THE BOHM-PENROSE-HAMEROFF MODEL FOR CONSCIOUSNESS AND FREE WILL

Theoretical foundations and empirical evidences

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ABSTRACT: The Bohm-Penrose-Hameroff (BPH) model offers a heuristic explanation of consciousness from the complementary works of Bohm and Penrose-Hameroff. Physically, in the microscopic regime, the quantum neurology of Penrose and the quantum potential of Bohm play a unified role in the BPH model. Both, Bohm and Penrose look for an answer to the emergence of the classical regime from the quantum background of reality. In the biological level, Bohm's macroneurons and Penrose's microtubules work together as biophysical crucial elements to understand the consciousness phenomenon. The mind as an unconscious neural system to control the body in the environment, the arising of the conscious subject with self-perception in the whole reality, and the subjective sensation of free-will in the law-ruled world, are some traditional philosophical problems that could be partially illuminated by the new biophysics of the BPH model.

KEY WORDS: mind, consciousness, determinism, emergentism, holism, microtubules, free-will.

Consciousness is a mystery. It is a well-stated phenomenon studied by science, but it is also a problem. We do not know how consciousness arises from matter. Many evidences show that consciousness is a material phenomenon, since it correlates with physical activity. Matter makes consciousness possible, although we have not yet a model to explain the psychical emergence from matter. Psychology describes conscious perceptions, self-perception, individuality, emotions, cognitive structures, time and space. Dream, drugs, pain are some examples of altered consciousness states. Nevertheless psychology is not able to explain neither consciousness nor free-will. And neurology can not understand matter good enough to describe its own evolution from life to conscious sensations and then to the emergence of consciousness.

Physics is the paradigmatic science of matter. Actually, it is well established that every empirical manifestation of consciousness is originated in matter. Consciousness is matched to material bodies, which need very fine tuned neurological and biophysical conditions. Nevertheless, physical sciences do not explain consciousness. Traditionally, consciousness has been studied rationally by philosophy. Philosophers have done a good work looking for the metaphysical reasons of consciousness, but nowadays they cannot continue without taking into account the new scientific discoveries. Physicists have only got involved in the pure physical phenomena and they have almost not even dared to explain consciousness.

In the last hundred years, the philosophical idea of matter has been regulated by the technological and scientific results. Scientific models allow us to control

the physical activity of matter and offer very new concepts about its physical nature. But all the reality cannot be understood from the reductionism of particle physics. Physics and philosophy must approach together to the study of the physical nature of matter. In this line, we present a theoretical model to explain the emergence of consciousness from the physical activity of matter. We integrate the historical developments of the new physics proposed by Roger Penrose and the metaphysical concepts defined by David Bohm. We present a brief historical overview in the recent research on consciousness around the works of Bohm, Penrose and Hameroff. We also show how the Penrose-Hameroff hypothesis and Bohm metaphysics can be successfully combined in a new model, and finally we will outline some of the most relevant experimental results that support the quantum model for consciousness. Finally, we also show relevant empirical evidences that support this new proposal and we finish this work remarking some conclusions about free-will.

1. A BIT OF HISTORY: SOME MODERN MILESTONES IN THE SCIENCE OF CONSCIOUSNESS

Going back fifty years we find the birth of AI and its original motto *Machines can contain minds just as human bodies do*. In those times, David Bohm published a book about determinism in physical sciences [1]. If all the physical laws are truly deterministic, free-will would be only a delusion, and there wouldn't be any physical difference between robots and human bodies. Fifteen years later, Hameroff got interested in the study of microtubules as information processors. Maybe there was already some intuition about some non-computational biophysical process in the brain.

The first crisis of AI came in 1975 when engineers became conscious of the vast amount of information needed to emulate commonsense and reasoning. Little time later, Bohm published his first dissertation on consciousness as a phenomenon of the universal material dynamic [2]. Some kind of spiritualism entered in the scientific community with the risky speculations written in *Wholeness and the implicate order*. The counterattack of the hard side of AI was not late in coming. In 1982 AI was reborn due to the economic contributions of the Japanese government. Since then AI seeks to explain the mind-body problem using only computable logical rules.

In the best years for AI, Hameroff published his book *Ultimate computer* [3] and Penrose strikes back against computationalists with his best-seller *The Emperor's New Mind* [4], whose title was inspired in a tale of Anderssen, which in turn is based

[1] BOHM, D. (1957), *Causality and Chance in Modern Physics*, London Routledge & Kegan Paul.

