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Quantum theory of consciousness

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ABSTRACT

The nature of consciousness, its occurrence in the brain and its ultimate place in the universe are unknown. Probably the most interesting attempt to create a quantum theory of consciousness is that of Roger Penrose (recipient of the 2020 Nobel Prize for Physics) and an American anaesthesiologist Stuart Hameroff. They are both well known for their studies of consciousness and for the thesis that consciousness originates from quantum states in neural microtubules. The starting point for this article are the authors' considerations contained in their joint work (Penrose & Hameroff, 2017). This paper also proposes an initial attempt to combine this theory with quantum logic.

KEYWORDS

consciousness; quantum theory; microtubules; quantum logic

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The Penrose-Hameroff approach is a fascinating attempt to create a quantum theory of consciousness. This concept was initially presented in *The emperor's new mind* (Penrose, 1989) and later in *Shadows of the mind* (Penrose, 1994). Penrose-Hameroff refer to this theory as an orchestrated objective reduction (Orch OR). In the opinion of many scientists, the brain and consciousness resemble the operation of a computer. Consciousness is in some way a kind of complex computation among simple neurons which each receive and integrate synaptic inputs to a threshold for bit-like firing. Roger Penrose's theory has been associated with the concept of Stuart Hameroff where the main focus is on protein polymers called microtubules. They are also the main components of the cell's structural cytoskeleton.

As Garrett Birkhoff and John von Neumann observe:

> There is one concept which quantum theory shares alike with classical mechanics and classical electrodynamics. This is the concept of a mathematical "phase-space". According to this concept, any physical system S is at each instant hypothetically associated with a "point" in a fixed phase-space Σ; this point is supposed to represent mathematically the "state" of S, and the "state" of S is supposed to be ascertainable by "maximal" observations (Birkhoff & von Neumann, 1936: 824).

Such maximal pieces of information about physical systems can also be called pure states. Quantum theory, as opposed to classical mechanics, is essentially probabilistic. Pure states assign probability-values to quantum events. Within this theory, pieces of information are at the same time maximal and logically incomplete. This state of affairs not only distances us from the reality of classical mechanics but also from classical logic. Therefore, it seems natural to try to interpret the above theory within quantum logic.

This theory consists of three parts: The Gödel part, The gravity part, and The microtubule part. Penrose is the author of the idea of using the Gödel incompleteness theorem to explain the nature of the human intellect. It turns out that the tools used in classical physics are not sufficient. In other words, man and his consciousness cannot behave according to the kind of rules given in a classical mechanical model. However, according to Penrose, we also cannot use the concepts used in quantum physics because they are not known to cognitive scientists. There are, however, arguments that are more familiar to them — Gödel-type arguments.

The gravity part of the Penrose-Hameroff approach refers to quantum dynamics, specifically to the question of when sudden quantum jumps take place. A quantum jump is the abrupt transition of a quantum system (atom, molecule, atomic nucleus) from one quantum state to another, from one energy level to another. Translating von Neumann's theory into the language of ontology, we can say that these jumps take place when the neural correlates of conscious thoughts become sufficiently well formed. Microtubules are responsible for, among other things, the precise separation of chromosomes in cell division and the regulation of synapses within brain neurons. As Penrose and Hameroff write:

> The term "quantum" refers to a discrete element of energy in a system, such as the energy E of a particle, or of some other subsystem, this energy being related to a fundamental frequency ν of its oscillation, according to Max Planck's famous formula (where h is Planck's constant): E = h ν (Penrose & Hameroff, 2017: 16).

As the authors claim, it exhibits the deep relationship between discrete energy levels and the oscillation frequencies that underlies the wave/particle duality inherent in quantum phenomena. These sub microscopic quantum entities differ from those governing our everyday classical world. To be precise, different laws govern these entities. Quantum particles can exist in two or more states or locations simultaneously and superpositions like that do not occur in the consciously perceived world where there are material objects and particles, classical things in specific locations and states. A separate quantum property is a:

> "non-local entanglement," in which separated components of a system become unified, the entire collection of components being governed by one common quantum wavefunction. The parts remain somehow connected, even when spatially separated by significant distances (Penrose & Hameroff, 2017: 17).

However, this raises another difficulty related to the measurement problem: Why are we unable to directly perceive quantum superpositions? The authors present the issue this way:

> To explain it more precisely, the measurement problem is the conflict between the two fundamental procedures of quantum mechanics. One of these procedures, referred to as unitary evolution, denoted here by U, is the continuous deterministic evolution of the quantum state (i.e. of the wavefunction of the entire system) according to the fundamental Schrödinger equation. The other is the procedure that is adopted whenever a measurement of the system — or observation — is deemed to have taken place, where the quantum state is discontinuously and probabilistically replaced by another quantum state (referred to, technically, as an eigenstate of a mathematical operator that is taken to describe the measurement) (Penrose & Hameroff, 2017: 18).

