The Quantum Mind/Classical Brain Problem

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Abstract

The quantum theory of mind allows a shift from the Mind/Brain metaphysical problem to the Quantum Mind/Classical Brain scientific problem: how could systematic and coherent quantum processes - assumed to be the physical support of our conscious experiences - occur in a macroscopic system as the brain? I discuss a solution based on a neurobiological model that attributes to quantum computation in intra-neuronal protein networks the role of directly supporting phenomenal experience. In this model, quantum coherence is *created* or *prepared* by classical mechanisms as recurrent neuronal networks, oscillatory synchrony and gated membrane channels, thus avoiding common theoretical constraints for the existence of quantum communication and computation (ultra-cold temperatures and quasi-isolation from the environment).

Key Words : Mind, Brain, Consciousness, Quantum Theory, Entanglement, Proteins

Summary

1) Introduction

An influential Cartesian thesis holds that the conscious mind is a substance deprived of spatial extension, while physical beings are extensive substances. One of the main criticisms of such theory, proposed by G. Ryle (1959), attacks Descartes' substantialism from the perspective of analytical philosophy of language, holding that the mind is a *process* and therefore its interpretation as *substance* (physical or not) would be a "categorical mistake". However Ryle, as well as the contemporary proponents of a dynamical conception of the mind (e.g., Port and van Gelder, 1995; Symons, 2001), agree in one aspect with Descartes: the mind *is not a spatial tridimensional system like the brain and the body*. While Descartes reached the conclusion that the mind is a *non-extensive* (and then non-physical) *substance* and Ryle didn't propose a full theory, Port and van Gelder (1995) chose a mathematical concept of dynamical systems ("systems with numerical states that evolve over time according to some rule") to propose that the mind could be modeled as *a dynamical process*.

However, when interpreted within the context of Newtonian physics, the "mind as a dynamical process" thesis seems to lead to a undesired consequence. If nature is composed exclusively of macroscopic tridimensional moving bodies and infinitesimal particles, the dynamical processes that can be described in this framework are merely movements of spatially extensive bodies/particles. As the mind belongs to a different category, such movements in principle cannot describe mental processes. The conclusion (see discussion in the next section) seems to be that the mind is not a *natural* entity. Shifting to a mathematical description of Newtonian processes won't help much, unless a Platonic view of mathematics is assumed, where *formal relations* between bodies/particles are interpreted to be *the true reality*, while the bodies/particles themselves are assumed to be mere *appearances*. In this case, an equally undesired dualistic approach reenters the scene.

Successful empirical approaches in neurobiology and cognitive sciences suggest that any system that shows signs of mentality is a complex system able of *recurrent* (nervous systems) or at least *recursive* processing (digital computers), and that the performance of such operations is supported by physical mechanisms. These mechanisms involve multiple spatio-temporal scales of activity, with different laws and empirical regularities. Classical physics is successful in the description of phenomena within a limited spatio-temporal range of activity, called the *macroscopic* level. Contemporary physics opened new possibilities for the conceptualization of physical mechanisms; they are believed to have other properties besides (or instead of) being composed of macroscopic bodies in tridimensional space. These possibilities include *being a quantum micro-process*, and/or being *a process in higher-dimensional spaces* (as those proposed in current string theories - see Greene, 1999, and Brian Flanagan's paper in this journal). Hypotheses based on the above possibilities are able to solve the mind/nature dualism, by conceiving the conscious mind as *a non-classical physical process*, possibly a quantum one (see original discussion in Lockwood, 1989).

In the philosophical (Fregean) meaning of the term "extension", if the conscious mind is a quantum process then it *has* an extension, corresponding to such processes and also to microstructures necessary for the brain (or other functionally/causally equivalent machine) to control such processes (in this paper I consider only biological systems as having mental activity, but the issue is clearly open to discussion). Therefore, a way to get out of Cartesian dualism is to assume that the conscious mind hasn't a *spatial* tridimensional extension but has a *logical naturalistic* extension: it denotes something that *exists* in nature. As this extension would be neither identical to the whole nature or to the whole brain, but limited to the domain of mechanisms able to generate large-scale quantum coherent processes, the denial of dualism doesn't lead to panpsychism or to a mind-brain identity view.

