More Neural Than Thou
(Reply to Pat Churchland's "Brainshy")

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Introduction: Neuralism

In "Brainshy: Non-neural theories of conscious experience," (this volume) Patricia Churchland considers three "non-neural" approaches to the puzzle of consciousness: 1) Chalmers' fundamental information, 2) Searle's "intrinsic" property of brain, and 3) Penrose-Hameroff quantum phenomena in microtubules. In rejecting these ideas, Churchland flies the flag of "neuralism." She claims that conscious experience will be totally and completely explained by the dynamical complexity of properties at the level of neurons and neural networks. As far as consciousness goes, neural network firing patterns triggered by axon-to-dendrite synaptic chemical transmissions are the fundamental correlates of consciousness. There is no need to look elsewhere.

However Churchland's "neuralism" and allegiance to the brain-as-computer doctrine obscures inconvenient details. For example:

1. Neurotransmitter vesicle release is probabilistic (and possibly non-computable). Only about 15% of axonal action potentials reaching pre-synaptic terminals result in actual release of neurotransmitter vesicle. Beck and Eccles (1992) suggested quantum indeterminacy acts here.
2. Apart from chemical synapses, primitive electrotonic gap junctions may play an important role in consciousness. For example gap junctions may mediate coherent 40 Hz-type activity implicated in binding in vision and self (Jibu, 1990; Hameroff, 1996).
3. It is quite possible that consciousness occurs primarily in dendritic-dendritic processing and that axonal firings support primarily automatic, non-conscious activities (e.g. Pribram, 1991; Jibu et al, 1996; Alkon, 1989).
4. Glial cells (80% of the brain) are ignored in neuralism.
5. "Neuralism" ignores the cytoskeleton (Figures 1 and 2).

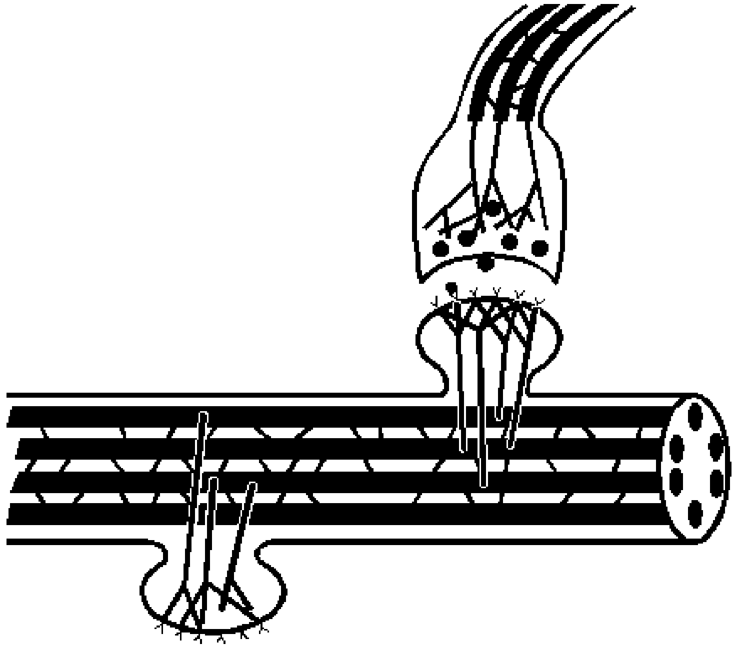

Figure 1. *Schematic of neural synapse showing cytoskeletal structures within two neurons. Top: Pre-synaptic axon terminals releases neurotransmitter vesicles (black spheres) into synaptic cleft. Thick, black rod-like structures at top indicate microtubules; thinner filaments (e.g. synapsin) facilitate vesicle release. Bottom: Dendrite on post-synaptic neuron with two dendritic spines. Microtubules in main dendrite are interconnected by microtubule-associated proteins. Other cytoskeletal structures (fodrin, actin filaments, etc.) connect membrane receptors to microtubules. Bases on Hirokawa (1991).*

Figure 2. *Immunoelectron micrograph of neuronal microtubules inter-connected by microtubule-associated proteins. With permission from Hirokawa (1991). Scale bar: 100 nanometers.*

Perhaps the most egregious oversight, neuronal microtubules and other cytoskeletal structures organizing the cell interior are known to establish, maintain and regulate neuronal architecture and synapses, service ion channels and synaptic receptors, provide for neurotransmitter vesicle transport and release, and be involved in "second messenger" post-synaptic signaling. They are also theorized to integrate post-synaptic receptor activation, process information, communicate and compute both classically and by quantum coherent superposition. Churchland's neuron *sans* cytoskeleton simulates a real neuron as an inflatable doll simulates a real person.

Shorn of these details, Churchland's neuralism remains convenient for computer analogy, but inadequate for consciousness. Here I begin by addressing some of Churchland's comments regarding Penrose-Hameroff quantum phenomena in microtubules.