The authors propose to denote this discontinuous jumping of the state by the letter R. The measurement problem or measurement paradox arises when we treat the measuring apparatus itself as a quantum entity. The apparatus, because it is constructed out of the same type of quantum ingredients, the system under observation, it ought also to be subject to the same quantum laws described in terms of the continuous and deterministic U.

Physicists, including Niels Bohr and Werner Heisenberg, have tried in many ways to solve this paradox, but their solutions seem unsatisfactory. For instance, the Copenhagen interpretation puts consciousness beyond science. On the other hand, in the multiple worlds hypothesis of Everett we have an infinite multitude of coexisting parallel worlds. In this interpretation the stream of consciousness of the observer is included and so the observer's consciousness must also somehow split into every world, at least in those worlds for which the observer remains alive and conscious.

According to the authors, a solution to the problem can be found in orchestrated objective reduction (Orch OR). OR is an extension of current quantum mechanics, taking the bridge between quantum and classical level physics as a quantum-gravitational phenomenon. This bridge is the result of different approaches, for instance environmental decoherence, observation by a conscious observer, or the choice between alternative worlds etc. The goal is to clarify how fundamentally quantum-superposed ingredients affect the classical world of one actual alternative. An important issue is also the fact that OR scheme involves an atypical different interpretation of the term quantum gravity. In contrast to current ideas about quantum gravity that refer to some sort of physical scheme that is to be formulated within the bounds of standard quantum field theory, we have a different approach:

> 'OR' here refers to the alternative viewpoint that standard quantum (field) theory is not the final answer, and that the reduction R of the quantum state ("collapse of the wavefunction") that is adopted in standard quantum mechanics is an actual physical phenomenon which is not part of the conventional unitary formalism U of quantum theory (or quantum field theory) and does not arise as some kind of convenience or effective consequence of environmental decoherence, etc., as the conventional U formalism would seem to demand (Penrose & Hameroff, 2017: 20).

So, in OR we have an attempt to combine the principles of Albert Einstein's general relativity with those of the conventional unitary quantum formalism U. According to this theory, any quantum measurement is a real objective physical phenomenon and is taken to result from the mass displacement between the alternatives which is sufficient, in gravitational terms, for the superposition to become unstable. Superposition can therefore be represented this way:

> In the DP (Diósi–Penrose) scheme for OR, the superposition reduces to one of the alternatives in a time scale τ that can be estimated (for a superposition of two states each of which can be taken to be stationary on its own) according to the formula

$$\tau \approx \hbar/EG.$$

Here ħ (=h/2π) is Dirac's form of Planck's constant h and EG is the gravitational self-energy of the difference between the two mass distributions of the superposition (Penrose & Hameroff, 2017: 21).

In this interpretation reduction acts according to non-computational new physics. Consciousness is then connected with the (gravitational) OR process. Consciousness emerges as a part of some highly organized structure, so that such occurrences of OR occur in an extremely orchestrated form. Only in this case does a conscious process take place. However, in the case of any individual occurrence of OR we are dealing with an element of proto-consciousness.

Therefore, the phenomenon of consciousness is explained on the basis of quantum mechanics in the Everett interpretation. Any state of the quantum world is objectively a superposition of its classical counterparts, or classical projections. As Michael B. Mensky explains:

They are "classically incompatible", but are considered to be equally real, or coexisting. We shall call them alternative classical realities or simply classical alternatives. According to Everett's interpretation, quantum reality is presented by the whole set of alternative classical realities (alternatives). However, these alternatives are perceived by humans separately, independently from each other, resulting in the subjective illusion that only a single classical alternative exists. The ability to separate the classical alternatives is the main feature of what is called consciousness. According to the author's Extended Everett's Concept (EEC), this feature is taken to be a definition of consciousness (more precisely, consciousness as such, not as the complex of processes in the conscious state of mind). It immediately follows from this definition that turning the consciousness off (in sleeping, trance or meditation) allows one to acquire access to all alternatives. The resulting information gives rise to unexpected insights including scientific insights (Mensky, 2017: 45).

In the many-worlds approach of quantum mechanics, the coexistence of parallel classical worlds is implied. The states of quantum systems are vectors. So, in this interpretation a state of any quantum system may be a sum or superposition of other states of the same system and, what is important, all the states which are counterparts of this sum are equally real. Such classically incompatible states of our world that coexist as a sort of parallel worlds are called Everett worlds.