[2] BOHM, D. (1980), *Wholeness and the Implicate Order*, London, Routledge.

[3] HAMEROFF, S. R. (1987), *Ultimate Computing. Biomolecular Consciousness and NanoTechnology*, Tucson, Elsevier.

[4] PENROSE, R. (1989), *The Emperor's New Mind: Concerning Computers, Minds and The Laws of Physics*, Oxford, University Press.

on a story from the Spanish medieval writer D. Juan Manuel. The moral of the story is that *only because the whole world believes that something is true, it does not mean that it is*. AI was too strong in the eighties, and many people believe that the mind is just a complex algorithm. Penrose used Gödel's incompleteness theorems [5] to refute them.

Nineties is full of alternative models for consciousness. Bohm developed his formalism of quantum potentials operating in the brain. Penrose proposed his physical model in *The Shadows of the Mind* [6], and finally in 1996 Penrore and Hameroff published a paper [7] on their Orch OR model that quickly had a major impact on the scientific community, and many scientists opposed. For example, Tegmark published some arguments against the Penrose-Hameroff model based on quantum decoherence timescales [8]. Some counter-arguments were given by Hameroff and Tuszynski [9]. Since then some few empirical evidences support the quantum functioning of the brain.

2. Phenomenology of consciousness

Often someone usually ask what is the definition of consciousness when we begin to explain the phenomenon. That's a tricky question. We don't really know what consciousness is in the same way that we don't know the nature of matter, although we can measure its physical properties. The very essence of matter keeps hidden. Actually, I think we cannot even give an operational definition of consciousness. For the present time we can only talk about the phenomenological properties of consciousness.

We are putting together some phenomenological features of consciousness from the point of view of different specialised authors. From psychology, J. Gibson [10] focuses on the perception of the psychic subject, who feels the energetic pressure of the environment that directly impacts on his cognitive system. From neurology, G. Edelman [11] remarks the inner world of the subject

[5] First: «Any effectively generated theory capable of expressing elementary arithmetic cannot be both *consistent* and *complete*». In particular, for any consistent, effectively generated formal *theory* that proves certain basic arithmetic truths, there is an arithmetical statement that is true, but not provable in the theory. Second: «For any formal effectively generated theory T including basic arithmetical truths and also certain truths about formal provability, T includes a statement of its own consistency if and only if T is inconsistent».

[6] Penrose, R. (1994), *Shadows of the Mind: A Search for the Missing Science of Consciousness*, Oxford, University Press.

[7] Hameroff, S. R., and Penrose, R. (1996), «Orchestrated Reduction of Quantum Coherence in Brain Microtubules: A Model for Consciousness», in S. R. Hameroff, A. W. Kasniak and A. C. Scott (eds.), *Toward a Science of Consciousness I*, 507-542, Massachusetts, MIT Press.

[8] Tegmark, M. (2000), «The importance of quantum decoherence in brain processes», *Phys. Rev. E.*, 61, 4194-4206.

[9] Hagan, S.; Hameroff, S. R., and Tuszynski, J. A. (2002), «Quantum computation in brain microtubules: Decoherence and biological feasibility», *Phys. Rev. E.*, 65, 61901-61911.

[10] Gibson, J. (1950), *The perception of visual world*, Boston, Houghton Mifflin.

[11] Edelman, G., y Tononi, G. (2002), *El universo de la conciencia*, Barcelona, Crítica.

that allows him to feel its own individuality as an integrated part of the whole. From philosophy, P. Heelan [12] insists in the stability of the visual perception. Fantasies are dynamic an easily modifiable whereas true perceptions are stable.

Once we have exposed the structural aspects of consciousness we continue with its functional aspects. First, the conscious subject perceives himself as a single organic whole. The body is felt nowhere. Self-perception is the holistic feeling that make possible to distinguish the self from the other. Second, good levels of self-perception carry free actions. With self-perception the conscious subject is able to drive his body properly in the environment for guarantying his own survival. Third, higher orders of conscious states integrate cognitive processes. The conscious subject becomes a cognitive subject that can develop a conceptual frame of meaning for reality.