The epistemological paradigm assumed here is *nonreductive physicalism*, where nature is conceived as composed of different levels of organization, each one with its proper empirical regularities, that require different methodologies to be studied and don't seem to be amenable to explanatory reduction (see Pereira Jr., 2001). In this new approach, mental processes can be thought to be directly supported by the activity of a specific level of organization in the brain, e.g. quantum computation in networks of neuronal proteins (Rocha, Pereira Jr. and Coutinho, 2001).

However, although overcoming the main metaphysical obstacles to a naturalistic theory of the mind, quantum approaches to consciousness have to face another puzzle: to understand how large-scale quantum coherent processes, allowed by physical theory, could occur in the brain, or in any other kind of physical macroscopic machine. The traditional mind/brain metaphysical problem then becomes the "*quantum* mind/*classical* brain" scientific problem: *how could systematic and coherent quantum processes* - assumed to be the physical support of our conscious experiences - *occur in a macroscopic system as the brain*?

More precisely, the above question - as any theoretical question - has a *scientific-metaphysical* dimension, as a consequence of underdetermination of theory by data (see discussion in Pereira Jr. and French, 1989). The difference between a scientific-metaphysical and a *purely metaphysical* question is that the first provides new ways of experimentation and can be inductively answered by adequate experimental results, while the latter can be treated and answered only non-empirically (i.e., with speculative methods or at best with formal methods as in mathematical proof). The change of perspective on the mind-brain problem that I am proposing in this study aims to bring the question of the relation between mind and nature from the purely metaphysical area to the scientific-metaphysical domain, where discussion is supported by results of empirical research.

2) Why the Classical Brain Isn't Sufficient

Dynamical systems are composed of structural elements (here called "things") and temporal relations between such elements. The "mind as a process" thesis states that the mental universe is not composed by things, but by dynamical *relations* between things. The concept of mind seems to depend on the concept of "relation", but what is a relation?

In set theory, relations are simply ordered pairs (or triplets or n-uples) defined over the cartesian product of elements of sets. It is not necessary the existence of physical meaning for one element to be standing by another, i. e. in this context relations (as well as functions, a one-to-one kind of relation) are conceived as merely *formal*. It may happen that a person who is constructing a mathematical model decides to establish a formal relation between elements that don't have any physical connection; this decision is by no means derogatory for the model, except if the work is intended to describe a physical process.

In classical physics each thing is conceived as separated of other things, unless a causal force operates between them. This property of *separability* is expressed, in mathematical models, as a *statistical independence* between events. For instance, in Shannon and Weaver's mathematical theory of information - one that is perfectly compatible with classical physics - the events in the source are regarded as statistically independent unless there is some causal force operating between them. In this view, causation is considered to be "the cement of the universe" (Mackie, 1974). This assumption implies that in the classical world all possible relations are necessarily causal relations. As there are only two kinds of force that operate in the macroscopic domain, the electromagnetic and gravitational ones, in classical physics all possible relations are supported by one or both of these forces.

In this framework, if there is a relation that is not causal then it doesn't belong to the physical world. However, mental relations are not causal; for instance, the meaning of a word doesn't "cause" an emotional reaction. A variety of events in the brain which support mental relations are determined by electromagnetic and gravitational forces, but mental relations - as the one that holds between the recognition of a meaning and the corresponding emotional reaction - are not directly controlled by those forces. Another example is the fusion of mental images of two existing animals to form the image of a hybrid; this process is not causal, i.e., not directly ruled by electromagnetic/gravitational forces. Therefore *mental relations, in the context of classical physics, cannot be physical*.