Plato and the Planck Scale

Churchland derides Roger Penrose for resorting to Platonism, for believing: "...ideas have an existence...an ideal Platonic world...accessible by the intellect only...a direct route to truth..." Plato, 400 B.C. In *Shadows of the Mind Penrose* (1994) described three worlds: the physical world, the mental world and the Platonic world. The physical world and the mental world are familiar and agreed upon as actual realities clearly, the physical world exists and thoughts exist. Penrose's Platonic world includes mathematical truths, laws and relationships, as well as aesthetics and ethics our senses of beauty and morality. The Platonic world appears purely abstract. Could it simply exist in the empty space of the universe? If truth and beauty are indeed fundamental, perhaps the Platonic world is ingrained at the most basic level of reality?

The same may be said of qualia. A line of panexperiential philosophy suggests that proto-conscious experience is fundamental. Leibniz (e.g. 1768) saw the universe as an infinite number of fundamental units ("monads") each having a primitive psychological being. Whitehead (e.g. 1929) described dynamic monads with greater spontaneity and creativity, interpreting them as mind-like entities of limited duration ("occasions of experience" each bearing a quality akin to "feeling"). More recently Wheeler (e.g. 1990) described a "pre-geometry" of fundamental reality comprised of information. Chalmers (1996a; 1996b) contends that fundamental information includes "experiential aspects" leading to consciousness.

If mathematical truth, aesthetics, ethics and experience are actual and fundamental entities, a plausible location for them is the most basic level of reality.

What is fundamental reality? The Planck scale (10^{-33} cm, 10^{-43} sec) is the scale at which spacetime is no longer smooth. At that scale, the vacuum of empty space actually "seethes with subtle activities" (e.g. Browne, 1997). Branches of quantum theory known as quantum electrodynamics (QED) and quantum field theory predict that at the Planck scale particles and waves ("virtual photons") continuously wink into and out of existence (e.g. Jibu and Yasue, 1995; Seife, 1997), and that the churning quantum fluctuations (the "quantum foam" Figure 3) imparts dynamic structure and measurable energy ("zero point fluctuations").

Figure 3. *Quantum electrodynamics (QED) predicts that at the Planck scale in the vacuum of empty space, quantum fluctuations produce a foam of erupting and collapsing virtual particles which may be visualized as topographic distortions of the fabric of spacetime. Adapted from Thorne (1994) by Dave Cantrell.*

This picture of the quantum vacuum had been developed by Max Planck and Werner Heisenberg in the 1920's. In 1948 the Dutch scientist Hendrick Casimir predicted that the all-pervading zero point energy could be measured using parallel surfaces separated by a tiny gap. Some (longer wavelength) virtual photons would be excluded from the gap region, Casimir reasoned, and the surplus photons outside the gap would exert pressure forcing the surfaces together. Recently, this "Casimir force" was quantitatively verified quite precisely (Lamoreaux, 1997), confirming the zero point energy. Lamoreaux's experimental surfaces were separated by a distance *d* ranging from 0.6 to 6 microns, and the measured force was extremely weak (Figure 4a).