From a phenomenological point of view we can define consciousness as *a felt mental state of matter*, because conscious beings can feel the mind. *It is a felt mental state of matter with personal knowledge of the own perceived existence and of the sensorial existence of the environment*. When the mind becomes conscious it is able to distinguish the individual self from the environment. *Every conscious state cannot be truly communicated.* Only the one who feels consciousness is aware of his experience and his own subjectivity. *Conscious states are always recounted to contents.* That is, consciousness in the temporal superposition of classical conscious states referred to something or someone. *Conscious states are globally perceived* as a whole unity *to manage life creatively.* Conscious beings can anticipate their actions, evaluate the consequences, and decide to execute or cancel plans [13].

3. A PHYSICAL MODEL FOR CONSCIOUSNESS

The origin of the universe is also a mystery. Penrose [14] understands the Big Bang as a special geometry defined by very special mathematical conditions. He links gravity with the Second Law of Thermodynamics to explain the temporal asymmetry of time, and relates temporal asymmetry and gravity to the irreversible quantum-classical transition in the measurement process.

Penrose distinguishes three physical problems related to consciousness. He hopes a clearer understanding of the mind nature once they were resolving them resolved. *i) The problem of mind.* Physics explains the macroscopic and microscopic worlds, but not mind phenomenon that appears between the large and the small. *ii) The problem of time.* The actual physical theory of time, Relativity, does not

[12] HEELAN, P. A. (1988), *Space-perception and the philosophy of science*, Berkeley, University of California.

[13] DAMASIO, A. (2010), *Y el cerebro creó al hombre. ¿Cómo pudo el cerebro generar emociones, sentimientos, ideas y el yo?,* Barcelona, Destino.

[14] PENROSE, R. (1989), *La nueva mente del emperador*, Madrid, Mondadori; ID. (1994), *Las sombras de la mente. Hacia una comprensión científica de la conciencia*, Barcelona, Crítica; ID., *Lo grande, lo pequeño y la mente humana,* Madrid, Malcolm Longair.

explain how time is psychologically felt flowing from the past to the uncertain future by every conscious subject. *iii) The problem of the quantum-classical transition.* No actual theory can unify gravity with the other three quantum interactions. There is still no quantum gravity theory and no well-established explanation about how the classical world can emerge form the quantum background. Analogy, quantum physics can neither explain how the mind can be conscious if the quantum world is unconscious.

3.1. *The biophysical basis of consciousness*

According to Penrose's physics, a new neurological quantum model of consciousness is possible. He uses the hollowed microtubules of the cells as entities that can support collective quantum states. Microtubules are quantum information processing systems. They are composed by many tubulins elements, which are the biological quantum bits to compute the physical information of the environment. If tubulins are enough well-isolated from the noisy hot brain then they could be able to work in quantum superposition until gravity destroys coherence just before the emergence of the classical conscious state. Tubulins elements codify information in binary code. Enough well-isolated from the noisy environment of the hot brain, tubulins work in the quantum regime until gravity destroys the coherence and induce the classical conscious state.

The transition from the quantum to the classical is tuned by microtubules associated proteins (MAPs) that orchestrate the gravitational objective reduction. The decoherence process is neither random – as it is in thermal chaotic systems – nor computable, because measurement is unpredictable. While tubulins are processing information in quantum superposition the mind is unconscious. Consciousness arises when MAPs orchestrate the objective reduction of quantum tubulins and the brain becomes classical.

Penrose drew up his model in collaboration with the American *anaesthetist* Stuart Hameroff [15]. According to the Penrose-Hameroff model, consciousness emerges from the quantum cooperation of microtubules in the brain. The isolated microtubules process the quantum information until the classical neuronal conscious state emerges from the unconscious mind. The quantum-classical transition is regulated by MAPs, which originate a gravitational objective reduction. Therefore, the brain operates most of the time in unconscious quantum functioning until the MAPs induce a process of decoherence to the classical conscious state.

[15] HAMEROFF, S. R. (2003), *Ultimate Computing. Biomolecular Consciousness and NanoTechnology*, Tucson, Personal edition; ID. (2004), «Quantum states in proteins and protein assemblies: The essence of life?», en D. ABBOTT, S. M. BEZRUKOV, A. DER and A. Sánchez (eds.), *Fluctuations and Noise in Biological, Biophysical, and Biomedical Systems II*. Proceedings of the SPIE, Volume 5467, pp. 27-41; ID. (2006), «Consciousness, Neurobiology and Quantum Mechanics: The Case for a Connection», en J. A. TUSZYNSKI (ed.), *The emerging physics of consciousness,* Berlin, Springer.