Quantum theory and experimentation opened the possibility of physical relations that are not causal. These relations are known as "spin entanglement": the spin of protons or electrons can be correlated even at considerable spatial distances, without any causal interaction between them (if a causal interaction exists in this phenomenon, it should operate faster than the velocity of light and then contradicts relativity theory). One interpretation of the phenomenon is that quantum waves are *inseparable* (Herbert, 1991) unless a "collapse" or "decoherence process" (see discussion below) occurs. Therefore the quantum world is ruled by a principle that is an inverse of the principle that rules the classical world: in the quantum world everything is (non-causally) united unless a separation process has occurred; in the classical world everything is separated unless causal connections have been established.

Entanglement, together with the weak and strong nuclear forces, are the cement of the quantum universe, and also *the cement of the mind*, if the mind has a quantum nature. In this perspective, mental relations are directly supported by quantum entanglement and therefore are physical (although not classical). It is well known the impossibility of generalized entanglement between macroscopic objects, and this would be the main reason why "mind" is not coextensive to "nature": only complex systems able to be kept at low entropy states, and to coordinate informational processes to the point of generating systematic entanglement, qualify to be called "minds". Therefore processes at the micro/mesoscopic levels in the animal brain, that generate systematic entanglement, are good candidates to form minds.

An individual mind comprises relations between many things, but the "things in themselves" are not incorporated into the mind - only the "relations in themselves". How is it possible? Such relations are *encoded* by a complex system (the brain) in a way that *entanglement* between the encodings (or between *informational patterns* - that's how the encodings are currently called) is possible. For instance, in the experience of seeing a forest, there are several relations between macroscopic (trees, birds, etc.) and microscopic elements (bundles of photons) in the forest, and between the forest and the visual system of the observer. A subset of these relations is encoded by the central visual system of the observer, according to her attentional constraints. As far as such informational patterns become entangled with each other and with other informational patterns, they are *mental relations*. Going one step further, such mental relations can articulate with other mental relations in a process of *quantum computing in the brain*, corresponding to what we call "conscious thinking".

Could the conception of mind as a dynamical process be sustained without the anti-naturalistic consequence implied by its interpretation in the context of classical physics? Here I attempt to give a positive answer, by considering three hypotheses:

Hypothesis 1: *quantum entanglement is the only way of supporting non-causal dynamical relations*.

Why are non-causal classical relations unreal (or "real" only in a metaphysical, Platonic sense of the word) while non-causal quantum relations (i.e., entanglement) should be believed to be real? The answer is straightforward: non-causal classical relations *are known to be just formal* while quantum non-causal relations should be believed of being real (as well as a scientific respectable subject) *because they are experimentally confirmed*. As Johnson (2001) put it, "experiment by experiment, the abstractions of quantum theory are taking on substance, impinging on phenomena closer to home. Physicists are developing a new finesse — getting a feel for quantum mechanics by playing with atoms the way their predecessors mastered Newtonian physics by fooling around with swinging pendulums or marbles rolling down inclined planes".

The above thesis is closely related to the discussion of informational *content* (as well as the meaning of *signs* in Peircean semiotics); it implies that such contents find their ultimate support in quantum relations (as in David Bohm's concept of *implicate order*). I will not discuss this issue here, since it demands a larger effort to be properly defended;

The above hypothesis is accompanied by two others:

Hypothesis 2: *mental relations are supported by systematic quantum entanglement*.

This hypothesis explains why mental relations cannot be accounted by categories belonging to the domain of classical physics, and suggests an approach based on quantum relations. It makes dynamical and quantum approaches to the mind compatible, at the cost of ruling out purely classical alternatives. The crux of what I call "the quantum mind/classical brain scientific problem" is precisely to discover the details of systematic quantum entanglement and to show that they are similar (or even isomorphic) to mental relations. In the last section of this work I discuss some cases where this approximation seems to be possible; and

Hypothesis 3: *brains generate the kind of quantum entanglement necessary to the existence of minds*.

This hypothesis explains why living and interacting brains are sufficient (and maybe necessary) to generate minds, and why minds are individual, namely because they depend on brains which are subsystems of biological individuals. The main scientific doubt regarding this thesis is how quantum relations could affect and be affected by macroscopic phenomena as those known to occur in the brain. The next sections are devoted to this discussion.

