TIME, CONSCIOUSNESS AND QUANTUM EVENTS IN FUNDAMENTAL SPACETIME GEOMETRY

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1. Introduction: The problems of time and consciousness

What is time? St. Augustine remarked that when no one asked him, he knew what time was; however when someone asked him, he did not. Is time a process which flows? Is time a dimension in which processes occur? Does time actually exist?

The notion that time is a process which "flows" directionally may be illusory (the "myth of passage") for if time did flow it would do so in some medium or vessel (e.g. minutes per what?) [1]. But if time is a dimension in which processes occurred, e.g. as one component of a 4 dimensional spacetime, then why would processes occur unidirectionally in time? Yet we perceive time as an orderly, unidirectional process.

An alternative explanation is that time does not exist as either a process or dimension, but that reality is a collage of discrete, disconnected and haphazardly arranged configurations of the universe, e.g. as described in Julian Barbour's "The end of time" [2]. In this view our perception of a unidirectional flow of time occurs because each moment, or "Now" as Barbour terms them, involves memory of other conceptually relevant moments, and the orderly flow of time is an illusion.

Barbour's deconstruction of time contrasts the Newtonian reality of objects moving deterministically through 4 dimensional spacetime. Newton's contemporary (and rival) Leibniz [3] viewed the world in a manner consistent with Barbour (and with Mach's principle that the spatiotemporal structure of the universe is dependent on the distribution of mass, a foundation of Einstein's general relativity). According to Leibniz the world is to be understood not as matter/mass moving in a framework of space and time, but of more fundamental snapshot-like entities that momentarily fuse space and matter into single possible arrangements or configurations of the entire universe. Such configurations, which can be fabulously rich and complex considering the vastness of the universe, are the ultimate "things" of reality, which Leibniz termed "monads". Subsequently Alfred North Whitehead [4,5] expounded on Leibniz's monads, conferring upon them mental aspects ("occasions of experience").

In whichever direction the answer lies, the problem of time is intimately related to our conscious perceptions. We experience time as a unidirectional flow; without consciousness there would be no mystery. Does time exist in the absence of consciousness? What is consciousness?

Much like St. Augustine's view of time, we know what our consciousness is unless we are asked to explain it. The nature of consciousness has been debated at least since the ancient Greeks and there are three types of explanations: 1) dualism implies that consciousness lies outside knowable science, 2) emergence views consciousness as a novel property appearing at a critical threshold of complex computational dynamics among relatively simple components in the brain, and 3) variations of panpsychism, pan-protopsychism, and/or pan-experientialism place essential features or precursors of consciousness as fundamental components of reality, accessed and organized by brain processes.

Whitehead's [4.5] pan-protopsychist philosophy best connects consciousness to modern science. Whitehead viewed the universe as a process comprised of events. Leibniz [3] had "quantized" reality, describing fundamental configurations of the universe ("monads") as it's ultimate entities. But to account for consciousness Whitehead transformed monads into "actual occasions" occurring in a "basic field of proto-conscious experience" [6].

Leibniz monads and Whitehead occasions are consistent with Barbour's view of independent snapshots, moments or "Nows" in which time as a dimension or process does not exist. But what are these moments? Abner Shimony [6,7] recognized that Whitehead's approach was compatible with modern quantum physics, with quantum state reductions, or "collapses of the wave function"—actual events—appearing to represent "occasions". Quantum state reductions are useful in the new technology of quantum computation; could quantum computation account for consciousness? And what about Whitehead's "basic field of proto-conscious experience"? Could it be the universe itself, i.e. at its most basic level?

2. Spacetime geometry

Newton's laws of motion and Maxwell's equations for electromagnetism adequately explain our everyday, large scale “classical” world. However at small scales in the "quantum realm" (and the boundary between the quantum and classical realms remains mysterious) objects may exist in two or more states or places simultaneously—more like waves than particles and governed by a "quantum wave function". This property of multiple coexisting possibilities, known as quantum superposition, persists until the superposition is measured, observed or interacts with the classical world or environment. Only then does the superposition of multiple possibilities "reduce", "collapse", “choose” or "decohere" to specific, particular classical states.

