Consciousness Is Quantum State Reduction Which Creates the Flow of Time

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Abstract
In neuroscience, the flow of time is a conscious experience produced by the brain. But in physics, time is either a process, or a dimension in four-dimensional spacetime geometry. Could all three explanations be correct? The Penrose–Hameroff ‘Orch OR’ theory suggests consciousness is a sequence of discrete, irreversible quantum state reductions occurring at an objective threshold (‘objective reduction’, ‘OR’) a process in fundamental spacetime geometry. These ‘self-collapses’ of the quantum wavefunction are ‘orchestrated’ in microtubules inside brain neurons. Each OR event selects microtubule states which purposefully regulate neuronal functions, and provide sequences of ‘NOW’ moments of conscious experience. Connected to fundamental spacetime geometry by Penrose ‘OR’, consciousness is quantum state reduction, a set of irreversible steps which ‘ratchet forward’ in the fine scale geometry of the universe, creating a flow of time.

Keywords
Consciousness, flow of time, objective reduction, retroactivity, Orch OR, OR, quantum mechanics, Roger Penrose, microtubules, hard problem

1. Introduction: The ‘Flow of Time’
For neuroscience and psychology (e.g., Dean Buonomano, see Buonomano & Rovelli, 2021) time is a subjective conscious experience moving along a one-way street, a process flowing from the present into the future. Backward time effects, or time ‘travel’ into the past are deemed impossible. There exists only the present moment, the ‘Now’. This view is called ‘presentism’.

However in physics (e.g. Carlo Rovelli, see Buonomano & Rovelli, 2021), time is more complicated. Special relativity precludes a ‘global present’, a universal ‘Now’,
but time does seem to ‘flow’ from present into the future. The distinction between past and future is presumed to depend on thermodynamics, and hence is statistical only — like eddy currents in rivers, backward time effects are possible. But time is also seen as a dimension, physicists often representing the world as a four-dimensional ‘block universe’ in which all of time exists, and in which particles move along bidirectional worldlines. This view is called ‘eternalism’.

As Buonomano and Rovelli (2021) tell us, physicists want neuroscientists to explain the flow of time, as it is a property of consciousness produced by the brain. Neuroscientists want physicists to explain the flow of time as a feature of reality. Neither can explain consciousness. Could consciousness and the flow of time be one and the same?

2. Consciousness and the Nature of Reality

Neuroscientists and philosophers generally see the brain as a complex computer of simple neurons connected by variable-strength synapses. Consciousness, it is asserted, emerges at a critical level of complex computation, a description which fails to distinguish brain functions from computational artificial intelligence (‘AI’). However ‘computationalism’ fails to account for critical features of consciousness including (1) the ‘hard problem’ of phenomenal experience (composed of ‘qualia’, Chalmers, 1995); (2) spatiotemporal unitary binding of conscious content; (3) the flow of time; (4) real-time conscious perception and action; (5) purpose and meaning; and (6) the nature of life (until consciousness is confirmed in machines, essential features of life may be necessary — Hameroff & Penrose, 1996a, b; 2014).

Regarding the ‘hard problem’, many neuroscientists and philosophers resort to panpsychism in which qualia are properties of all matter. But at what level — molecules, atoms, sub-atomic particles ...? And how do panpsychist qualia of individual particles combine, or become coherently bound, into rich, unified conscious experience? How would they exert causal action? Perhaps consciousness is even more fundamental, a basic process in the universe?

Small particles can be in quantum superposition of multiple possible states and locations simultaneously, and non-locally connected by entanglement. However, when superpositions are measured, or consciously observed, the possibilities are then found to exist in definite states or locations. Why this occurs is unknown, and constitutes the ‘measurement problem’ in quantum mechanics. One set of explanations suggests quantum state reduction, or ‘collapse of the wavefunction’ is due to the measurement process, or conscious observation itself (Chalmers & McQueen, 2022). Other possible explanations avoid reduction, each possibility evolving to form its own universe (‘many worlds’, Everett, 1957).