3) "Functionalist" Versus "Structuralist" Styles of Explanation

At the macroscopic level, brain activity is like the activity of any other living tissue, except for mechanisms of electro/chemical communication between relatively distant cells. Such mechanisms have inspired the construction of artificial neural networks, simulated in digital computers, where the dynamics of the patterns of connectivity (which are electrical *and chemical* in the brain) have been used to simulate and predict cognitive phenomena, including responses to subjective sensations.

These results can be epistemologically interpreted in basically two ways, commonly referred as "functionalism" and "structuralism". In the functionalist interpretation, the phenomenon to be explained is usually defined as a logical function, e.g., the logical inference reported by a subject who is experiencing a visual illusion. Any machine able to make the same inference (by manipulating symbols in a language translatable to the subject's) can be said to simulate or predict it, without experiencing the subject's visual illusion. The functionalist concept of explanation is one that takes such logical simulations/predictions as sufficient to *explain* cognitive phenomena.

In cognitive neuroscience, the concept has its roots in the proposal advanced by D. Marr (1982). The methodology he proposed has four pillars:

a) measurement of behavior;

b) attempts to find empirical correlation (using EEG, invasive electrodes, or, more recently, PET, MEG or fMRI) of such behavior with brain regions or networks putatively responsible for them;

c) formulation of mathematical/computational functions able to account for it, and

d) if the simulations/previsions of such functions satisfy the measured behavior, it is taken as a proof that the activity of the correlated brain regions/networks "implements" the mathematical/computational function.

Left alone, this methodology makes available a beautiful *map* of "localization of function" in the brain, as well as a set of mathematical/computational functions that *formally* describe the workings of the correlated brain regions/networks. However, it cannot afford a *biological* explanation of mental functions like consciousness and emotion, since it doesn't reveal the biological mechanisms underlying such functions. If a "structuralist" (as opposed to "functionalist") style is adopted, the explanation should go beyond the construction of cognitive maps and formal description of functions, and reveal the *mechanism* (the activity of the structure) by which the observed (and/or reported) phenomena are generated.

In an attempt to construct a "structuralist" explanation of consciousness and emotion, it is necessary at first to realistically describe the properties of the phenomenon to be explained. Philosophers and psychologists have done this task, and I will not try to summarize all the results here. Besides the famous 'qualia', there are other fundamental properties of conscious experience in human beings, such as: sense of unity, sense of reality, sense of space and time, sense of decision (or problem-solving), and a sense of 'Self'.

The next step is to study in detail how the brain works, looking for mechanisms able to generate (or at least to trigger) the phenomena to be explained. It is important to note that the brain works in different spatial and temporal scales, therefore any mechanism to be identified for this task should be a multiscale one. The problem with the explanation of consciousness based on artificial neural networks is that they only simulate a limited range of brain activity, i.e. electrical connectivity, leaving aside the mesoscopic/microscopic chemical, molecular and (putative) quantum processes in synapses, membrane, cytoplasm, reticulum and nucleus of neurons, which may turn out to be essential for the explanation.

Finally, the biological mechanisms should be related to the corresponding aspects of conscious experience. There are two steps in this association: a *conceptual* (although non-deductive) connection between the kind of mechanism and the corresponding aspect of conscious experience. Making such a conceptual connection *in advance* minimizes the probability that any empirical correlation found to confirm it would be merely casual. Second, the conceptual connection (hypothesis) must be *experimentally* tested to gather empirical evidence in favor of or against it (Frith et al., 1999, is an excellent review about the experimental framework in the study of consciousness). Of course, both steps are *inductive*. Dualistic interpretations of the mind-body problem rely on the impossibility of a *deductive* explanation or a irrefutable proof, but fail to note the possibility of solving the problem with inductive reasoning and planned experimentation.