Quantum superpositions and reduction are used technologically in quantum computers. Whereas conventional classical computers represent digital information as "bits" of either 1 or 0, in quantum computers, "quantum information" may be represented as quantum superpositions of both 1 *and* 0 (quantum bits, or "qubits"). While in superposition, qubits interact with other qubits (by nonlocal quantum entanglement) allowing computational interactions of enormous speed and near-infinite parallelism. After the computation is performed the qubits are reduced (e.g. by environmental interaction/decoherence) to specific classical bit states which constitute the solution.

Quantum computing may be useful, but what does it mean for an object to exist in multiple places or states simultaneously? The puzzle of quantum superposition has baffled science, moreover the fate of isolated superpositions remains unresolved. One solution was put forth by Hugh Everett in his "multiple worlds" view [8]. Everett's idea was that superposition is a separation in underlying reality, that the universe at it's fundamental level splits, or separates, and that each possibility branches off to form a new universe, a new reality. Thus, according to this view, there exist an infinite number of parallel universes corresponding to the infinite number of superposition possibilities which have ever existed. Assuming for a moment that the multiple worlds view is at least partially correct (and many believe it is correct), how do we envision the universe separating? How do we envision the structure of reality? What is empty space?

At very small scales, space is not smooth, but quantized. Imagine viewing the ocean from an airplane. The ocean surface may look perfectly smooth. However if you were in a small boat on the ocean surface you'd be tossed about by the roughness of the sea invisible from high above. Similarly as we go down in scale from the size of atoms (10-8 centimeters) empty space seems smooth until eventually we find granularity at the incredibly small "Planck scale" (10-33 centimeters, 10-43 seconds). There are several types of descriptions of the Planck scale: string theory, "quantum foam", and loop quantum gravity. In the context of loop quantum gravity, Penrose [9] portrayed the Planck scale as a dynamical spider-web of spin. Taking spin as an irreducible, fundamental entity, spin networks define spectra of discrete Planck scale volumes and configurations which dynamically evolve and define spacetime geometry [10,11]. The amount of potential information in Planck scale spin networks is vast; each Planck scale volume, or "pixel of reality" may be shaped by huge variability and nonlocal interactions. Plus their sheer number is enormous—there are roughly 10107 Planck volumes in the volume of a human brain, far greater than the number of particles in the universe.

So the universe may be constructed of Planck scale spin networks whose configurations and dynamics lead to all matter and energy. If, as Whitehead and others proposed, consciousness derives from fundamental, irreducible entities which are "proto-conscious" (what philosophers call "qualia"), then proto-conscious qualia must also be embedded in Planck scale spin networks (where else *could* they be embedded? Fundamental spacetime geometry is all there is!). We can envision proto-conscious qualia as specific, nonlocal distributed configurations of Planck scale spin networks. But why would these, or some of these, give rise to consciousness?

Let us return to the problem of superposition. As previously mentioned, Everett's "multiple worlds view" describes separations in underlying reality. For simplicity and illustration we can condense our 4-dimensional spacetime (with a basement level of Planck scale spin networks) into a 2-dimensional spacetime sheet: one spatial dimension and one time dimension (Figure 1, top). This spacetime is slightly curved, in accordance with Einstein's general theory of relativity, in a way which encodes the gravitational fields of all distributions of mass density. Each mass density—each object or particle—effects a spacetime curvature, albeit tiny for small objects. Consequently we can view any mass in one location as spacetime curvature in a particular direction, and location of the mass in a different location as spacetime curvature in another direction. Therefore quantum superposition of a particle in two locations may be considered simultaneous curvatures in opposite directions [12,13]. As in the "multiple worlds" view, the spacetime sheet separates into two opposing curvatures, resulting in a "bubble" or "blister" in underlying reality (Figure 1, bottom).

