“Hameroff-Penrose Theory: an Update”

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The Penrose-Hameroff Orch OR model of consciousness

Microtubules are protein polymers inside brain neurons proposed to act as quantum computers.
Tubulin is a globular protein and the fundamental component of microtubules. Microtubules (MTs) constitute the cytoskeleton of all the eukaryotic cells and are supposed to be involved in many key cellular functions.
**Microtubules (MTs)**

*Microtubules* are cylindrical polymers composed by alpha and beta-tubulin dimers. MTs diameter is around 15 nm and their length can vary from a few nm up to some cm.

MTs have optical, electrical and quantum properties that might explain long-distance intracellular communication processes.
In recent years coherent excitations have been found in living cells emanating from microtubules at 8 Megahertz

Resonance

- **Microtubules**: sharp (0.30 Hz) peak of mechanical resonance at a frequency of 1510 MHz
- **Tubulin** and control solution did not show any reaction

*MT molecular tubular structure can be responsible for the observed amplification of the signal*

Birefringence

MTs react to electromagnetic fields in a different way than tubulin and control: birefringence effect is always higher in MTs than in tubulin and control, with statistical significance

*This suggests again that the molecular structure of MTs could be the cause of their reaction to electro-magnetic fields*

MTs which in the dynamic evolution at zero field tend to move off their initial position, under the influence of the electric field tend to return to the starting position and to stabilize.

Their spatial organization is stronger than tubulin alone even in absence of field. The presence of electric field causes a decrease of conflicts, indicating a better structural organization, confirmed both by SONNIA and by the ITSOM attractors, that show a high regularity and compactness.

Evidence for wavelike energy transfer through quantum coherence in photosynthetic systems

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Photosynthetic complexes are exquisitely tuned to capture solar light efficiently, and then transmit the excitation energy to reaction centres, where long term energy storage is initiated. The energy transfer mechanism is often described by semiclassical models that invoke ‘hopping’ of excited-state populations along discrete energy levels$^{1,2}$. Two-dimensional Fourier transform electo-
Long-lived quantum coherence in photosynthetic complexes at physiological temperature

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Photosynthetic antenna complexes capture and concentrate solar radiation by transferring the excitation to the reaction center that stores energy from the photon in chemical bonds. This process occurs with near-perfect quantum efficiency. Recent experiments at cryogenic temperatures have revealed that coherent energy transfer—a wave-like transfer mechanism—occurs in many photosynthetic pigment-protein complexes. Using the Fenna–Matthews–Olson antenna complex (FMO) as a model system, theoretical studies incorporating both incoherent and coherent transfer as well as thermal dephasing predict that environmentally assisted quantum transfer efficiency peaks near physiological temperature; these studies also show that this mechanism simultaneously improves the robustness of the energy transfer process. This theory is corroborated by experiments in which excitation can travel to reach the lowest energy state. While classical trajectories can navigate such funnel-like landscapes, the wave-like motion through the complex improves efficiency by avoiding kinetic traps. In higher plants, this mechanism likely becomes more important because the landscape is more rugged without a downhill arrangement (17).

Recent investigations of photosynthetic systems at 77 K have found evidence of coherent energy transfer in many antenna complexes and even in the reaction center of purple bacteria (2–4). This wave-like energy transfer mechanism, however, can contribute to the near-perfect quantum efficiency of photosynthesis only if coherences survive in these systems during energy transfer at physiological temperatures. As temperature increases, thermally excited vibrational modes of the protein backbone...
Coherently wired light-harvesting in photosynthetic marine algae at ambient temperature

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Photosynthesis makes use of sunlight to convert carbon dioxide into useful biomass and is vital for life on Earth. Crucial components for the photosynthetic process are antenna proteins, which absorb light and transmit the resultant excitation energy between molecules to a reaction centre. The efficiency of these electronic energy transfers has inspired much work on antenna proteins isolated from photosynthetic organisms to uncover the basic mechanisms at play¹⁻⁵. Spectral variation between species because they use mainly tunable linear tetrapyrroles (bilins) for light-harvesting. Another remarkable feature of cryptophytes is that they can photosynthesize in low-light conditions, which suggests that the absorption of incident sunlight by phycobiliprotein antennae in the intrathylakoid space¹⁴ and the subsequent transfer of that energy among these proteins and eventually to the membrane-bound photosystems is particularly effective¹⁵. Theory
Tubulin: a Schrodinger's protein?