Yet another group of interpretations suggests that as superpositions evolve and grow, they entangle more particles and reach an objective threshold at which reduction occurs to definite states (‘objective reduction’ theories, ‘OR’). Some OR
models are ‘continuous state localization’ theories (Pearle, 1989) in which reduction occurs sequentially by position over time. Collapse is incremental through the spatial domain of the superposition, there being no one temporal instant, no ‘Now’ when OR occurs for the entire superposition. Other OR theories are instantaneous among all entangled superpositioned components, and do involve a unified NOW among the components. These include GRW (Ghirardi, Rimini & Weber, 1986) in which reduction is said to occur when a particular number of superpositioned particles is reached. Still other OR models predict instantaneous reduction/collapse among all entangled particles, and these include gravity-related OR proposals.

3. Penrose ‘Objective Reduction’ (‘OR’)

In 1989, Sir Roger Penrose proposed a type of instantaneous OR dependent on properties of fundamental spacetime geometry, related to general relativity and quantum gravity. Penrose OR also gave an account for the origin of consciousness, and flow of time.

First, Penrose addressed the nature of superposition, how particles could conceivably exist in two states or locations simultaneously.

To do so, he used Einstein’s general relativity comparing matter to curvature in fundamental spacetime geometry. General relativity had predicted, for example, that the mass of the sun would curve spacetime, such that stars behind the sun could be visible on earth, a prediction proven experimentally during an eclipse by Eddington in 1919 (Gilmore & Tausch-Pebody, 2022). What is spacetime? What is it that curves?

The makeup of fundamental spacetime geometry at its most basic Planck scale level (10^{-33} cm, 10^{-43} s) has been described as the ‘Plenum’ (ancient Greek philosophy), ‘Brahman’, or the ‘Ground of Being’ (Eastern philosophy), or as the spacetime metric (Einstein). Penrose and others have approached it through loop quantum gravity, spin networks and/or ‘Twistor’ theory (Penrose, 2004). Whatever it is, spacetime ‘curvature’ corresponds with matter, or mass.

Penrose used simple two-dimensional ‘sheets’ to represent four-dimensional spacetime with one dimension of time (Fig. 1). Equating quantum particles with tiny spacetime curvatures, superposition can then be represented as separated curvatures (Fig. 1A). Some suggest that measurement, or conscious ‘NOW’ observation causes quantum state reduction (Fig. 1B), a dualist position putting consciousness outside science (e.g., Chalmers & McQueen, 2022). Were such spacetime separations to continue, one might imagine bifurcations in the universe itself, leading to ‘many worlds’ (Fig. 1C).

But Penrose considered that spacetime separations would be unstable, and undergo reduction at an objective threshold (hence objective reduction, ‘OR’) related to the quantum uncertainty principle (Fig. 1D). OR would occur at times...
Figure 1. Two-dimensional spacetime sheets represent four-dimensional spacetime with curvature corresponding to mass. (A, left) A particle and its spacetime curvature oscillate between two locations; (right) superposition of the particle in two locations with separated curvatures. (B) Conscious observation (NOW) causes quantum state reduction and one possibility ceases to exist, the other continues. (C) There is no state reduction and each possible curvature continues in its own universe — ‘Many Worlds’. (D) In Penrose OR, superpositioned curvatures reduce spontaneously at time $t = \hbar/E_G$, producing a moment of ‘proto-conscious’ experience ‘NOW’ and an irreversible moment in time.