A contemporary consensus has been formed that consciousness cannot be explained by deductive reasoning, including theoretical reduction of psychology to neuroscience. Chalmers (1996) correctly argued that conscious experience is *not logically* supervenient from the brain's physical mechanisms. However, there is another consensus - even for property dualists like Chalmers - that consciousness is *naturally* supervenient. Therefore, an inductive scientific explanation of consciousness should be possible, as long as scientists abandon false philosophical dichotomies between "subjective" and "objective", "first-person" and "third-person" perspectives.

When consciousness is defined by an adequate set of properties which are both "subjectively" and "objectively" describable (unity of diverse informational patterns, solving computational conflict, reliability of perception, spatio-temporal flux of events) and reasoning based on empirical evidence is made to discover the kind of biophysical mechanism able to generate them, a new way of explaining consciousness emerges, that goes far beyond the "functionalist" method of cognitive science. Functionalism helped to explain the nervous system's processing of informational patterns that become conscious, but lacks the resources to explain the mechanism that directly supports consciousness. For instance, neural networks can account for the timing of conscious processing, but cannot account for the integration of informational patterns - the well-known problem of "psychological binding". In visual processing, it can be formulated as follows: there are different neural networks in the brain, specialized in different visual features; how are such features put together in an integrated visual image?

The problem has been clearly recognized by Zeki (2001): "the primate visual brain consists of many separate, functionally specialized processing systems, each consisting of several apparently hierarchical stages or nodes. The evidence...leads me to speculate (a) that the processing systems are autonomous with respect to one another, (b) that activity at each node reaches a perceptual end point at a different time, resulting in a perceptual asynchrony in vision, and (c) that, consequently, activity at each node generates a microconsciousness. Visual consciousness is therefore distributed in space and time, with the universal organizing principle of abstraction applied separately within each processing system. The consequence of spatially and temporally distributed microconsciousnesses is that their integration is a multistage, nonhierarchical process that may involve a neural "glue"". As the "mesoscopic" scale of brain activity where the "binding" process is expected to occur is very close to the quantum domain, the "glue" should be a quantum non-local effect, the only known physical mechanism able of performing this task.

The simulation of neural networks in digital computers, and more probably the workings of a real connectionist machine, may implicitly include some quantum aspect. Possibly some arrangements made with digital computers - including several CPUs with feedback loops - allow the emergence of quantum-like effects, although different from conscious processes generated by brains. Also Edelman and Tononi's concept of *coherence* (Tononi et al., 1998), although *not* referring to quantum entanglement, may be useful to describe the whole brain function, including both classical and quantum levels of activity (this possibility is discussed in the section 8 of this paper).

4) The Decoherence Process Produces a Classical Brain

It is well known that virtually all explanatory strategies in current neuroscience are based on classical physics, or on a "collapsed" concept of macroscopic physical states and processes. In other words, such explanations refer to patterns of electrical and/or chemical activity which do not involve one kind of phenomenon (namely, *entanglement*) that is allowed by the laws of quantum physics for particles/waves at the microscopic scale.

In fact, these laws *do not forbid* the occurrence of entanglement between a large number of particles/waves in a macroscopic system. Although studies of quantum processes have showed that such occurrence is very hard to produce experimentally, promising results have recently been obtained (e.g., Julsgaard et al., 2001). Based on this kind of difficulty, or on metaphysical assumptions (originally created by the Copenhagen and von Neumann/Wigner schools), the concept of a "collapse" of the wave function entered the scene. One way to avoid the Copenhagen/von Neumann metaphysics, while retaining a physical sense for the "collapse", is the concept of "decoherence" advanced in the last decades (see discussion in Pessoa Jr., 1998). It is proposed to denote an interaction process between large populations of particles/waves, destroying the previously existing entanglement between couples of particles/waves.

