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'Orch OR' is the most complete, and most easily falsifiable theory of consciousness

Stuart Hameroff

Departments of Anesthesiology and Psychology, Banner-University Medical Center,Center for Consciousness Studies, The University of Arizona, Tucson AZ, AZ

ABSTRACT

The 'Orch OR' theory attributes consciousness to quantum computations in microtubules inside brain neurons. Quantum computers process information as superpositions of multiple possibilities (quantum bits or qubits) which, in Orch OR, are alternative collective dipole oscillations orchestrated ('Orch') by microtubules. These orchestrated oscillations entangle, compute, and terminate ('collapse of the wavefunction') by Penrose objective reduction ('OR'), resulting in sequences of Orch OR moments with orchestrated conscious experience (metaphorically more like music than computation). Each Orch OR event selects microtubule states which govern neuronal functions. Orch OR has broad explanatory power, and is easily falsifiable.

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Introduction – Penrose 'objective reduction' ('OR')

The 'Orch OR' theory (Hameroff & Penrose, 1996a, 2014) attributes consciousness to quantum computations in microtubules inside brain neurons. Quantum computers process 'superpositions' of possibilities (quantum bits or 'qubits') which unify by entanglement, evolve and compute, until reduction, or 'collapse' to definite output states. Nobel laureate Sir Roger Penrose (1989) proposed that *reduction* occurred spontaneously due to an *objective* threshold in the fine-scale structure of the universe *('objective reduction', 'OR')* at time $t = \hbar/E_G$, where $\hbar$ is the Planck-Dirac constant, and E_G the gravitational self-energy of the superposition. At each such OR moment, Penrose further proposed, random (proto-) conscious moments of experience occur, composed of basic 'qualia,' the most specific scientific proposal for phenomenal experience (the 'hard problem') yet put forth (Hameroff & Penrose, 1996b). Were there 'orchestrated' quantum computers and qubits in the brain which could reduce by OR to produce full, rich conscious moments?

Microtubules and 'Orch OR'

Polymers of 'tubulin' protein, microtubules organize intraneuronal activities. In 1996, Penrose and I proposed microtubules 'orchestrated' quantum superpositions, encoding inputs, and memory as entangled qubits of collective quantum dipole oscillations ('Orch'). These then compute and terminate by '*orchestrated OR*' ('Orch OR'), producing conscious moments, and selecting microtubule states which regulate neurons. We faced several issues.

Decoherence and anesthesia Biological quantum computing seemed unlikely due to thermal decoherence, however 1) photosynthesis proteins utilize superpositioned 'pi resonance' electrons, 2) quantum electron states resonate in microtubules at terahertz, gigahertz, megahertz and 10 kilohertz frequencies (Figure 2, Sahu et al., 2014; Saxena et al., 2020), and, 3) anesthetics may selectively erase consciousness by quantum interactions inside microtubules (Emerson et al., 2013). Computer modeling shows collective terahertz oscillations among tubulin's 86 pi electron resonance rings are specifically dampened by anesthetics (Craddock et al., 2017).

The Orch OR qubit Inside tubulin, pi-electron resonance forms 'quantum friendly' regions which extend to neighboring tubulins along helical lattice pathways to support collective 'giant dipole oscillation' qubits (Fröhlich, 1975; Figure 1).

A spectrum of conscious moments By $t = \hbar/E_G$ higher frequency Orch OR moments involve more tubulins, greater content, and are proposed to have higher experiential intensity. For example, 10 MHz (10^7 Hz) Orch OR events would require 5×10^{15} tubulins, 10^{-4} of brain capacity, such oscillations interfering 'holographically,'

CONTACT Stuart Hameroff hameroff@u.arizona.edu Department of Anesthesiology, 1501 N. Campbell Ave., Room 4401, P.O. Box 245114, Tucson, AZ 85724 USA