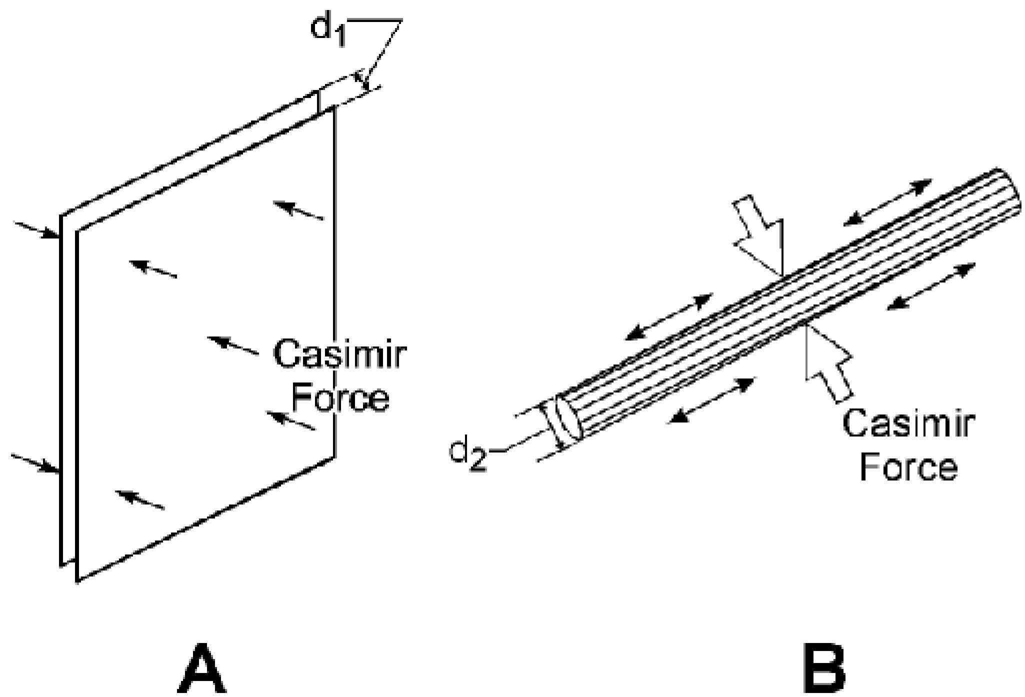

Figure 4. *A: The Casimir force of the quantum vacuum zero point fluctuation energy may be measured by placing two macroscopic surfaces separated by a small gap d. As some virtual photons are excluded in the gap, the net "quantum foam" exerts pressure, forcing the surfaces together. In Lamoreaux's (1997) experiment,* d_1 *was in the range 0.6 to 6.0 microns (~1500 nanometers). B: Hall (1996; 1997) calculated the Casimir force on microtubules. As the force is proportional to* d^{-4}*, and* d_2 *for microtubules is 15 nanometers, the predicted Casimir force is roughly* 10^6 *greater on microtubules (per equivalent surface area) than that measured by Lamoreaux. Hall calculates a range of Casimir forces on*

microtubules (length dependent) from 0.5 to 20 atmospheres.

At the Tucson II conference, physicist George Hall (Hall, 1996; 1997) presented calculations of the Casimir force on model microtubule cylinders. Hall considered the microtubule hollow inner core of 15 nanometers diameter as the Casimir gap*d*. As the force is predicted to be proportional to d^{-4}, Hall's models predict significant pressure (0.5 to 20 atmospheres) exerted by the quantum vacuum on microtubules of sufficient length (Figure 4b). Microtubules actually are under compression in cells, a factor thought to enhance vibrational signaling and tensegrity structure (e.g. Ingber, 1993). In the well known "pressure reversal of anesthesia," unconscious, anesthetized experimental subjects wake up when ambient pressure is increased on the order of 10 atmospheres. This implies that a baseline ambient pressure such as the Casimir force acting on microtubules as suggested by Hall may be required for consciousness.

To provide a description of the quantum mechanical geometry of space at the Planck scale, Penrose (1971) introduced "quantum spin networks" (Rovelli and Smolin, 1995a; 1995b) in which spectra of discrete Planck scale volumes and configurations are obtained (Figure 3). These fundamental spacetime volumes and configurations may qualify as philosophical (quantum) monads. Perhaps Planck-scale spin networks encode proto-conscious experience and Platonic values?

The panexperiential view most consistent with modern physics is that of Alfred North Whitehead: 1) consciousness is a process of events occurring in a wider, basic field of raw proto-conscious experience 2) Whitehead's events (discrete occasions of experience) are comparable to quantum state reductions (Shimony, 1993).

This suggests that consciousness may involve a self-organizing quantum state reduction process occurring at the Planck scale. In a panexperiential Platonic view consistent with modern physics, quantum spin networks encode proto-conscious "funda-mental" experience and Platonic values. In this view, various configurations of quantum spin geometry represent varieties of experience and values. A self-organizing process capable of collapsing quantum wave functions at Planck scale geometry while somehow coupling to neural action is a candidate for consciousness. Is there such a process?

Objective reduction (OR) is Penrose's proposed quantum gravity solution to the problem of wave function collapse in quantum mechanics (Penrose, 1989; 1994; 1996). In Penrose's OR, quantum superposition actual separation, or displacement of mass from itself causes underlying spacetime (spin networks) to also separate (simultaneous curvatures in opposite directions). Such separations are unstable and a critical degree of separation results in instantaneous self-collapse objective reduction (OR). Superposed (separated) mass and spacetime geometry select particular "unseparated" states. An event occurs. A choice is made.

The critical degree of spacetime separation causing Penrose's objective reduction is related to quantum gravity and given by the uncertainty principle E = h/T. E is the gravitational self-energy of the superposed mass (displaced from itself by the diameter of its atomic nuclei), h is Planck's constant over 2 pi, and T is the coherence time until self-collapse. (Without an objective criterion for reduction, spacetime separation could presumably continue and result in separate, multiple spacetime universes as described in the Everett "multi-worlds" or "multi-minds" view of quantum theory.)

If isolated from environmental decoherence, a quantum superposed mass E will self-collapse after time T to definite mass locations and spacetime geometry. The post-reduction mass locations and spacetime geometry are chosen non-computably but only if the quantum collapse occurs by the OR process, rather than by environmental interaction causing decoherence (in which case the states are chosen randomly). The non-computable influence in OR may be a Platonic grain in Planck-scale geometry.

"... one's consciousness breaks through into this world of ideas..." Plato, 400 B.C.

Could an OR process be occurring in our brains? How could biology "break through" to "funda-mental" spacetime? The Penrose-Hameroff Orch OR model describes a biological OR occurring in microtubules (MTs) in the brain's neurons (Penrose and Hameroff, 1995; Hameroff and Penrose, 1996a; 1996b; Figures 4 and 5).