Figure 2. A scale-invariant hierarchy from left: pyramidal neuron (Hz), microtubule bundles (kHz), microtubules (MHz), tubulin rows (GHz), tubulins (THz), atomic nuclei (PHz),…, and potentially to fundamental Planck time $10^{-43}$ s. Orch OR is proposed to occur at any of these levels, or combinations across different scales via resonance and interference, not unlike music (Hameroff, 2022). Individual Orch OR conscious events could act like notes and chords in music, each being an irreversible step forward in time.
\[ t_i = \frac{\hbar}{E_G} \]

where \( t_i \) is the time at which OR event \( i \) occurs, one in a sequence of events \( i \). \( E_G \) is the gravitational self-energy of mass/spacetime superposition separation reaching threshold at times \( t_i \), and \( \hbar \) is the Planck–Dirac constant. Penrose further predicted that OR events would include a moment of phenomenal experience, a ‘Now’ moment composed of ‘qualia’, the raw components of consciousness as an intrinsic property of spacetime geometry. Rather than consciousness causing collapse/reduction, Penrose proposed that collapse/reduction occurred spontaneously by a property of the universe which caused, or was identical to (‘proto’-) consciousness. Such events would be ubiquitous in the random micro-environment; their experiential aspects are presumed also to be random and isolated, without context or memory, thus considered merely ‘proto-conscious’. Metaphorically, proto-conscious moments are like the disconnected tones of musicians tuning their instruments before a performance. How might ‘proto-conscious noise’ be converted to a ‘conscious symphony’?

4. Orchestrated Objective Reduction (‘Orch OR’)


Microtubules are cylindrical lattice polymers of the protein tubulin, the brain’s most prevalent protein, and part of the cell cytoskeleton. Intraneuronal microtubules provide structural support, organize dynamic activities, form and regulate synapses, process and encode information, and are proposed to collectively generate consciousness.

Microtubules have coherent resonances and excitations over at least 12 orders of frequency, into the quantum regime. In a series of experiments, Anirban Bandyopadhyay discovered coherent vibrations and conductive resonances in microtubules at multiple scales. Measurements from tubulin, single microtubules, cytoskeletal bundles containing microtubules, neurons, neuronal networks, and entire brain measured from scalp have shown self-similar patterns (‘triplets-of-triplets’) of quantum resonance conduction and excitations repeating approximately three orders of magnitude in hertz, kilohertz, megahertz, gigahertz, terahertz and/or petahertz frequency ranges (Sahu et al., 2013a, b, 2014; Saxena et al., 2020).

Microtubules are ‘time crystals’ (Ghosh et al., 2022), and it appears a microtubule-based scale-invariant hierarchy exists in the brain, one which extends inwardly to include quantum-level phenomena with non-locality (Fig. 2, adapted from Hameroff, 2022).
Orch OR events can in principle occur at any particular time $i$ in $t_i = \hbar/E_G$ and are thus able to generate a frequency spectrum of possible conscious moments, with time $t$ inversely related to $E_G$, the number of tubulins required in superposition. Faster events at higher frequencies ($1/t$) require more $E_G$, and are proposed to be more intense experientially, have greater content, and can include quantum non-locality.

For example, Orch OR events could have superposition times $t = 10^{-7}$ s, a frequency of 10 MHz, experimentally shown, and brief enough to avoid decoherence. At $t = 10^{-7}$ s, $E_G$ would need $10^{15}$ superpositioned tubulins, and there are $\sim 10^{9}$ to $10^{10}$ tubulins per human brain, and $\sim 10^{8}$ to $10^{9}$ tubulins per neuron. So, one Orch OR conscious moment at $10^{-7}$ s would require about $10^{-4}$ to $10^{-5}$ of total brain tubulins, a reasonable fraction. Higher frequency events would require more entangled tubulins, and involve more quantum non-locality.

However, time domains for cognitive epochs, conscious perceptual activity, and electro-encephalography (‘EEG’) are relatively slow, in the range of tens to hundreds of milliseconds. Avoiding environmental decoherence of quantum states for that long would be difficult. The origin and full significance of EEG are still unknown, although EEG signals at scalp are known to be generated mostly by apical dendrites of layer 5 cortical pyramidal neurons which rise vertically to the brain surface. In Hameroff and Penrose (2014) we suggested EEG was comprised of interference beats and resonant interactions of faster microtubule vibrations, resulting in slower, self-similar patterns. Each Orch OR superposition can entangle, resonate and interfere with others in the brain across frequencies and locations, such that Orch OR moments may be somewhat like notes and chords played by an orchestra. Sequences of such moments give rise to our familiar stream of consciousness, discrete quantum events perhaps synchronized to the most basic level of the universe, spacetime geometry, similar to ‘fundamental time’ as suggested by Gruber et al. (2022).