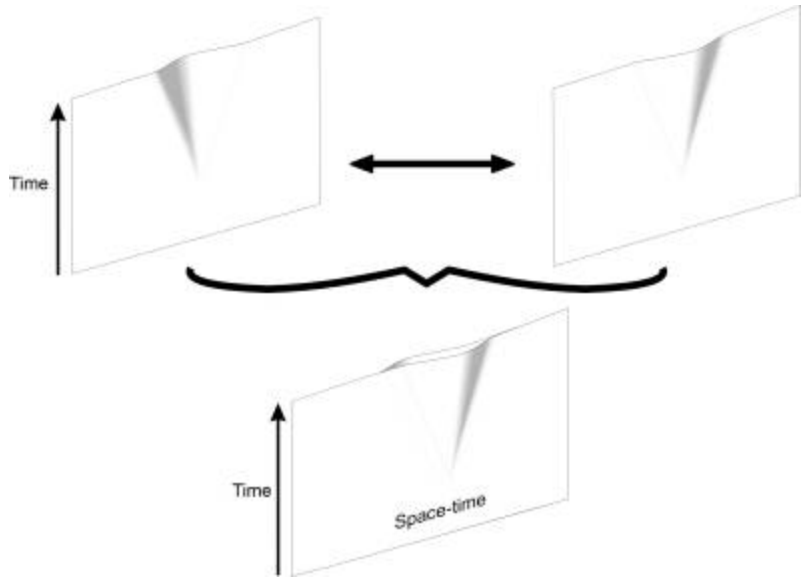

Figure 1. Four dimensional spacetime may be schematically represented by one dimension of space and one dimension of time: a two dimensional "spacetime sheet." Mass is curvature in spacetime, and the two spacetime curvatures in the top of Figure 3 represent mass in two different locations or conformations respectively. Mass in quantum superposition (mass separated from itself) is simultaneous spacetime curvature in opposite directions, a separation, or bubble in spacetime. At a critical degree of separation, the system becomes unstable and must select either one state or the other (from Penrose [13] p. 338).

What is the fate of isolated superpositions/spacetime separations? In a cartoon version of the multiple worlds view each spacetime sheet—each side of the "blister"—evolves into a separate universe. However Roger Penrose [12-14] has proposed an alternative explanation which avoids the need for multiple universes, connects quantum theory to general relativity, and poses an explanation for consciousness!

4. Penrose "objective reductions"

In Penrose's view superpositions, or spacetime separations, bubbles, or blisters are unstable, and somewhat like bubbles in a bubble bath will eventually reduce, or collapse to one particular curvature or the other. The instability is inherent in the properties of spacetime geometry (quantum gravity) and constitutes an objective threshold for an isolated quantum state reduction, hence "objective reduction (OR)".

In the Penrose formulation, objective reduction due to the quantum gravity properties of fundamental spacetime geometry occurs at a time T given by the Heisenberg indeterminacy principle $E=h/T$, in which E is the magnitude of superposition/separation, h is Planck's constant over 2π, and T is the time until reduction. The magnitude E is related to the gravitational self-energy of the superposition and may be calculated from the amount of mass "separated from itself" and distance of separation. Since E is inversely related to T, small separations/superpositions (if isolated) will reduce at a long time T, and large separations/superpositions (if isolated) will reduce quickly. For example an isolated superpositioned electron would reduce by OR only after 10 million years. A large isolated superpositioned object (such as Schrödinger's mythical one kilogram cat) would reduce by OR after only 10-37 seconds (too quickly for anyone to notice).

The point is that Penrose objective reductions are self-organizing events occurring at the level of—actually in the medium of—fundamental spacetime geometry in which proto-conscious qualia may be embedded. Accordingly Penrose OR events could qualify for Whitehead occasions in a "wider field of proto-conscious experience" [6]. Thus Penrose OR events are potentially equivalent to Whitehead "occasions of experience", Leibniz configurations and in some ways to Barbour's "Nows".

OR events require fairly stringent conditions: superpositions/spacetime separations must be large enough to reach threshold in a brief enough time period, yet able to be isolated/protected from disruption by environmental decoherence. In quantum computers the superpositioned qubits are likely to be electrons, of extremely low mass and

hence incapable of reaching OR threshold in a reasonably short time; instead, the superposition is interrupted by decoherence when the computation is complete. Thus the OR threshold is never reached and quantum computers as presently envisioned will not be conscious by this criterion. On the other hand OR events may occur cosmologically due to very large scale superpositions, e.g. in neutron stars, or the early universe [15]. Presumably, these OR events, which would occur at very fast time scales, would lack any organized information and while they may be very briefly "conscious" would have no cognition, intelligence or memory.