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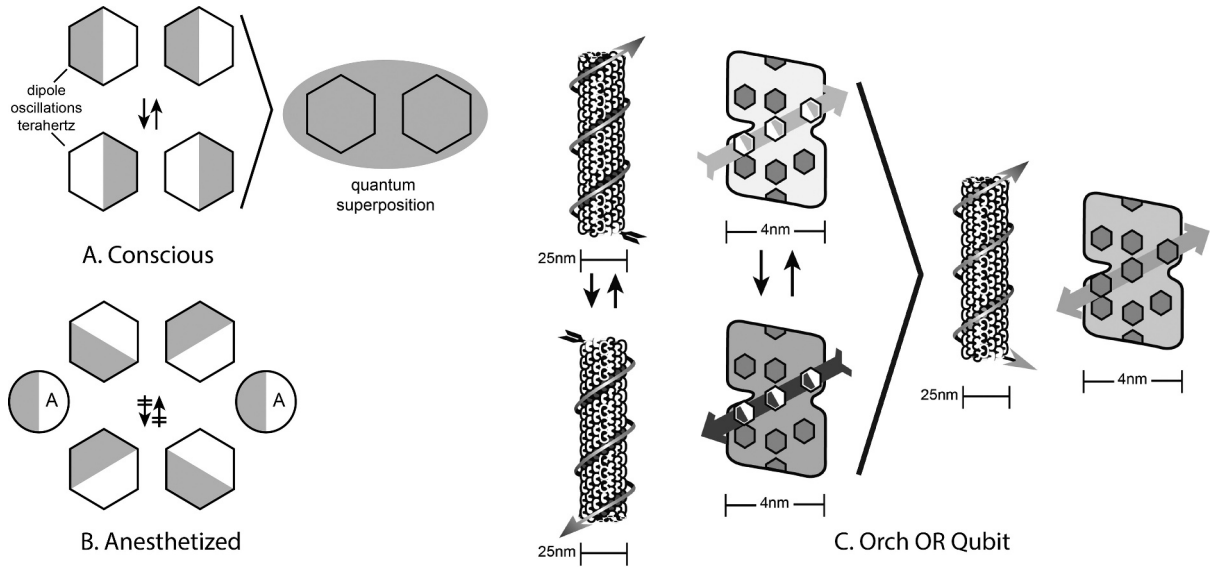

Figure 1. (a). Organic benzene/phenyl 'pi electron resonance' molecules couple, form oscillating dipoles, and quantum superposition. (b). Anesthetic gas molecules disperse dipoles, disrupt coherent oscillations, preventing consciousness. (c). The Orch OR qubit - Left: Collective dipoles oscillate in single tubulin, and along a helical microtubule pathway. Right: Quantum superposition of both orientations in a tubulin pathway qubit.