According to H-P theory Tubulin exist in quantum superposition of different states and function like a quantum bit, or qubit.


Penrose observed that quantum superposition – an object in two places/states simultaneously – equated to two spacetime curvatures in different directions: a bubble or separation in the fabric of reality.

But the separations are unstable, and after a time $t$ (given by $E=\hbar/t$) will spontaneously self-collapse to one curvature or the other (an “objective reduction” – O.R.).
The Penrose-Hameroff model suppose that quantum-superposed states develop in tubulins, remain coherent and recruit more superposed tubulins until a mass-time-energy threshold, related to quantum gravity, is reached (up to 500 msec). This model predicts dendritic webs of approximately 100,000 neurons for discrete conscious moments, or frames, occurring every 25 ms in gamma synchrony.
Interior schematic of dendrites in quantum isolation phase. Actin has polymerized into gel form and MAPs detached, shielding and isolating MTs whose tubulins have evolved into quantum superposition.
The Craddock and Tuszynski model

Describe classical and quantum information processing in MTs based on a double-well potential in the interior of the tubulin dimer.

Mapping electrostatic partial charges in the interior of tubulin dimer shows a region in the alpha monomer near the neck to the beta monomer of two areas of positive charge in the range of 100-150 meV.

Electrostatic map of a horizontal slice through tubulin near the “neck” between the alpha and beta monomers shows a “double well” of positive charge.

Left: Molecular simulation of tubulin with beta tubulin (dark gray) on top and alpha tubulin (light gray) on bottom. Non-polar amino acids phenylalanine and tryptophan with aromatic phenyl and indole rings are shown. (By Travis Craddock and Jack Tuszynski.) Right: Schematic tubulin with non-polar hydrophobic phenyl rings approximating actually phenyl and indole rings. Scale bar: 1 nanometer.
Four versions of the schematic Orch OR tubulin bit (superpositioned qubit states not shown). A) Early version showing conformational change coupled to/driven by single hydrophobic pocket with two aromatic rings. B) Updated version with single hydrophobic pocket composed of 4 aromatic rings. C) McKemmish et al (2009) mis-characterization of Orch OR tubulin bit as irreversible conformational change driven by GTP hydrolysis. D) Current version of Orch OR bit with no significant conformational change (change occurs at the level of atomic nuclei) and multiple hydrophobic pockets arranged in channels.
Using nanotechnology they interface via AFM/STM electrodes to opposite ends of a single viable microtubule (MT). They vary AC and DC conditions and study electronic transport properties at temperatures ranging from 10K to room temperature. At specific conditions they found:

1) spontaneous MT growth leading to Frohlich condensation
2) ballistic electronic transport,
3) ferroelectric MT properties.

- Multilevel information processing and memory (beyond binary logic) in MT
- Efforts to understand room temperature coherent transport in terms of band energies.
- Challenges and resolution of detection of MT topological quantum bits, or qubits based on Hemchandra/Fibonacci MT geometry at physiological temperature.

Bandyopadhyay (2011) has evidence for ballistic conductance and quantum interference along such helical pathways which may be involved in topological quantum computing. Quantum electronic states of London forces in hydrophobic channels result in slight superposition separation of atomic nuclei, sufficient $E_G$ for Orch OR. This image may be taken to represent superposition of four possible topological qubits which, after time $T=\tau$, will undergo OR, and reduce to specific pathway(s) which then implement function.