According to Penrose, outcomes selected in OR events are chosen neither randomly nor logarithmically, but "non-computably", i.e. influenced by "Platonic values" embedded in Planck scale geometry. Because OR selections are non-computable, or non-algorithmic, they are irreversible from the standpoint of classical information. Thus each OR event "ratchets forward" classical information in spacetime, effectively creating conscious perception of a forward flow of time. A sequence of OR events/conscious moments occurring in the brain could give rise to our familiar "stream" of consciousness. Could Penrose "objective reductions" occur in the brain?

5. Penrose – Hameroff "Orch OR" model of consciousness

Penrose and Hameroff [12-16] have proposed a model of consciousness involving quantum computation with OR in microtubules within the brain's neurons. Microtubules are cylindrical polymers of the protein tubulin which organize cellular activities.

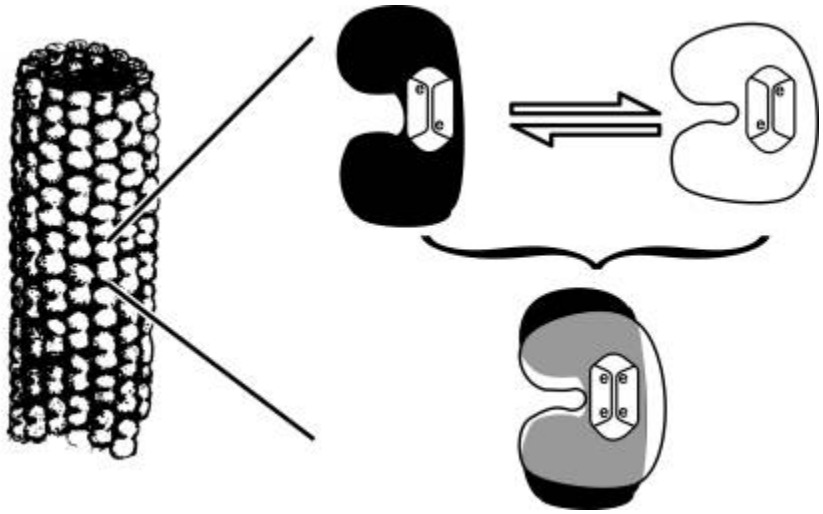

Figure 2. Left: Microtubule (MT) structure: a hollow tube of 25 nanometers diameter, consisting of 13 columns of tubulin dimers arranged in a skewed hexagonal lattice [13]. Right top): Each tubulin molecule may switch between two (or more) conformations, coupled to London forces in a hydrophobic pocket. Right (bottom): Each tubulin can also exist in quantum superposition of both conformational states [12,13].

Switching of tubulin conformational states is governed by quantum mechanical forces within each tubulin interior, and an essential feature of the Orch OR model is that tubulins may exist in quantum superpositions of two or more conformations and function as quantum bits, or "qubits" by interacting nonlocally (entangling) with other tubulin qubits so that MTs act as quantum computers.

When enough entangled tubulins are superpositioned long enough to reach Penrose's OR threshold by E=h/T, an objective reduction (OR) "conscious event" occurs. Each Orch OR event chooses a particular set of classical tubulin states which may proceed to regulate classical neural activities, e.g. trigger axonal firings, adjust synaptic strengths and rearrange the cytoskeleton, thus exerting causal efficacy, learning and memory. Feedback provides "orchestration" of the quantum computation, hence "orchestrated objective reduction: Orch OR". In the context of pan-protopsychist/pan-experiential philosophy, each Orch OR event is "conscious" because a particular configuration of proto-conscious qualia embedded in fundamental spacetime geometry is selected.

Brain processes occur in time scales on the order of tens to hundreds of milliseconds. For example sensory responses are on the order of 500 milliseconds (1/2 second), alpha EEG is roughly 100 milliseconds (1/10 second), and "coherent 40 Hz", the brain-wide synchrony which seems to correlate with conscious activity, is on the order of 25 msec (1/40 second). For Orch OR events in the brain to correspond with known neural events we can use E=h/T. For T=25 msec (coherent 40 Hz), E in terms of number of tubulins may be calculated, and estimating for percentage of tubulins/neuron involved in consciousness, we find that 10,000 to 100,000 neurons are involved in each Orch OR conscious event.