Let's remark a few questions that we need to know about the Penrose-hameroff hypothesis. If coherence is completely necessary to keep microtubules in quantum functioning. *What mechanisms are expected to occur in the brain for producing long-time coherence?* Once we assume long-time coherent quantum superposition in brain microtubules. *Why do not we enlarge quantum entanglement to the whole body?* Supposing Orch OR model truly produces the emergence of consciousness in the brain, *how could we explain the different experienced conscious states?*

3.2. *The physical ontology of consciousness*

Bohm [16] is a scientist interested in metaphysics, who predicted the developing of quantum neurology twenty years ago. Every physical phenomenon is ontologically originated in the implicate order, i.e. the ultimate metaphysical structure of the whole reality in permanent movement. Consciousness is explained as an intrinsic property of matter in the holemovement. It is to say that consciousness emerges from the dynamic of the whole mind-matter movement.

Every individual consciousness is a coherent unity in the holomovement. Consciousness cannot be separated from the whole movement of matter. The action of quantum potentials causes the emergence of the consciousness from the holemovement. Many neurons coupled by the quantum potential lose its individuality to form one macroneuron, which behaves as a whole entity in quantum evolution. Macroneurons process the physical information until the action of the quantum super potential induces the quantum-classical transition to the conscious state. They work as psychic resonators of the physical activity. Therefore the brain operates both in the quantum and the classical regime. And it is in the confluence between the classical and the quantum where consciousness arises.

Bohm proposed that there are classical and quantum potentials. Classical potentials produced classical forces and quantum potentials put matter in quantum functioning. The physical world is ontologically based on a quantum reality named the implicate order. The same quantum potential that dominates the implicate order is able to make individual neurons behave as a collective system of quantum macroneurons, which process the physical information of the environment, until the action of the quantum super potential induces the transition to the classical state.

The quantum super potential works like a system of active information that tells matter how to move and allow complexity to emerge from the quantum background. Active information operates on the brain as it does in the implicate order, and put the brain in quantum functioning. In consequent neurons loose its individuality and behave like one unitary macroneuron. That is to say the brain behaves holistically.

Here we have a few answers that Bohm would give us on the Penrose-Hameroff hypothesis. *What mechanisms are expected to occur in the brain for*

[16] Bohm, D. (1980), *La totalidad y el orden implicado*, Barcelona, Kairós.

producing long-time coherence? Quantum potentials match the brain to the quantum dynamics of the implicate order. The brain uses quantum computation to decode the information of the explicate order. *Why don't we enlarge quantum entanglement to the whole body?* The quantum potential put the brain in quantum functioning. The quantum super-potential cut off the quantum coherence in such a way that the brain operates in multiple independent modes. *How could we explain the different experienced conscious states?* EPR-phenomena could be used to entangle the brain and reality. Active information could tell MAPs how to be placed on microtubules. The physical fields of the environment operate at a distance on the microtubules to orchestrate a concrete mental hologram.

3.3. *The Bohm-Penrose-Hameroff model for consciousness*

Given the main phenomenological features of consciousness, as well as the internal problems of physics related to the consciousness phenomenon we proceed to present a new model for consciousness using Bohm's quantum potentials and Penrose-Hameroff physical processes in microtubules, namely the Bohm-Penrose-Hameroff (BPH) model. The BPH model is a heuristic interpretation of the mind, which brings us closer to understand the physical nature of consciousness.

Three pillars founded the BPH model. *i) The ontological unity of mind and matter.* Bohm based his theory on one energetic background of mind-matter reality, and Penrose explains the mind from physical principles. *ii) Entropy and evolution.* Both the metaphysical holemovement and the emergent physical evolution of consciousness are explanatory proposals described by the Second Law. *iii) Quantum consciousness.* Information is processed by the brain via quantum as well as the classical channels. Consciousness phenomenon appears in the border of coherent quantum states and macroscopic biophysical structures.

Basically the BPH model states that gravity causes the origin of complex structures and the consequent increase of entropy. Microtubule's tubulins are designed to increase the entropy in agreement with the Second Law. Tubulins process quantum information in the brain while the quantum potential makes the brain behaves as a collection of macroneurons. Quantum potential keep the brain on quantum functioning until the quantum super potential induces the gravitational transition to the classical conscious state by the gravitational perturbation of the MAPs. Then quantum coherence is lost, classical reduction is completed and a new conscious states is emerged.