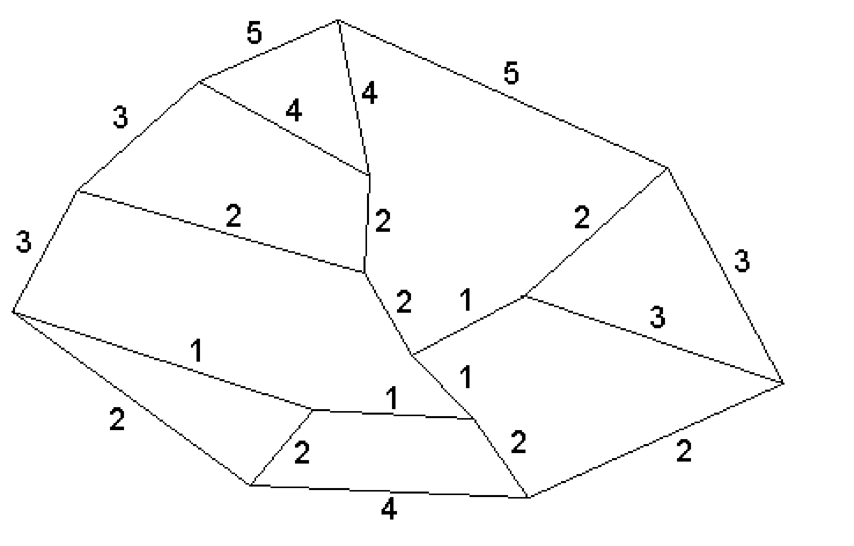

Figure 5. *A spin network. Introduced by Roger Penrose (1971) as a quantum mechanical description of the geometry of space, spin networks describe spectra of discrete Planck scale volumes and configurations (with permission, Rovelli and Smolin, 1995a). Scale bar*

(lower right): Planck length (10^{-33} cm; 10^{-25} nm).

Quantum reductions in MTs are consistent with Whitehead "occasions of experience" and coherent 40 Hz neural-level "cognitive quanta" (e.g. Crick and Koch, 1990; c.f. Llinas, e.g. Joliot et al, 1994). Such events could link Platonism, biology and funda-mental experience at the Planck scale.

Anesthesia

Churchland raises the interesting issue of the mechanism of anesthesia. A wide variety of types of molecules including inhaled gases and intravenous drugs are able to inhibit consciousness, and be safely administered and eliminated from the body (See Franks and Lieb, this volume). Even in the presence of significant doses of these anesthetics, some brain neural activities persist in unconscious patients (EEG, evoked potentials, autonomic drives etc.). Thus although anesthetics have other effects not directly related to consciousness (e.g. blood pressure, heart rate, muscle tone), anesthetic mechanisms may distinguish brain sites essential for consciousness. Churchland correctly remarks that "evidence points to proteins in the neuron membrane as the principle locus of hydrophobic anesthetics."

There is no consensus regarding anatomical sites of anesthetic effect. During anesthesia with volatile gases like halothane or isoflurane, the anesthetic molecules are widely distributed in most brain areas (although recent brain imaging has localized some effects of intravenous anesthetics like propofol. See Alkire et al., 1997). However the sites of anesthetic action at cellular and molecular levels has been studied extensively, particularly in the past two decades by Franks and Lieb (e.g. 1982; 1985; present volume; c.f. Halsey, 1989).

Their work shows:

1) anesthetics act directly on proteins, rather than on membrane lipids, 2) a relatively small number of brain proteins are anesthetic target sites, 3) anesthetics act in hydrophobic ("lipid-like") regions within target proteins, 4) anesthetics bind in these hydrophobic "pockets" mainly by weak van der Waals forces (some polar binding also occurs).

Franks and Lieb (1997) suggest the predominant anesthetic targets are post-synaptic membrane proteins belonging to the acetylcholine receptor genetic "superfamily." Strangely, some of these receptors are excitatory (serotonin, nicotinic) while others are inhibitory (GABA, glycine), so anesthetics appear to potentiate some proteins and inhibit others. (Interestingly, the GABA receptor is regulated by cytoskeletal microtubules Franks and Lieb, 1997; Delon and Legendre, 1995).

Conspicuous by the absence of sensitivity to inhaled gas anesthetics are receptors for glutamate, the principal excitatory neurotransmitter in the mammalian central nervous system. However glutamate receptors (e.g. "NMDA": n-methyl-d-aspartate receptors) are sensitive to "dissociative" anesthetics like ketamine, and the street drug/animal anesthetic phencyclidine ("PCP"). In low dose receptor occupancy these drugs induce sensory illusions, visual and auditory hallucinations, distortions of body image, and disorganized thought (see Flohr, this volume). In high doses they cause general anesthesia.

Other neural proteins are only slightly anesthetic-sensitive, but widely distributed and heavily prevalent throughout the brain. These include voltage gated ion channels, pre-synaptic vesicle release proteins, and microtubules. As Franks and Lieb (1997) point out, slight anesthetic effects on a large number of sites could be important, particularly if those sites are essential for consciousness.