Each OR event is instantaneous, so the 25 milliseconds/conscious events are in the pre-conscious quantum superposition phase of multiple possibilities of perceptions or choices. During the pre-conscious superposition phase there are quantum superpositions of all possible perceptions or choices which then reduce/collapse/choose one particular set of qualia at the moment of OR . The pre-conscious superposition phase may also be equated with the Freudian sub-conscious including dreams and perhaps altered states.

This approach suggest that consciousness is a "stream" of discrete events, rather than a continuous state. Obviously we perceive our world as continuous rather than as discrete events, but a movie appears continuous though it is in fact a sequence of frames. Of course a movie has an external conscious observer, whereas in the Orch OR quantum approach each OR (self-collapse) event *is* conscious.

6. Conclusion: Consciousness creates time

William James described our "stream of consciousness" as a series of the "specious present—the short duration of which we are immediately and incessantly sensible". To characterize the specious present, James cited experimental work on sound perception implying a duration of roughly 6 seconds. However James recognized that the "present" implies a durationless instant, the latter boundary of his specious present [17]. Thus James' specious present is really "past", equivalent to what is described in modern psychology as "working memory". But what of the conscious present, or the "Now"?

Leibniz, Whitehead, Barbour and the Orch OR model are each consistent with James' view of consciousness as a set of discrete moments. But do the discrete moments form a contiguous stream-in-time as James suggested, or a collage of haphazardly arranged moments whose continuity is an illusion of memory as Barbour has argued. In either case we consciously perceive a continuity, a "flow" of time; moreover the apparent rate of the flow of time may vary.

Subjects in extreme situations often report variations in their perceived rate of the passage of time. People in car accidents describe "time slowing down", and famous athletes like the basketball player Michael Jordan are able to excel because the other teams' players seem to be reacting in relative slow motion. Physical speed aside, this may occur by an increase in the frequency of conscious OR events. For example if Jordan is having 60 conscious events per second, and the players defending him are only having 40 conscious events per second, Jordan has 50% more perceptions, decisions and reactions over any given time interval than his opponents, who will appear to him to be in slow motion. An opposite situation may be someone who has had too much alcohol; they may have fewer conscious events per standard time interval, and hence their conscious perception is that events in the outside world are occurring more rapidly than the pace of their own conscious perceptions (not a good idea to drive a car under these circumstances).

Another strange feature of consciousness is temporal synchrony of sensory inputs. Even simple acts such as walking involve potentially conflicting sensory inputs. The tactile