The quantum potential entangles many tubulins in whole coherent systems that process the information of the environment. The mind saturates when the quantum potential energy is more or less constant. The system would then maintain its internal coherence until the thermal chaos starts decoherence. The action of the super quantum potential energy prevents the thermal reduction and induces an orchestrated gravitational evolution regulated by MAPs.

The quantum super potential cuts short the coherent processing of the brain and gravity unleashes the decoherence process that ends in a new conscious state.

The brain receives directly the physical information of the environment and processes it in the microtubules of different cells. MAPs modify their position by the action of quantum potentials according to the energy of the environment. Microtubules run the information to look for the quantum waves compatible with the distribution of MAPs, which are located in the wave nodes. Out of all the patterns the one that reaches the highest degree of coherence would be resolved to produces the conscious state.

4. Where do life, evolution and complexity emerge from matter?

If we agree with Hameroff hypothesis and Penrose's arguments on the implications of Gödel Theorems, we shouldn't think that computable system could emulate consciousness. All the computable systems are deterministic and incompatible with the subjective sensation of free-will, because their main feature is predictability.

In this plot we represent all the computable systems inside this set, which is in included in a larger one where every deterministic system is included. Out of determinism we find indeterminism. But we must be cautious because the border line between deterministic and non-deterministic systems is not clearly defined. Some dynamical systems are chaotic and unpredictable at all. Somehow they resemble quantum systems in which we cannot completely predict the result of the measurement. Far away from the fuzzy frontier we find the purely non-deterministic random systems. For example, we could place quantum fluctuations there.

Consciousness appears in a fuzzy band between the border lines of deterministic and non-deterministic systems. In the graphs shown in the figure below we represent some of the main properties of living beings: regularity, information and adaptability. In each figure the region suitable for the emergence of consciousness is shaded. On your left we represent regularity in different regions of our plot. It is difficult to find order within randomness, so that complexity couldn't emerge. On the other end, regularity increases when we approach to computability, but when the order is so predictable the system cannot store information.

On your right we plot the ability of a system to store information. Basically information has to do with a reduction or selection of alternatives. A computable system is too predictable because it always do the same. Information of the regularity in a computable system can be saved in a short chain of bits. On the other end, pure randomness has no information because is not regular at al. Order fluctuations cannot be amplified to the macroscopic regime. When we talk about useful information we have to look for in the shaded region between randomness and computability.

Learning and evolution need to distinguish regularity from randomness. Complex adaptive systems get environmental information identifying regularities and choosing between the alternatives. Life can only be originated under very suitable physical conditions. As we can see in the central figure, complex adaptive systems emerge between determinism and indeterminism, where regularity and probability coexist [17].

Please notice that although the peak of the function is centered in determinism the long tail of the graph goes into the indeterminism. That's important for evolution. Chance can lead to highly complex forms from the very simple. If evolution had provided a steady improvement of adaptation, complex systems would be rapidly trapped in determinism and classical stimulus-response behaviour. To avoid that, complex systems must experiment the indeterminism. Complex systems learn how to get regularity in a pseudorandom background. Life could be the result of amplified quantum events. In this sense, conscious systems could have use quantum amplifications for better adaptation to the environment.

In synthesis, the BPH model for consciousness is based in the next three pillars.

Gamma synchrony as the classical neural correlate of consciousness. Consciousness needs a strong communication between the inner brain and the cortex. Classical neural networks throughout the brain are the mind of the body. When the neural activity correlates the mind becomes conscious. The very existence of synchronized gamma indicates that a conscious experience is occurring. The lost of consciousness implies the lost of Gamma synchrony (30-90 Hz) in EEG. We can measure the correlation, because consciousness is ultimately classical.

Microtubules as biophysical resonators of quantum information. The brain uses quantum physics to process the environmental information. Quantum potentials put tubulins in quantum superposition. The brain operates as a quantum network system, until the action of the quantum super potential on microtubule proteins induces the orchestrated reduction to the classical conscious state.

Gap junctions as biological Josephson cell-cell quantum couplings. Gamma synchrony involves gap junctions. Gap junctions couple microtubules of different cells, and propagate quantum coherence through the neural network that behaves like macroneurons during the time of decoherence. Gap junctions or quantum synapses allow the whole brain to be in macroscopic quantum coherence.