Like consciousness, anesthesia appears to be a global, collective phenomenon involving multiple sites. At anesthetic concentrations just sufficient for loss of consciousness, hydrophobic pockets in a class of neural proteins (ion channels, receptors, second messengers, enzymes, microtubule tubulin, actin etc.) are likely to bind and mediate anesthetic effect.

Anesthesia and Microtubules

Tubulin, the component protein of microtubules, has a hydrophobic region comprised of aromatic and other hydrophobic amino acids (e.g. Andreu, 1986). The first studies of anesthetic effects on microtubules were performed by Allison and Nunn (1968; Allison et al, 1970). They studied the heliozoan actinosphaerium, a tiny urchin with hundreds of delicate spines (axonemes, or axopodia). The internal structure of each spine axoneme is a parallel array of microtubules interconnected in a double spiral (Figure 5, Hameroff, 1997). Allison and Nunn found that adding an anesthetic like halothane to the medium caused the spines to withdraw as the microtubules disassembled. When the anesthetic was removed, the spines reassembled. The amount of anesthetic required for complete axoneme disassembly was equivalent to about four times the amount required for clinical anesthesia, although axoneme shortening began at only twice the clinical dose. The esteemed authors suggested that anesthesia might be caused by reversible disassembly of brain microtubules. However subsequent studies in nerve preparations failed to show effects of clinically relevant doses of anesthetic on microtubule assembly (Hinkley and Green, 1971; Saubermann and Gallager, 1973) and axoplasmic transport (Kennedy et al, 1972), and the "microtubule hypothesis" fell on hard times.

Refined techniques led to further studies. Hinkley and Samson (1972; Hinkley 1978) clearly demonstrated that halothane caused microtubules in vitro to reassemble into "macrotubules" larger (48 nm vs 25 nm diameter) with more protofilaments (24 vs 15). In myelinated axons, Livingston and Vergara (1979) showed significant decrease in microtubule numbers and density after 20 millimolar (mM) halothane. Vergara and Livingston (1981) later studied binding of halothane to tubulin from rat brain. They found that 28 mM halothane displaced tubulin-bound colchicine. Hinkley and Telser (1974) and Uemura and Levin (1992) showed that very low concentrations of halothane cause disruption of actin gelation. Concentrations of gas anesthetics within cells are difficult to determine due to poor solubility in the aqueous phase, but it appears that at clinical concentrations anesthetics do bind to tubulin (without causing microtubule disassembly) and to actin in addition to membrane proteins.

The real question is why hydrophobic pockets are essential to consciousness.

Consciousness and Quantum Effects in Hydrophobic Pockets

The collective locus of anesthetic effect is an array of hydrophobic sites in various types of proteins throughout the brain. They have a common hydrophobic solubility parameter which can best be described as similarity to olive oil. The "cutoff effect" (e.g. Franks and Lieb, 1997) tells us that anesthetic sites are smaller than a cubic nanometer. So we have an ordered array of discrete, tiny olive oil pockets in strategic neural sites throughout the brain. The components of these pockets (e.g. aromatic amino acid rings) have large van der Waals energy, the energy of electron quantum fluctuations. This promotes delocalization: electrons are mobile and relatively free to roam within the pocket among resonance orbitals of several stacked rings (e.g. phenylalanine, histidine, tyrosine and tryptophan). Isolated from water, hydrophobic pockets are ideal settings for electron quantum effects. According to Fr□Ehlich's (1968) suggestion, electron localization in one particular portion of a hydrophobic pocket causes the entire protein to assume one particular conformation; electron localization in a different intra-pocket area results in the protein assuming a different conformation. However in quantum theory, individual electrons (or electron pairs) can also be in a state of quantum"superposition" in which both positions are occupied (and the protein assumes both conformations e.g. Figure 2, this volume). Anesthetics bind in hydrophobic pockets by weak van der Waals forces which are attractive couplings among quantum fluctuations in the electron clouds of anesthetic and pocket. (Van der Waals attractions are closely related to the Casimir force Lamoreaux, 1997.) Anesthetics are known to inhibit electron mobility (Hameroff and Watt, 1983) and (by computer simulation) reduce hydrophobic pocket van der Waals energy in an anesthetic-sensitive protein (Louria and Hameroff , 1996). Quantum fluctuations in hydrophobic pockets may be necessary for consciousness.

It may be concluded that anesthetics act by preventing quantum coherent superposition in hydrophobic pockets of a) membrane proteins, b) tubulins c) both. Another possibility is that anesthetics disrupt actin gelation required for quantum state isolation.