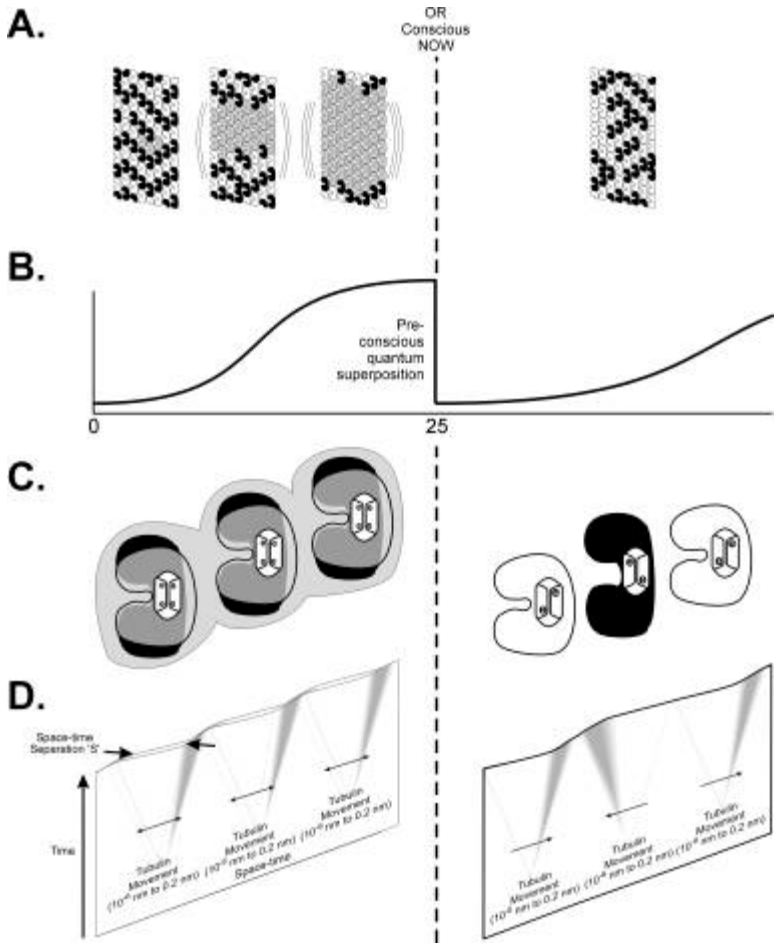

Figure 3 A. Microtubule automaton sequence reaching threshold for OR. B. Schematic of buildup of quantum superposition reaching threshold for OR and conscious event. C. (Left) Superposition of 3 tubulins prior to OR threshold, (Right) Tubulin states chosen in OR process, D. (Left) Superposition of corresponding spacetime geometry prior to OR threshold, (Right) Spacetime curvatures chosen in OR process.

sensations of our feet contacting the pavement travel via fairly long and slow sensory nerves through our legs and spinal cord to our brain; the visual input of seeing our feet contact the pavement arrives in our brain much faster via the shorter and faster optic nerves. Yet we perceive the visual and tactile information as simultaneous. There are several possible explanations for this: the philosopher Daniel Dennett [18] has argued that our conscious perceptions are non-synchronized (we see our feet strike the pavement, then a fraction of a second later feel them striking the pavement) but that we remember them as synchronized, an "Orwellian" revision of history. This implies that our view of reality is

purely a construction, an "illusion". Another explanation is that the fast perceptions (vision) are delayed to wait for the slow perceptions (touch). This implies that we are consistently "living in the past", our consciousness lagging behind reality.

However experimental evidence [19,20] suggests that the brain refers information "backwards in time". In fact such backwards referral may be commonplace [13], allowing us to live in the present moment despite finite delays in our sensory experience. Such a mechanism would allow us to act, and then slightly afterwards to decide on the action.

In the quantum realm time is uncertain and events may run "backwards". The second law of thermodynamics apparently does not apply in quantum systems which may become more ordered [21]. Quantum state reductions such as OR events may send quantum information "backwards in time", for example according to the Aharonov "dual vector" theory [22]. Time may simply be indeterminate in the quantum superposition phase. Backwards time referral of quantum information can account for effects in EPR entanglement and quantum cryptography [23]. In all these situations it is quantum information rather than classical information which seemingly travels backwards. In the Orch OR approach, quantum information is "pre-conscious" or "sub-conscious" information which "becomes conscious" at the "Now" moment of objective reduction. Thus each moment of consciousness may incorporate

quantum information from both the past and future, as well as classical information from the past ("working memory", the "specious present").

But what about time itself? Henri Bergson concluded that time is "grasped by, and belongs only to, inner consciousness". But what is consciousness? In the Orch OR model, with the equivalence of quantum superposition (e.g. of tubulin protein conformations) and spacetime separation consciousness is a sequence of OR events which reconfigure spacetime geometry "non-computably", and hence non-algorithmically. Thus with each