At first sight any isolated (relatively) small microscopic system would be "coherent", in the sense that entanglement of particles/waves would be the rule, and any (relatively) large macroscopic system would be "decoherent", in the sense that any property of this system, available to macroscopic observation and experimentation, would reveal no signal of entanglement between its elements. A widespread belief used to explain why nature behaves this way is the so-called "law of large numbers", that identifies the size of the system (i.e., its number of elements) as the critical parameter for statistical cancellations to apply, thus generating a *most probable* behavior that would correspond almost exactly to the predictions made by classical physics (see Feynman, 1985, Chapter 2). In this view, the existence of quantum coherence at the macroscopic level would be *extremely improbable*, and could not frequently and continuously occur in the conscious brain.

For the defenders of the quantum mind hypothesis, or even for physicists who have worked with quantum macroscopic effects, there must be something wrong with such usage of the "law of large numbers". The central aspect, in my view, is that the statistic of a large population of particle/waves cannot be so simple; there must be some kinds of interactions that really *cancel* opposite tendencies, but there may well be other kinds where some *apparently opposite* tendencies are *summed* instead of cancelled. This would be a case of *non-linearity*, an important concept advanced in the study of dynamic systems (in critical conditions, a small variation can trigger a large effect) and perfectly plausible for quantum macroscopic effects as superconductivity.

Therefore, if the "law of large numbers" is not universal and/or is not really a physical law, a theoretical possibility is open, for a large macroscopic system as the brain, to be continuously generating quantum coherent processes between particles/waves distributed along its volume. These processes function as a "second-order brain", controlling and being controlled by classical processes that occur in that same system (i.e., in the "first-order brain"). This "second-order brain" would be the ultimate support for the flux of experiences that we call "the conscious mind". In this sense, the mind is not *identical* to the brain, as proposed by identity theorists, but a process directly supported by a *part* of brain activity - more precisely, by the "second-order brain".

A central implication concerning the above hypothesis is the existence (in the brain) of mechanisms allowing the transition from classical to quantum domains, and vice-versa. How could such mechanisms be conceived in the context of current neurobiology? Answering this question requires a discussion of explanation in biology.

5) Are Biological Explanations Committed to Classical Physics?

Although biological explanations seem to be dependent on classical physics, they are in fact neutral relatively to the physical nature of the processes. More precisely, they are neutral relatively to the question about the studied processes being completely classical or also involving quantum coherence.

The biological method begins by describing structures (macromolecules, cells, tissues, systems) and functions (biological, not mathematical), which can be minimally defined as "the activity of the structure". A *biological mechanism* is a specific arrangement of the structure performing a specific kind of transformation (the use of the term "mechanism" in this context hasn't a direct relation with the philosophical doctrine of *mechanism* derived from Newtonian physics). A mathematical function may be used to describe the transformations. Symbols in the function refer to the activity of elements of the structure, but their usage doesn't imply that biological phenomena are intrinsically discrete. The choice of a mathematical formulation (e.g., deterministic or purely statistical) is made by the scientist who is creating the mathematical model. In summary, mathematical descriptions of biological phenomena don't need to have ontological commitments with classical physics or any kind of Platonism.

Physical theory may be brought to help explaining biological phenomena, if the observed transformations fall in the domain of transformations predicted by the theory, but there is no need to *deduce* biological phenomena from physical theories. Instead of deduction, biological methodologies (as well as other empirical sciences) use careful (i.e., controlled by statistics) inductive reasoning. It is based on a detailed description of the phenomenon, leading to explanations that invoke a variety of factors. The network of factors that interact to generate the phenomenon may also be called a "biological mechanism" (again no reference to the modern - XVII-XVIIIth centuries' - doctrine of mechanism).

As the philosophy of biology (see e.g. Hull, 2000) developed after several decades of philosophy of physics, the main paradigms of scientific explanation still make reference to classical physics. Ernst Nagel's influential view of explanation as deduction from general theories (Nagel, 1959) is possibly inspired by the determinism of classical physics, and leads to some problems when applied to biological explanation. If the rules for deduction are too severe, biological theories can't explain anything; on the other hand, if stipulations of initial and boundary conditions are too liberal and/or ad hoc assumptions are allowed as auxiliary hypotheses, they can explain everything at the cost of becoming trivial. This problem is not effective for biological methodology since it employs mainly non-deductive kinds of explanation.

