Blackwell, Oxford.
- Madsen P.L., S. Holm, S. Vorstrup, L. Friberg, N. Lassen, G. Wildschjødzt (1991) *Human regional cerebral blood*

- flow during rapid-eye-movement sleep* J. Cereb. Blood Flow & Metab. **11** 502-7.
- Marcel A. and Bisiach E. eds. 1988 *Consciousness in contemporary science* Oxford University Press N.Y.
- Margenau H., (1984), *The Miracle of Existence*, Ox Bow Press, Woolbridge, Conn.
- Marr David (1982) *Vision* Freeman, San Francisco.
- Miller Jonathan (1992) *Trouble in mind* Sci. Am. **Sep** 132.
- Mishkin M. & Appenzeller T., (1987) *The anatomy of memory*, Sci. Am. **June**, 62 - 71.
- Mountcastle V. (1978) in *The Mindful Brain* Edelman G., Mountcastle V. eds. MIT Cambridge MA.
- Nagel Thomas (1986) *The View from Nowhere* Oxford Univ. Pr. 15.
- Parfit D., (1987) in Blakemore C., Greenfield S., *Mindwaves* Basil Blackwell, Oxford.
- Peitgen H.O. & Richter P.H., (1986), *The Beauty of Fractals* Springer-Verlag, Berlin.
- Penrose R., (1987), *Minds, machines & mathematics*,
in Blakemore C., Greenfield S., *Mindwaves* Basil Blackwell, Oxford.
- Penrose R., (1989), *The Emperor's New Mind* , Oxford University Press.
- Penrose R., Isham C., (1986), *Quantum Concepts in Space & Time* , Oxford University Press.
- Peterson, I. (1991) *Back to the Quantum Future* Science News **140** [Nov 2] 282-284.
- Popper K.R. & Eccles J.C., (1977) *The Self and Its Brain*, Springer Int. Berlin, Heidelberg, New York, London.
- Rose S., (1973), *The Conscious Brain*, Weidenfeld & Nicholson, London.
- Rosenthal D. (1986) *Two concepts of consciousness* Phil. Stud. **49** 329-59.
- Ryle Gilbert (1949) *The Concept of Mind* Hutchinson London.
- Schierwagen A.K., (1986) *Dendritic branching patterns*,
in *Chaos in Biological Systems* ed. Degn H., Holden A.,V., Olsen L.F. Plenum Press, New York, 191-193.
- Schuster H.J., (1986), *Deterministic Chaos* , Springer-Verlag.
- Searle J. (1980) *Minds Brains and Programs* Behav. Brain Sci. **3** 417-458.
- Searle J. (1990a) *Consciousness, explanatory inversion and cognitive science* Beh. Br. Sci. **13** 585-642.
- Searle J. (1990b) *Is the brain's mind a computer program?* Sci. Am. **262** 26-31.
- Shatz, Carla J. (1992) *The developing brain* Sci. Am. **Sep** 35-41.
- Skarda C.J., Freeman W.J., (1987), *How brains make chaos in order to make sense of the world*,
Behavioral & Brain Sciences **10**, 161-195.
- Snyder D. (1988) *On the time of a conscious peripheral sensation* J. Th. Biol. **130** 253-4.
- Stevens C. *The Neuron*, (1989)
in Flanagan D. ed., *The Brain* Scientific American Books, Freeman, ISBN 0-7167-1150-8, 15-25.
- Stewart I., (1989), *Does God Play Dice?* Basil Blackwell, Oxford.
- Skinner J.E., Martin J., Landisman C., Mommer M., Fulton K., Mitra M. Burton W., Saltzberg B. (1989), in
Basar E., Bullock T.H. eds. (1989) *Brain Dynamics* Springer-Verlag, 158-173.[bulb, reduct]
- Stowell H., Bullock T.H., Basar E., *How brains may work : Panel discussion*,
in Basar E., Bullock T.H. eds. *Brain Dynamics*, Springer-Verlag 1989, 482-511.
- Tank D., Hopfield J., (1987), *Collective computation in neuron-like circuits*, Sci. Am. **Dec**, 62-70.
- Taylor J. (1992) *A global gating model for attention and consciousness* Brain & Mind, Roy. Dan. Acad. Sci.
- Tomsovic, S., E. J. Heller (1991) *Semiclassical dynamics of Chaotic Motion :*
Unexpected long-time accuracy Phys. Rev. Lett. **67/6** 664-7.
- Uzer T., Farrelly D., Milligan J., Raines P., Skelton J. (1991) *Celestial Mechanics on a microscopic scale*
Science **253** 42-8.
- Vendler Zeno (1972) *Res Cogitans* Ithaca Cornell Univ. Press
- Vendler Zeno (1984) *The Matter of Minds* Oxford Clarendon Press.
- Wilhelm Richard (1951) *The I Ching*, Routledge & Kegan Paul, N.Y.
- Winson J. (1990) *The meaning of dreams* Scientific American **Nov**, 42-48.
- Wintgen, D., A. Honig (1989) *Irregular wave functions of a Hydrogen atom in a uniform magnetic field*
Phys. Rev. Lett. **63/14** 1467-70.
- Yao Y., W. Freeman, B. Burke, Q. Yang (1991)
Pattern recognition by a distributed neural network : An industrial application Neural Networks **4** 103-121.
- Zeki Semir (1992) *The visual image in mind and brain* Sci. Am. **Sep** 43-50.
- Zhang W., Yuan J., Feng D., Pan Q., Tjon J. (1990) *Quantum fluctuations in classical chaos* Phys. Rev. A **42/6** 3646-9.
- Zurek, W. H. (1991) *Decoherence and the transition from quantum to classical chaos* Physics Today **Oct** 36-44.

NOTE: All diagrams are digitally processed by the author. All original sources are indicated in the text or captions.