[17] GELL-MANN, M. (1995), *The Quark and the Jaguar: Adventures in the Simple and the Complex,* London, Abacus.

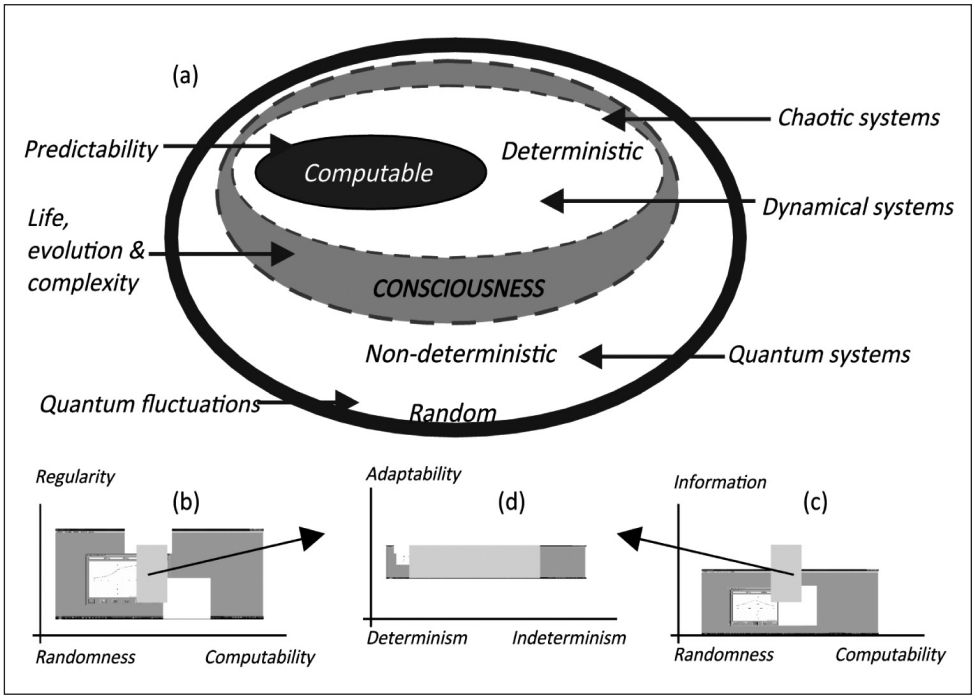

FIGURE: Living beings are complex adaptive systems. **(a)** *Where do life, evolution and complexity emerge from matter?* Within classical physics is difficult to find structures to explain the dynamics and evolution of conscious beings. Computable deterministic evolution is able to describe the algorithmic path of robotic system but it cannot reproduce the complex phenomenological behavior of animals. On the other hand, purely non-deterministic physics is too random to make possible the emergence of stationary and stable structures needed for life. Our hypothesis is to place life, evolution and complexity in the fuzzy bordering between deterministic and non-deterministic physical processes. A physical model form consciousness should include well-established regular structures from classical physical and highly-dynamical holistic properties form quantum physics. **(b)** *Regularity* is one of the fundamental features of complex living beings. It is hardly difficult to find regular structures in pure random systems as quantum fluctuations. On the opposite side, once regularity reaches the highest levels systems becomes so computable and predictable that there is no room for freedom. It is expected to place complex adaptive systems in the transient region (shaded region) between randomness and computability. **(c)** *Information* is everywhere is the physical world. Living beings uses information patterns to replicate themselves. As it is explained by physical information theory extremely random and computable systems have low levels of information. The ability to save and use richer levels of information is placed in the midway between (shaded region) randomness and computability. Finally **(d)** *Adaptability* is the main property of complex living beings. It is a magnitude that results from the combination of regularity and information. The peak in adaptability is achieved when regularity and information are optimized. That is when both magnitudes are in the middle of the respective shaded regions, i.e. between deterministic and non-deterministic systems. We notice that the shaded region is expanded because complex systems need to use non-deterministic hazardous behaviors to make adaptability possible. Life is risk. No risk, no better adapting possibilities.

5. Empirical evidences of the BPH model

5.1. *Macroscopic quantum phenomena. BEC-Mott transitions*

Many different quantum physical phenomena keep quantum coherence in the macroscopic world. Bose-Einstein condensates and superconductors are paradigmatic examples. Due to thermal noise, most of quantum macro-coherence phenomena jump rapidly to classical. But some technological devices keep on quantum coherence during long times and behaves as macroscopic quantum systems.