On the other hand, some aspects of biological phenomena do resemble the epistemology of quantum physics. According to Mayr's hypothesis of allopatric especiation (Mayr, 1942), the fluctuation of genetic frequencies in small populations doesn't follow Hardy-Weinberg's equilibrium law (the same "law of large numbers" with a different name). Such fluctuations, together with geographic separation of the small group from the original population, may lead to the formation of a new species. The fluctuations of molecular binding in chromosomes generate "mutations" that may have non-linear effects over the phenotype, causing the death of the organism or (conjointly with the above populational fluctuations) leading to major biological transformations. Although biologists from the XVIII to the XX century have tried to shape biological knowledge according to the model of classical physics, the diversity, complexity and historical contingence of biological phenomena didn't fit in that model, suggesting a possible role for non-classical mechanisms in the evolution and maintenance of life.

The above considerations also apply to the workings of the brain. A good example is the entrance of calcium ions in the post-synaptic neuron, activating vital proteins as calmodulin and CaMKII.

6) Beyond the Synaptic Dogma

Proponents of quantum theories of consciousness (as well as many neural network theorists) have relied on the dogma that the brain activity directly supporting conscious experiences is located at the synapse. Beck and Eccles (1992) proposed that Ca2+ entering the synapse and opening transmitter vesicles would be the mechanism by which the mind controls brain activity; Eccles (1993) and Walker (2000) proposed similar quantum mechanisms at the synapse generating conscious experiences, and Hameroff (1998) proposed that quantum processing in microtubules would also control transmitter release at the synapse.

Of course, synaptic mechanisms are central to brain activity, playing a crucial role in information processing and control of behavior. However, in a quantum theory of consciousness it doesn't follow from such premises that quantum computation/communication processes must also be directly based on synaptic mechanisms. These mechanisms might participate in the *preparation* or *creation* of a quantum coherent system in the brain (see discussion in the next section) but it is not clear why the quantum system itself should be constituted by microprocesses located exactly at the synaptic region.

The only kind of synaptic process based on a specific quantum mechanism seems to be the action of Ca2+ on transmitter vesicles, referred to in Beck and Eccles' hypothesis. All the other relevant mechanisms, especially the binding of transmitters and receptors, seem to follow the rules of classical chemistry. Processes that mainly invoke the quantum domain are those following the entrance of Ca ions through membrane channels. Such processes are known in the literature as "signal transduction pathways". They include classical "lock and key" molecular binding mechanisms, but also have some aspects (as the multi-conformational states of some proteins) that suggest the possibility of quantum communication/computation be occurring in this domain.

As Bertil Hille states (reproduced from Kandel et al., 1993, p. 209): "electricity is used to gate channels and channels are used to make electricity. However, the nervous system is not primarily an electrical device. Most excitable cells ultimately translate their electrical excitation into another form of activity. As a broad generalization, excitable cells translate their electricity into action by Ca2+ fluxes modulated by voltage-sensitive Ca2+ channels...(that) serve as the only link to transduce depolarization into all the nonelectrical activities controlled by excitation". Therefore, as a flux of ions - in other words, transmission of information at the quantum level - is "the only link" to transduce all sensory information to the interior of the post-synaptic neuron, at this level quantum processes assume the main role in cognitive processing. One possibility would be that this role is limited to generating feedback on the synapse, as the expression "second messenger" (used to describe the role of intra-neuronal calcium ions) suggests. However, progress of molecular research has showed that internal Ca2+ ions have many other complex functions besides providing feedback to the synapse (see e.g., Alkon et al., 1998).

Chemical mechanisms at the synapse control and are controlled by complex signal transduction pathways inside the cells, leading to gene transcription and morphological changes of neurons. In summary, the information that reaches a synapse, in the form of an electrochemical pulse, may have two functions:

a) if the released transmitters bind to ionotropic receptors (with the exception of NMDA) then the result is cell depolarization or hyperpolarization (depending on the transmitters being excitatory or inhibitory) and the transmission of new pulses to other neurons (all similar to what is modeled in artificial neural networks);

b) if the transmitters bind to NMDA or metabotropic receptors, something very different occurs: the activation of a signal transduction pathway inside the neuron that has no correspondence in artificial neural networks. Here we are at the "mesoscopic" level, very close to quantum phenomena.