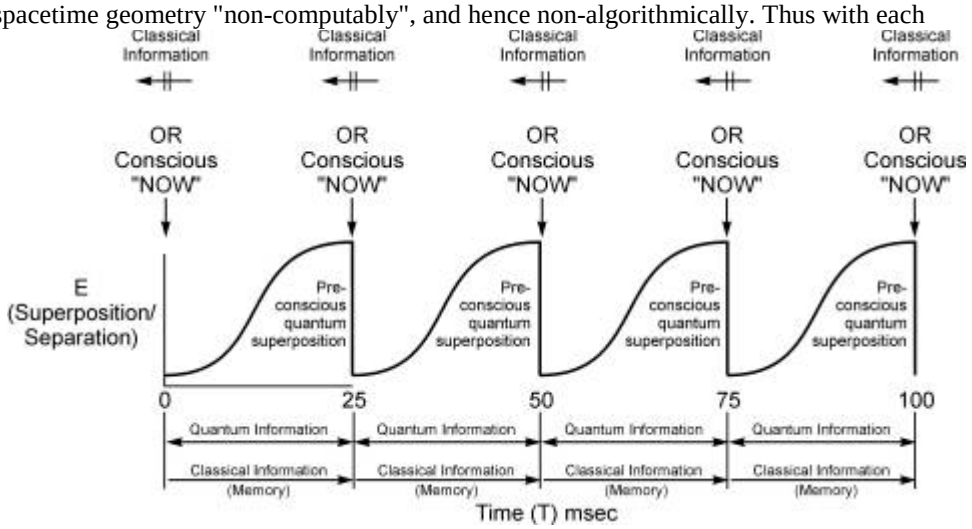

Figure 4. A sequence of OR conscious events occurring every 25 msec (consistent with brain activity at a frequency of 40 Hz). Pre-conscious quantum information reaches OR threshold (by E=h/T) resulting in an instantaneous conscious "NOW" which sends quantum information in both "forwards and backwards" time directions. Classical information (working memory, the "specious present") travels only forwards. Thus conscious perception of the classical world flows in a forward direction only.

conscious moment a new organization of Planck scale geometry is selected irreversibly. For classical information there is no going back along that same non-algorithmic path. OR events "ratchet" forward in spacetime geometry (Figure 5). Unlike the aphorism "time marches on", it is consciousness as a sequence of OR events which marches through and rearranges fundamental spacetime geometry (Figure 6). The unidirectional, orderly flow of time is a function of our consciousness. Consciousness creates time.

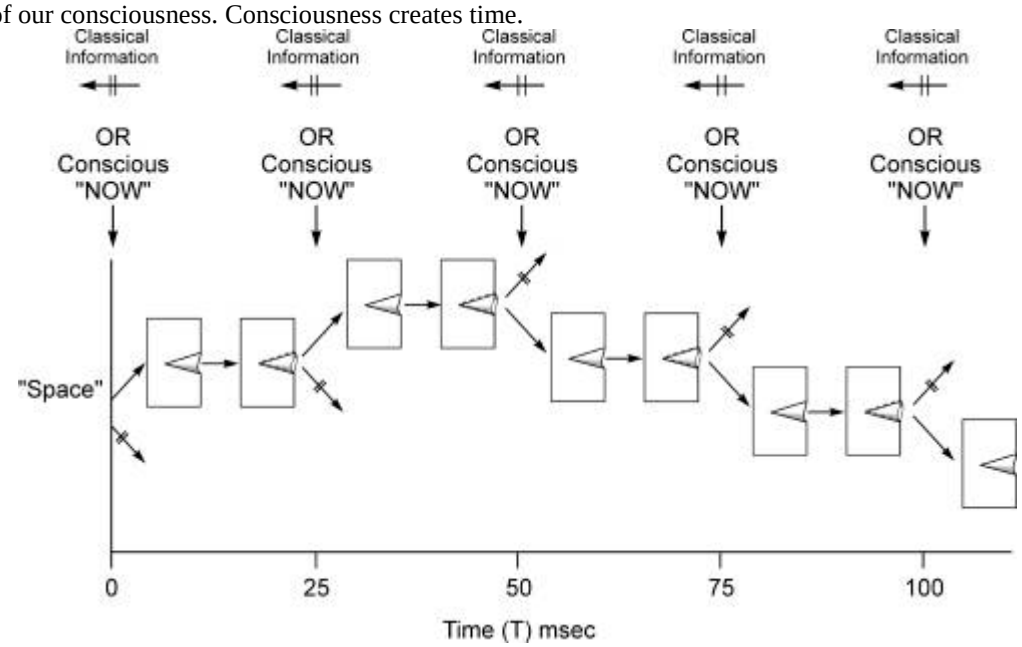

Figure 5. A trajectory through spacetime is described by a sequence of OR ("Conscious NOW") events. Nominal 4 dimensional spacetime is represented in "cartoon" version by 2 dimensional spacetime sheets, each with one spatial and one temporal dimension. As in figures 3 and 8, quantum superposition is represented by separation of the 2 dimensional sheet (simultaneous curvature into, and out

of, the plane of the figure). Each OR event selects one curvature, following which superposition resumes. As each OR event is non-computable/non-algorithmic, it is irreversible with respect to classical information. Hence conscious perception of the classical world moves "forward.

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