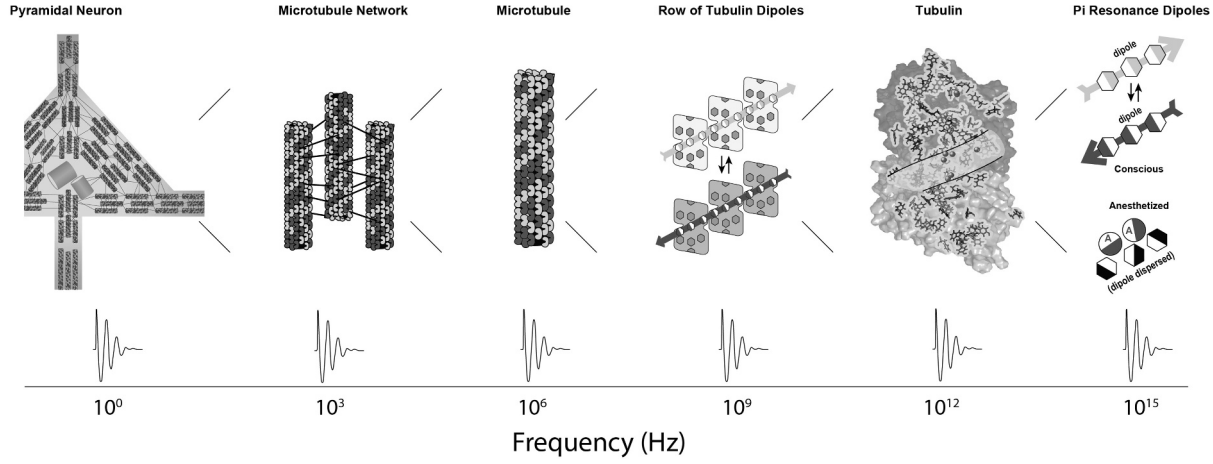

Figure 2. A multi-scale hierarchy in which Orch OR can occur. From left, cortical pyramidal neuron, microtubule network, single microtubule, row of tubulins displaying collective dipoles, tubulin with pi resonance amino acid rings and anesthetic binding sites (spheres), pi resonance dipole oscillations with anesthetic dampening. At bottom, self-similar dynamical activity repeats at different scales (Sahu et al 2014; Saxena et al, 2020).

resulting in slower cognitive epochs and electroencephalography, 'EEG' (Hameroff & Penrose, 2014).

Orch OR and the brain Orch OR are likely in cortical layer five pyramidal neurons whose dendrites and soma 1) have large arrays of mixed polarity, antiparallel microtubules, optimal for interference and recursive processing, 2) are crossroads of ascending, and horizontal cortical-cortical interactions, and 3) have apical dendrites responsible for EEG (Figure 2).

Falsifiability Quantum interference 'beats' in tubulin and microtubules ('Orch') will be sought experimentally in a top laboratory, and if detected, exposed to anesthetic gases as part of the Templeton World Charity Foundation Program 'Accelerating Research on Consciousness' (https://www.templetonworldcharity.org/our-priorities/accelerating-research-consciousness, http://osf.io/zqnjd/). A correlation between anesthetic dampening of quantum beats in microtubules, and anesthetic clinical potency would validate 'Orch' as a (sub-)neural correlate of consciousness. If quantum interference in tubulin/microtubules is not found, or if found is not dampened by anesthetics, then Orch (and Orch OR) would be falsified.

Paradigm cases

Conscious vs nonconscious I strongly dispute that Orch OR fails to distinguish conscious from non-conscious processes. Under anesthesia (Orch OR prevented), non-conscious evoked potentials can continue by 1) membrane and synaptic activities, and 2) non-quantum microtubule processes. 3) Quantum computations in microtubules ('Orch') which don't reach threshold may have sub-conscious influence (e.g., dreams).

Small network criterion Can 10 neuron networks be conscious? With approximately 10^8 tubulins/neuron (10^9 tubulins/10 neurons), by $t = \hbar/E_G$, 10^9 tubulins would require 500 msec to reach threshold for a low intensity, low content conscious moment. But microtubule quantum states are shown to persist only 0.1 msec. A 10 neuron network is unlikely to sustain 'Orch' for 500 msec, although it's possible.

Reduced brain volume and normal function Figure 3 in Doerig et al. (2020) shows the brain of a person with markedly reduced brain volume, but normal cognition and consciousness. Brain compensation by neuronal and synaptic plasticity directly requires microtubules.

Minimization of mysteries Orch OR has been derided for seeming to invoke a mythical 'law of minimization of mysteries' to explain both quantum mechanics and consciousness. But wouldn't 'Occam's razor' *favor* a 'minimization of mysteries'? Indeed, Orch OR may also help explain other mysteries including how anesthesia works, the origin and evolution of life, free will, the flow of time, memory, dreams, and how general relativity relates to quantum mechanics.

Conclusion

Spanning disciplines and scale, with high explanatory power, Orch OR is the most complete theory of consciousness. But if quantum interference in microtubules ('Orch') cannot be demonstrated, or if demonstrated, proves insensitive to anesthesia, Orch OR will be falsified. Orch OR is the most complete, and most easily falsifiable theory of consciousness.

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Disclosure statement

No potential conflict of interest was reported by the author.

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