Summary of Bandyopadhyay results (2011)

1) Microtubules have 8 resonance peaks for AC stimulation (kilohertz to 10 megahertz) which appear to correlate with various helical conductance pathways around the geometric microtubule lattice.
2) Excitation at these resonant frequencies causes microtubules to assemble extremely rapidly, possibly due to Fröhlich condensation.
3) In assembled microtubules AC excitation at resonant frequencies causes electronic conductance to become lossless, or 'ballistic', essentially quantum conductance, presumably along these helical quantum channels. Resonance in the range of kilohertz demonstrates microtubule decoherence times of at least 0.1 millisecond.
4) Eight distinct quantum interference patterns from a single microtubule, each correlating with one of the 8 resonance frequencies and pathways.
5) Ferroelectric hysteresis demonstrates memory capacity in microtubules.
6) Temperature-independent conductance also suggests quantum effects.

If confirmed, such findings would demonstrate Orch OR to be biologically feasible!
A new approach in Quantitative Psychiatry

Is it possible that psychopathological diseases such as depression and psychosis involve different states of consciousness through the biological interface called Cytoskeletal Quantum Nanowire-Network?
MTs and Actin filaments can be viewed as computationally relevant nanowire networks that operate within neurons providing several functions among them the connection of the cell nucleus with the postsynaptic density (Woolf, 2010). Potential computational modes for MTs and actin filaments are beginning to be understood, with two main quantum models for MT information processing having been proposed.
According to Woolf et al. MTs dysfunction occurring in mental illness might be expected to cause abnormal tubulin oscillations between polymerization-depolymerization cycles resulting in different arrays mixtures (classified by Craddock as types I–IV behaviors). Depression could result from too little type IV behavior which is associated with information processing systems. Billions of quantum computations in MTs would be responsible for moving millions of proteins over nanometer distances, with the most salient among the collective effects affecting neural activity on millisecond time scales. Woolf concluded that: “....classical and quantum information processing in brain MTs could be impaired in mental illness, to the extent that such information processing modes are validated by experimental support”.

The $G_{\text{sa}}$ Protein

Regulate actin cytoskeletal remodeling in cells

Interact with Tubulin

Serotonin receptor
Lipid rafts are specialized structures on the plasma membrane that have an altered lipid composition as well as links to the cytoskeleton. S-Palmitoylation is the covalent attachment of fatty acids, such as palmitic acid, to cysteine residues of membrane proteins including $G_{\alpha s}$.

Donati RJ, Dwivedi Y, Roberts RC, Conley RR, Pandey GN, Rasenick MM. Postmortem brain tissue of depressed suicides reveals increased $G_s$ localization in lipid raft domains where it is less likely to activate adenylyl cyclase. *J Neurosci* 2008; 28: 3042-50.
Depending on the system, cytoskeletal elements present in rafts would be expected to facilitate or inhibit neurotransmitter signalling by contributing to the raft organization of the signalling molecules.

Lipid rafts preferentially accumulate $G_{s\alpha}$ during depression.
The $G_{\alpha}$ – Tubulin Interaction

A molecular circuit, starting from the membrane viscosity can modulates the molecular cascade which involves $G_{\alpha}$ protein and Tubulin

$G_{\alpha}$ protein interact with Tubulin promoting its GTPase activity and increasing the dynamic behavior of MTs

CONCLUSION

It seems to be consistent the hypothesis that Schrödinger proteins interactoma and in particular the cytoskeleton nanowire network is the best biological interface for potential expression of consciousness, being typical and specific for each animal species and that consciousness is always a potential. It’s very fascinating to think that every animal possess a primary Schrödinger proteins complex (cytoskeleton) and even in the absence of circulating serotonin there is a potential of consciousness that is essential to the behavior of some life forms, while other species such as invertebrates, procariotes and even archea possess expertise in their own domain probably mediated by their own Schrödinger proteins interactoma.
A great leader should mix Science & Art, Public & Private, Politics & Religions and think that this is the Creativity of Life.

(Massimo Pregnolato)

Thanks