Optical condensates look especially interesting to explain consciousness because they are continuously swinging between quantum and classical states, i.e. they experiment BEC-Mott transitions [18]. Decoherence time of optical condensates come closer to the dynamic time of the system. It is expected that some quantum neurological processes could behave in a similar way in the brain. In this sense we would explain consciousness as an emergent phenomenon in the frontier between the quantum uncertainty and the classical concretion.

Quantum-classical oscillations are described by quantum potentials in the BPH model. The system is alternatively dominated by quantum and classical potentials. The quantum-classical transition would be regulated by the quantum super potential. In optical condensates wave-particles are confined in the minima of the optical net coupled by the quantum potential – suffering non-local interactions until the action of the quantum super-potential. In a similar way MAPs are confined in the nodes of the quantum waves in microtubules, which process the physical information until orchestrated MAPs provoke the quantum-classical transition and the consequent emergence of the concrete conscious state.

5.2. *Empirical evidences of quantum biophysical phenomena*

Despite of the controversial scientific discussion about quantum phenomena in living systems, there is growing evidence of quantum influences in genetic, protein's folding, photosynthesis and biological self-organization.

Wavelike energy transfer through quantum coherence in photosynthetic systems [19, 20]. Scientists have demonstrated that long-lived (>660 fs) quantum coherences play an important role in the dynamics of energy transfer in photosynthetic complexes – that is to say the energy transfer is described by wavelike coherent motion instead of incoherent hopping. In other words, the protein environment protects electronic coherences to enhance the energy transfer efficiency.

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[18] Köhl, M., and Esslinger, T. (2006), «Fermionic atoms in an optical lattice: a new synthetic material», *Europhysics News*, 37(2), 18.

[19] Engel, G. S., *et al.* (2007), «Evidence for wavelike energy transfer through quantum coherence in photosynthetic systems», *Nature*, 446, 782-786.

[20] Lee, H., *et al.* (2007), «Coherence Dynamics in Photosynthesis: Protein Protection of Excitonic Coherence», *Science*, 316, 1462-465.

New experiments [21] evidence long-time electronic quantum coherence in biological systems. The observed highly-efficient energetic quantum transfer in photosynthetic processes could explain how living beings are so well-designed to take advantage of the solar light. Coherence oscillations due to quantum states superposition emerge when the biological system is excited by a short-time light pulse [22]. The long-time coherence evolution of the quantum biophysical system is due to quantum cooperation of proteins, which regulate the system as a whole entity. Proteins use electronic quantum superposition to try every energetic transduction path until finding the one which minimizes the energy. In the same line new experiments have achieved to turn off the brain with light pulses [23]. Once the light stopped the conscious activity was immediately restored.

Biological quantum transport effects at room temperature [24]. The role of quantum coherence in promoting the efficiency of the initial stages of photosynthesis is an open and intriguing question. Scientists have performed an experiment on a bacterial reaction center that enabled direct visualization of the coherence dynamics. The data revealed long-lasting coherence between two electronic states that are formed by mixing excited states of molecules in bacteria. The results suggest that correlated protein environments preserve electronic coherence and allow the excitation to move coherently in space. This observation extends the paradigm of protein-protected coherences to nanoscale materials at ambient temperatures [25].

Nanotubes help cells pass messages. Animal cells connected by nanotubes can be electrically coupled through gap-junctions [26, 27]. Tunneling nanotubes are recently discovered conduits for a previously unrecognized form to connect cells over long distances. Scientists have demonstrated that tunneling nanotubes mediate the bidirectional spread of electrical signals over distances of 0,1mm. Similar results implicate gap junctions in long-distance communication, suggesting that electrical coupling may be a widespread characteristic of animal cells. Electrical signals are transmitted through gap junctions at a membrane interface between tunneling nanotubes.

Few years ago electrical synapses namely gap junctions, were considered promising quantum information channels between cells. Gap junctions are

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[21] Engel, G. (2007), «Evidence for wavelike energy transfer through quantum coherence in photosynthesis systems», *Nature*, 446, 782-786.

[22] Zhang, F. *et. al.* (2007), «Multimodla fast optical interrogation of neural circuitry», *Nature*, 446, 633-639.