Therefore, it seems obvious that we can use quantum logic (QL) to interpret the above theory. The official birth of QL occurred in the 1936 seminal paper *The logic of quantum mechanics* (Birkhoff & von Neumann, 1936). Birkhoff and von Neumann made the proposal of a non-classical logic for the theory. They noted that projections on a Hilbert space can be viewed as propositions about physical observables. The most notable difference between quantum logic and classical logic is the failure of the propositional distributive law:

$$x \wedge (y \vee z) = (x \wedge y) \vee (x \wedge z).$$

This is due to the fact that propositional variables can be substituted by the particles that have momentum in the different interval.

The propositional structure that gave rise to QL was the orthomodular lattice <L(H), $\vee$, $\wedge$, $^{\perp}$, 1, 0>. Quantum logic can be axiomatized as the theory of propositions modulo the following identities:

$$x = \neg\neg x$$

$\vee$ is commutative and associative.

There is a maximal element $\top$, and $\top = y \vee \neg y$ for any y.

$$x \vee \neg(\neg x \vee y) = y.$$

Orthomodular lattices can additionally satisfy the orthomodular law:

$$\text{If } \top = \neg(\neg x \vee \neg y) \vee \neg(x \vee y) \text{ then } x = y.$$

It is worth mentioning at this point that the meaning of the logical connectives is different from classical logic. For example, a quantum disjunction may be true even if neither of its members is true. This is what happens when we meet a state such as that of a spin 1/2 system which is in a linear combination of states up and down. Both propositions, the state is up and the state is down, may have no definite truth value (the excluded middle principle is violated), but the disjunction, the state is up or the state is down, is a tautology.

As Maria Luisa Dalla Chiara et al. note (Dalla Chiara, Giuntini, & Greechie, 2004: 4–6), there is an interesting correlation between the investigations about fuzzy and quantum structures, in the framework of the so-called unsharp approach to quantum theory. As we know, bivalence implies determinism. Jan Łukasiewicz was the first to notice this. One of Łukasiewicz's arguments against classical bivalent semantics was the fact that determinism contradicts our basic intuition about necessity and possibility (Łukasiewicz, 1970). However, there is no doubt that quantum theory is necessarily indeterministic. Another aspect of the ambiguity of the quantum world is that quantum theory is essentially probabilistic. So, in quantum mechanics pure states turn out to represent pieces of information that are at the same time maximal and logically incomplete. This kind of ambiguity is connected with the possibly fuzzy character of the physical events within the quantum world. A simple example shows the difference between the two levels of fuzziness. The following two sentences apparently have no definite truth-value:

I) Hamlet is 1.70 meters tall;

II) Brutus is an honourable man.

As Dalla Chiara et al. explain:

> The semantic uncertainty involved in the first example seems to depend on the logical incompleteness of the individual concept associated to the name "Hamlet." In other words, the property "being 1.70 meters tall" is a sharp property. However, our concept of Hamlet is not able to decide whether such a property is satisfied or not. Unlike real persons, literary characters have a number of indeterminate properties. On the contrary, the semantic uncertainty involved in the second example, is mainly caused by the ambiguity of the concept "honourable" (Dalla Chiara, Giuntini, & Greechie, 2004: 7).

In the first sentence we have the first level of fuzziness or, to put it another way, a sharp interpretation that corresponds to pure states of quantum objects. However, in the second case there is an unsharp interpretation of quantum world.

As has been noted, this is what distinguishes quantum logic and classical logic is the failure of the propositional distributive law. Because both interpretations, sharp and unsharp, are nondistributive, they are strongly non-Boolean. From this reason they are represented by orthomodular posets and orthomodular lattices. Thanks to this interpretation, distributivity is weakened and strengthened orthomodularity.

Another important issue is the semantic interpretation of logic. Generally, we distinguish two semantic approaches: an algebraic semantics and a possible-world semantics or Kripkean semantics. In the algebraic approach we have an interpretation of language in which we assign an abstract meaning to a sentence that corresponds to an element of a given abstract structure, whereas in Kripkean semantics we have an interpretation of language in which we assign a set of the possible worlds or situations to a sentence where it holds. As Dalla Chiara et al. show (Dalla Chiara, Giuntini, & Greechie, 2004) sharp and unsharp quantum logics can be characterized by different forms of algebraic and Kripkean semantics. This problem will be the subject of further studies.

To sum up, Penrose and Hameroff believe that the human brain is a biological computer and human consciousness is a program operated by the quantum computer located inside. Both scientists argue that what humans perceive as consciousness is, in fact, the result of quantum gravity effects located within the microtubules. What may be most surprising about this theory, however, is this that microtubules during clinical death lose their quantum state but retain the information contained within them. In other words, the quantum information inside the microtubules is not destroyed and can be distributed and dissipated in the universe at large. A separate issue that requires further research is the interpretation of this theory within quantum logic.

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