Drugs like the hallucinogenic ("psychedelic") tryptamine and phenylethylamine derivatives bind in a class of hydrophobic pockets, but obviously exert quite different effects than anesthetics. Composed of aromatic rings with polar "tails," these drugs are known to bind to serotonin and NMDA receptors but their psychedelic mechanism is basically unknown (e.g. Weil, 1996). Nichols et al (1977; Nichols, 1986) showed that psychedelic drugs bind in hydrophobic pockets in serotonin receptors of less than 6 angstroms (0.6 nanometers) length. Kang and Green (1970) and Snyder and Merrill (1965) showed correlation between hallucinogenic potency and the drug molecules' capability to donate electron orbital resonance energy (comparable to increase in Van der Waals energy). In Louria and Hameroff (1996) we speculated that by such a mechanism psychedelic drugs promote quantum coherent superposition in receptors and other proteins including cytoskeleton. In Hameroff and Penrose (1996a) it is suggested that such a quantum-enhanced state increases intensity and frequency of conscious events and merges normally pre- and sub-conscious processes with consciousness by a baseline shift in quantum coherence. Psychedelic perceptions and hallucinations may be glimpses into a pre-conscious/sub-conscious quantum superposed world.

Pixie Dust Vs. Orch OR

Churchland asserts that "pixie dust in the synapses" is as explanatory as the Penrose-Hameroff Orch OR model. Let's compare explanatory power of Orch OR with her synaptic pixie dust (I assume she is referring to "neuralism," as described in the Introduction). Let's see how each handles five enigmatic features of consciousness: (1) the nature of experience (hard problem), (2) binding, (3) free will, (4) non-computability, (5) transition from pre-conscious processes to consciousness.

Feature 1: Experience, hard problem (e.g. Chalmers, 1996a; 1996b)

Pixie dust (neuralism): Postulate conscious experience emerging from critical level of neuronal computational complexity.

Orch OR: Philosophically ascribe to panexperientialism, following e.g. Spinoza, Leibniz, Whitehead, Wheeler and Chalmers. Experience, qualia are deemed fundamental, a basic property of the universe like matter or charge. If so, experience must be represented at the most basic level of reality namely the 10^{-33} cm Planck scale at which spacetime is no longer smooth. Penrose's (1971) quantum spin networks (Rovelli and Smolin, 1995) are possible descriptions of fundamental spacetime geometry capable of experiential qualities. Orch OR is a self-organizing process in the Planck scale medium which selects particular configurations of fundamental geometry (Figure 6).

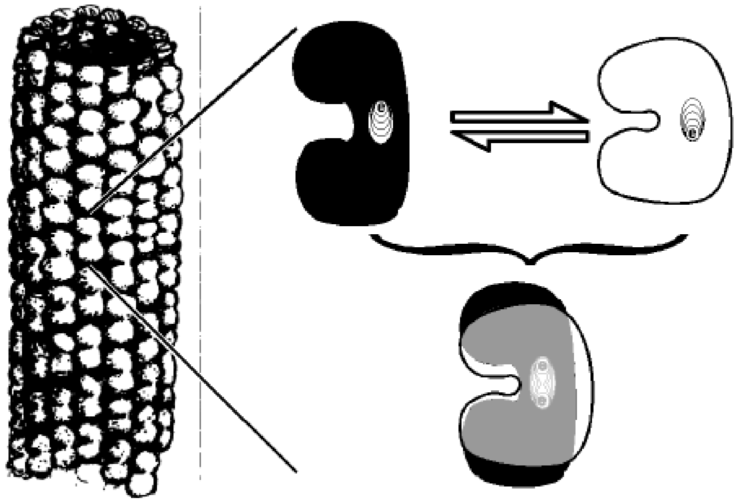

Figure 6. *Left: Microtubule (MT) structure: a hollow tube of 25 nanometers diameter, consisting of 13 columns of tubulin dimers arranged in hexagonal lattice (Penrose, 1994). Right (top): Each tubulin molecule can switch between two (or more) conformations, coupled to a quantum event such as electron location in tubulin hydrophobic pocket. Right (bottom): Each tubulin can also exist in quantum superposition of both conformational states (Hameroff and Penrose, 1996).*

So Orch OR postulates experience as a "funda-mental" feature of reality, and provides a mechanism to access and select particular configurations of experience. The "smell of cinnamon" is self-selection of a particular funda-mental geometry.

Feature 2: Binding

Pixie dust (neuralism): Coherent neural membrane activities (e.g. coherent 40 Hz) bind in vision, and in "self" by temporal correlation of neural firing.

Orch OR: Macroscopic quantum states (e.g. Bose-Einstein condensates) are single entities, not just temporally correlated.

Feature 3: Free will

Pixie dust (neuralism): ?

Orch OR: The problem in understanding free will is that our actions seem neither deterministic nor random (probabilistic). What else is there in nature?

Penrose's objective reduction ("OR") is a possible solution (Figure 7).