[23] Chow, B. Y., *et al.* (2010), «High-performance genetically targetable optical neural silencing by light-driven proton pumps», *Nature,* 463, 98-102.

[24] Collini, E. *et al.* (2009), «Coherent Intrachain Energy Migration in a Conjugated Polymer at Room Temperature», *Science*, 323, 369.

[25] Chow, B. Y., *et al.* (2010), «High-performance genetically targetable optical neural silencing by light-driven proton pumps», *Nature*, 463, 98-102.

[26] Maxmen, A., *et al.* (2010), «Nanotubes help cells pass messages. Actin cables transmit electrical signals between cells», *Nature*, 10.1038.

[27] Wang, X., *et al.* (2010), «Animal cells connected by nanotubes can be electrically coupled through interposed gap-junction channels», *PNAS* 107, 17194.

proteins that form pores between two adjacent cells for comunication. Recently it has been discovered that electric signals can communicate distant cells across nanotubes made of proteins – ultra thin cables containing actin proteins like microtubules [28]. Nanotubes uses gap junctions for sending signals. Nanotube-mediated communication provides other modes of cell-cell interaction in the brain as it was expected by Penrose and Hameroff. As Michael Levin (Tufts University) says *we can no longer just think of cells touching each other to coordinate movement. Understanding what physiological information these nanotubes pass on will now be a key question for the future,*

Gap junctions resemble to superconducting Josephson junctions that preserve quantum coherence tunneling isolated barriers. Qubits can be coupled by Josephson junctions. I guess that biological gap junctions can support quantum properties as do Josephson junctions. In the future quantum junctions will play an important role to understand the origin of complexity and the emergence of consciousness.

6. Conclusion: free-will in the BPH model

Consciousness is more than awareness. Awareness is the ability to feel, perceive and be conscious of events. Without consciousness we would not be able to experience our own subjective reality. And without subjectivity there would be neither creativity nor free-will. Consciousness emerged from awareness when subjectivity was added to the mind process. Mind does not need subjectivity to exist. Mind is still working while dreaming. The unconscious mind regulates the heart-beating, respiration, corporal temperature… It is continuously adapting itself to the physical conditions of the environment. Why does consciousness emerge from the unconscious mind?

Mind dominates consciousness, because mind is the clue for adaptation. Consciousness is a subtle property of the mind. The conscious subject is not only well adapted to the medium but he has a subjective experience about the cognitive parameters of reality. Cognitive images emerge in the mind process as an innovation of the conscious subject. Subjectivity arises when the brain integrates its own mind. Therefore, the conscious subject reveals the unconscious mind. What we directly know about our minds is what each subject is conscious of. That is a corner stone in evolution. Consciousness is able to manage life creatively, and creativity is an adaptive ability to live autonomously. Consciousness is the origin of autonomy, freedom and free-will – freedom in absence of compulsion.

Free-will could be understood as a natural consequence of the intrinsic non-deterministic physics of the BPH model. Truly creativity states would correlate with high-coherence quantum states in the brain. While the running unconscious mind is mapping reality deterministically under neural networks, consciousness

[28] Maxmen, A. (2010), «Actin cables transmit electrical signals between cells», *Nature news*, 20 September 2010 |doi:10.1038/news.2010.482.

is ruled by non-deterministic orchestrated decoherence processes in microtubules. In this framework, creativity is in itself a non-computable mind process. Perhaps, free-will might be able to influence the decoherence process in highly quantum coherence brain states. Thus, free-will would appear when the conscious subject finds a purpose in innovation as an autonomous adaptive process, i.e., when the brain is dominated by non-deterministic quantum processes [29].

I would like to finish this article quoting one paragraph of the excellent last book of A. Damasio [30]. *To place the construction of the human mind in the history of the biology and of the culture, it opens the way that leads to reconciling the traditional humanism with the modern science, so that when the neuroscience explores the human experience in the unknown worlds of the cerebral physiology and the genetics, the human dignity not only remains, but it works out reaffirmed.*

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[29] BÉJAR, M. (2008), «Physics, Consciousness and Transcendence: The Physics of Roger Penrose and David Bohm as Regards a Scientific Explanation of the Human Mind Open to Reality», *Pensamiento,* 242, 715-739.

[30] DAMASIO, A. (2010), *Y el cerebro creó al hombre. ¿Cómo pudo el cerebro generar emociones, sentimientos, ideas y el yo?,* Barcelona, Destino.