If consciousness is a sequence of events, as its frequency of Orch OR conscious moments changes, e.g., increasing when stimulated or excited, perceived conscious experience may slow down. Because OR events are irreversible, ratchet-like steps in spacetime (Hameroff, 2003), there is both a conscious perception and reality of a unidirectional flow of time in the classical world (Fig. 3). Consciousness is due to quantum state (objective) reductions which create the flow of time.
5. Retroactivity

There are exceptions to every rule, for example eddy currents in rivers commonly flow upstream against the main current. In neuroscience and psychology, there are credible reports of seemingly backward time effects in mental states. Bem published a series of studies showing 'precognition', information from the future, in a very mainstream psychology journal (Bem, 2011). Famous experiments by Benjamin Libet and coworkers (1979) seemed to show that the brain utilizes backward time referral in sensory conscious perception (not the famous volitional studies ‘move your finger’; Libet et al., 1983).

In conscious perception, sensory inputs to the primary cortex feed forward to the frontal cortex, and are then broadcast in feedback to other cortical and subcortical brain regions. This feedback activity seems to correlate with conscious perception, but occurs 300 to 500 ms after sensory impingement, often after we have responded, seemingly consciously. The unfortunate conclusion in modern neuroscience and philosophy is that we respond nonconsciously, and have a false illusion afterwards that we were in conscious control. Consciousness is therefore considered epiphenomenal illusion, merely ‘along for the ride’. Free will for real-time events is deemed impossible (Wegner, 2002).

However Penrose (1989, 2022) has proposed that OR has a retroactive effect which deletes unselected superpositioned spacetime curvatures, and that this may enable functional retroactive effects in mental perceptions and actions. Tennis players who could perceive their opponent’s movement from the near future would have a significant advantage. Hameroff (2012) suggested that quantum
backward time effects which can occur in Orch OR could enable real-time con-
scious control, and rescue conscious free will.

But could retroactive effects result in causal paradox, e.g., going back in time to
kill your ancestor and thus prevent your birth? It needn’t if the retroactive effect
only affects superpositions which have yet to collapse. Thus, quantum retroactiv-
ity would avoid causal paradox and not alter the inexorable flow of time in the
classical world, like eddy currents do not alter the overall flow of a river.

6. Conclusion
As described by Buonomano and Rovelli (2021), physicists believe the flow of
time is a property of consciousness produced by the brain, and neuroscientists
believe it is a feature of reality. They are both correct — consciousness and the
flow of time are one and the same.

Microtubules are biological ‘time crystals’ (Ghosh et al., 2022), essentially
clocks within clocks within clocks, proposed to be the major features in a scale-

invariant brain hierarchy in which consciousness occurs. He et al. (2010) proposed
hierarchical brain levels upward in size from neurons into networks, and networks
of networks at nested EEG frequencies. Hameroff and Penrose (2014) proposed
hierarchical levels inside neurons in microtubules, going inward, deeper and
faster in kilohertz, megahertz, gigahertz and terahertz frequencies in the brain,
and perhaps faster and deeper into spacetime geometry, perhaps to an intrinsic
oscillatory system — ‘fundamental time’ — inherent in the universe (Gruber
et al., 2022).

The Orch OR theory describes consciousness as an ‘orchestrated’ quantum
state step in spacetime geometry, ratcheting into the future. Sequences of such
events create the flow of time in the classical world, subjectively giving our ‘stream
of consciousness’. Within the scale-invariant hierarchy, consciousness is proposed
to occur, interfere and resonate somewhat like notes and chords in music.

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