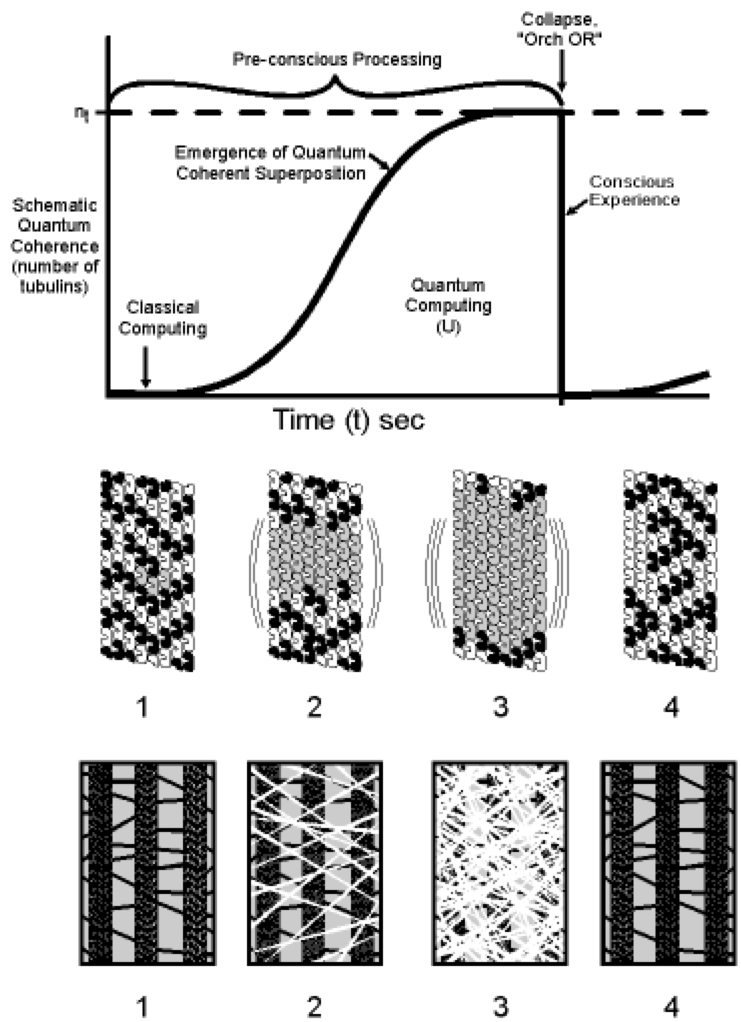

Figure 7. *Steps in an Orch OR event. Top: Schematic graph of proposed quantum coherence (number of tubulins) emerging vs time in microtubules. Area under curve connects mass-energy differences with collapse time in accordance with gravitational OR (E=h/T).* N_t *is the number of tubulins whose mass separation (and separation of underlying space time) for time T will self-collapse. For example, for time T=25 msec (e.g./40 Hz oscillations), T=2 x* 10^{10}*tubulins. Middle: Microtubules simulation in which classical*

computing (step 1) leads to emergence of quantum coherence s uperposition (and quantum computing--steps 2-3) in certain (gray) tubulins. Step 3 (in coherence with other microtubule tubulins) meets critical threshold related to quantum gravity for self-collapse (Orch OR). A conscious event (Orch OR) occurs in the step 3 to 4 transition. Tubulin states in step 4 are non-computably chosen in the collapse, and evolve by classical computing to regulate neural function. Bottom: Schematic sequence of phases of actin gelation (quantum isolation) and solution (environmental communication) around MTs.

In OR, quantum superposed systems evolve (if isolated) until their energy-time product reaches a barrier related to quantum gravity, at which instant they reduce, or collapse, to definite states. The collapse "choices" are neither deterministic nor probab ilistic, but rather are "non-computable" possibly reflecting influence by some hidden quantum-mathematical logic.

In Orch OR, the microtubule quantum superposition evolves (analogous to a quantum computer) so that it may be influenced at the instant of collapse by hidden non-local variables, or quantum-mathematical logic. The possible outcomes are limited, or probabilities set ("orchestrated"), by the neurobiological self-organizing process (in particular microtubule associated proteins MAPs). The precise outcome is chosen by the effect of the hidden logic on the poised system.

Perhaps a sailboat analogy would be helpful. A sailor sets the sail in a certain way; the direction of the boat will then be determined by the action of the wind on the sail. Let's pretend the sailor is a non-conscious robot zombie trained and programmed to sail a boat across a lake. Setting and adjusting of the sail, sensing the wind and position etc. are algorithmic and deterministic, and may be analogous to the pre-conscious, quantum computing phase of Orch OR. The direction of the wind (seemingly capricious) may be analogous to hidden non-local variables (e.g. "Platonic" quantum-mathematical logic inherent in space-time) which provide non-computability. The choice, or outcome (the direction the boat sails, the point on shore it lands) depends on the deterministic sail settings acted on repeatedly by the unpredictable wind. Our actions could be the net result of deterministic processes acted on by hidden quantum logic at each Orch OR event.

