Consciousness, the Brain, and Spacetime Geometry

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David Salvetti
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Stuart Hameroff

- Anesthesiologist and professor at the University of Arizona (Department of Anesthesiology and Psychology)
- He is now the director of the Center for Consciousness Studies at the University of Arizona
What is consciousness?

• A century ago it was showed the brain to be a large group of individual neuronal cells that communicate by synapses

• The brain is commonly viewed as a hierarchical system, comprising layers of organization with bottom-up, as well as top-down feedback

• Neuronal interactions are seen as the bottom level, with consciousness emerging as a novel property at an upper level of the hierarchy, for example, coherent 40-Hz oscillations

• Consciousness “emerges” as a novel property of complex interactions among relatively simple neurons
Beyond conventional approaches

• Conventional approaches:
  – Emergent property of complex interactions among individual neurons

• These approaches fail to address enigmatic features of consciousness:
  1. Why other emergent phenomena are not conscious
  2. What critical threshold or level of complexity produces consciousness

=> Need to examine the phenomenon of consciousness from a different point of view
Non-computability in conscious thought processes

• In 1931, Kurt Gödel proved that any effectively generated theory capable of expressing elementary arithmetic cannot be both consistent and complete.

• In 1989 Penrose argued that while a formal proof system cannot prove its own incompleteness, Gödel-type results are provable by human mathematicians. The brain could perform functions that no computer could perform, known as "non-computable" functions.

• If correct, the Penrose’s argument creates a need to understand the physical basis of non-computational behavior in the brain. Most physical laws are computable, and therefore described by algorithms. However, the nature of quantum collapse is not known making it a candidate for a non-computable process.
**Objective Reduction: “OR”**

- Existing ideas on wave function collapse might only apply to situations where the quanta are the subject of measurement.
- If quanta remain isolated, these quanta may be subject to a different form of wave function collapse.
- **Quantum gravity approach**: each quantum superposition has its own piece of spacetime curvature.
- Limit to the size of this spacetime blister: $E=\hbar/T$.
- Beyond this value the system becomes unstable, and collapses in a “non-computable” way so as to choose just one of the possible locations for the particle: **Objective Reduction (OR)**.
- Where and how could such quantum processes be implemented in the brain?
- A particular quantum computation may occur in the brain.
Microtubules

• Only large collections of particles acting coherently in a single macroscopic quantum state could sustain isolation and support coherent superposition in a time frame brief enough to be relevant to our consciousness.

• Hameroff and Penrose nominated a quantum computational OR process with the requisite characteristics to be occurring in cytoskeletal microtubules.

**Microtubules (MTs)**

1) hollow cylindrical polymers of individual proteins known as tubulin;
2) interconnected by linking proteins (MAPs) to other MTs to form cytoskeleton lattice network;
3) help maintain and regulate synaptic strengths responsible for learning and cognitive functions;
4) collective Frohlich excitations of tubulin subunits support computation and information processing.
The Orch-OR model (I)

1) Quantum-superposed states develop in MT subunit proteins, remain coherent, and recruit more superposed tubulins until a mass-time-energy threshold is reached

2) Self-collapse (OR) abruptly occurs

3) MAPs can “tune” the quantum oscillations of the coherent superposed states; the OR is thus self-organized: “Orch OR”

4) Each Orch OR event selects MT subunit states which regulate synaptic/neural functions using classical signaling

Pre-reduction phase => pre-conscious processes
Istantaneous OR => discrete conscious event
The Orch-OR model (II)

Orch OR events may be of variable intensity and duration pre-conscious processing. From $E = \hbar / T$ for a pre-conscious processing time of $T = 25$ msec, $E$ is roughly the superposition/separation of $2 \times 10^{10}$ tubulins. Thus, millisecond events would involve roughly one billions neuron, 1% of brain capability.
Conclusions

• Consciousness is a sequence of discrete quantum events at the fundamental level of spacetime geometry
• Such events are connected to the brain via quantum processes in microtubules
• Orch OR model can explain the enigmatic features of consciousness
• **BUT** there are some problems in the model:
  – Brain environment is “warm, wet and noisy”;
  – Max Tegmark (Phys. Rev. E, 2000) calculated decoherence times of $10^{-13}$ sec by ions in the brain’s milieu;
  – Some predictions of the Orch OR model have been falsified
  – OR theory has to be tested by experiments
  – The Penrose’s argument about the implications of Gödel's incompleteness theorem for computational theories of human intelligence has been widely criticized

There is much work to be done!
References

1. “Consciousness, the Brain, And Spacetime Geometry”, *The Annals of the New York Academy of Sciences* special issue Cajal and consciousness

2. You can find other interesting publications on the website:

   http://www.quantum-mind.org/publications.html