Feature 4: Non-computability

Pixie dust (neuralism): What non-computability? Penrose's argument from G del's theorem that human thought requires non-computability provoked a torrent of critical papers, mainly from defendants and dependents of artificial intelligence (AI) (1). The over-reaction reached the point of Penrose being awarded a sarcastic prize from AI henchmen (see Churchland, 1997). Most harped on issues already answered (but apparently unnoticed) in *The Emperor's New Mind* and *Shadows of the Mind*! Penrose responded point by point to a collection of critics ("Beyond the doubting of a shadow" Penrose, 1996b). For Penrose, the key to non-computability is the nature of mathematical understanding, but non-computability may also be evident in creativity (Casti, 1996), and as favorable unpredictability in predator-prey interactions important in evolution (Hanes et al., 1996; Barinaga, 1996).

Orch OR: Self-organized quantum gravity collapse of the wave function, Penrose's "objective reduction" is predicted to be non-computable (Penrose, 1989; 1994; 1996). The specific post-collapse states are neither random nor chosen algorithmically, but rather are influenced by unknown (non-local hidden variable) quantum logic inherent in fundamental spacetime geometry.

Feature 5: Transition from pre-conscious processes to consciousness

Pixie dust (neuralism): Conscious experience emerges at a critical threshold of neural activity?

Orch OR: The pre-reduction tubulin superposition ("quantum computing") phase is equated with pre-conscious processes (Figure 8).

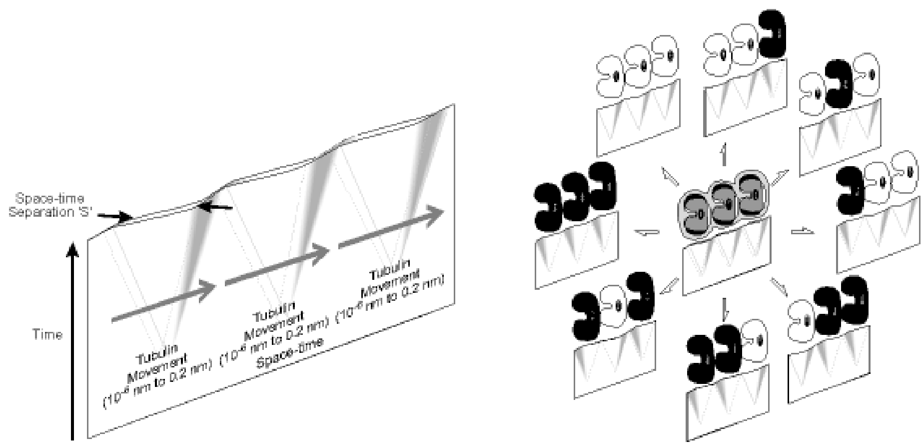

Figure 8. *Spacetime representations of tubulin superpositions. (Left) Schematic spacetime separation illustration of three superposed tubulins. The Planck-scale spacetime separations S are very tiny in ordinary terms, but relatively large mass movements (e.g. hundreds of tubulin conformations, each moving from 10^{-6} nm to 0.2 nm) indeed have precisely such very tiny effects on the space-time curvature. A critical degree of separation causes an abrupt selection of one curvature, or the other. (Right) Center--Three superposed tubulins with corresponding schematic spacetime separation illustrations. Surrounding the superposed tubulins are the eight possible post-reduction "eigenstates" for tubulin conformation, and corresponding spacetime geometry. The post-reduction state is chosen*

noncomputably in Orch OR events.

When the quantum gravity threshold is reached according to E=h/T, self-collapse =(objective reduction) abruptly occurs. The tubulin superposition is a separation in underlying spacetime geometry in which "funda-mental" experience is presumably contained. With each self-collapse a new geometry of experience is selected each Orch OR is a conscious event. Although I may be biased it appears that regarding difficult issues related to consciousness, Orch OR is far more explanatory than synaptic pixie dust (Churchland's neuralism).

Conclusion: Neuralism

I applaud Professor Churchland's devotion to neurobiology and thank her for her interest, criticism, kind comments and for the honor of being grouped with John Searle, David Chalmers and Roger Penrose. However I am obliged to inform her that there is much more to neurons than meets her eye. Dendritic processing, gap junctions, probabilistic vesicle release, glial processing and classical cytoskeletal dynamics clearly indicate the neuron-as-switch concept is hopelessly naive. Add to this the possibilities of quantum coherence in microtubules, actin gelation cycles, gap junction quantum tunneling and quantum gravity self-collapse rearranging funda-mental spacetime. And add one more certainty: neurons are alive! Until proven otherwise, consciousness is a process peculiar to living systems. We can't sweep the question of life under a carpet.

Churchland's neuralism may stem from reaction to her high school biology teacher---an avowed vitalist! She explains that he could not imagine how living things emerged from dead molecules, how life arose from bits of proteins, fats and sugars. Surely, he thought, there was something else. Perhaps the rebellious position for a resolute teenager was to imagine that life did indeed arise directly from its material constituents. No mystery, just fact. What you see is what you get.

But sometimes you get more than you see. Take life, for example. With all we have learned about molecular biology in the past decades, are we any closer to understanding what life is? Pat's biology teacher was right, something is missing. Could it be that like consciousness, life is a quantum process?

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