What is the biological function of the information that is transduced to the interior of the neuron, and how can intra-neuronal processing in one neuron be integrated with similar processing in other neurons? An answer to these questions depends on the role of quantum mechanisms in conscious processing. One of the functions of intra-neuronal processing is the formation of long-term memory (Bailey and Kandel, 1995). Although unconscious memories do exist (i.e., procedural memory, subliminar learning), *for conscious (declarative, semantic, episodic) modalities* of memory it seems that an informational pattern is not conserved if in a first instance it wasn't consciously attended. The provisory conclusion would be that the *same* molecular mechanisms that, in a larger time scale, participate in the formation of long-term memory, could support conscious processing in a shorter time scale (100 ms-3s). This possibility is evident when the time scaling of intra-neuronal processes triggered by Ca2+ entry is considered (see Alkon et al., 1998).

If the above is true, there must be a supplementary mechanism to integrate signal processing inside one neuron with signal processing inside the others. Quantum entanglement (and, as a consequence, non-local communication), in biological neuronal networks - having mechanisms able to create or prepare it - appears as a candidate to support integrated conscious processing.

7) A Possible Quantum-Classical Interface

At the level of organization of ion currents and internal signal transduction pathways, the neuron can be understood as a quantum system. Recently evidence has emerged about how this system could work. For instance, one of the proteins activated by Ca2+ entrance through the membrane channel controlled by the NMDA receptor is calmodulin (CaM). A study by Wilson and Brunger (2000) revealed that this protein "can bind specifically to over 100 protein targets in response to a Ca2+ signal. Ca2+-CaM requires a considerable degree of structural plasticity to accomplish this physiological role...the evidence for disorder at every accessible length-scale in Ca2+-CaM suggests that the protein occupies a large number of hierarchically arranged conformational substrates in the crystalline environment and may sample a quasi-continuous spectrum of conformations in solution. Therefore, we propose that the functionally distinct forms of CaM are less structurally distinct than previously believed, and that the different activities of CaM in response to Ca2+ may result primarily from Ca2+-mediated alterations in the dynamics of the protein".

The very existence of such sub-states could be an evidence for their functionality. Current technology is able to detect what Wilson and Brunger call "structural disorder", leading them to work with "multi-conformer models" able to account for this aspect. However, the most interesting question would be: is this functionality limited to classical local interactions, or do they involve quantum coherent non-local interactions? One possible interpretation is that "when two proteins actually dock by way of complementarity in surfaces and charges, even though they are conformationally constrained, yet they fluctuate or continue to sample the conformational sub-states accessible to them. Then there is some kind of 'resonance' whereby some quanta of energy or mass transfer takes place" (R. Banerjee, personal communication). "Structural disorder" may be a sign of this kind of local interaction, or a sign of non-local transactions, or even both. It may also be the case that some of these interactions can be observed only 'in vivo'.

Ca2+-mediated alterations can express local interactions as well as control non-local quantum computations in the brain. Little is known about this level of "mesoscopic" processes (at the spatial scale of 10 to 1,000 angstroms), as was argued by researchers from the Institute for Complex Adaptive Matter at Los Alamos (Blakeslee, 2001). Molecular biologists who study molecular interactions frequently limit themselves to the old "lock-and-key" metaphor when referring to molecular binding (effector-protein, protein-substrate and/or protein-protein). Such kind of matching, based on geometrical structure and charge, is a general mechanism that is not violated if and when their protons and/or electrons undergo non-local transactions. However, non-local interactions between intra-neuronal proteins may be necessary to make sense of what we know about the brain. Quantum computation and communication may be occurring with particles/waves pertaining to proteins that have a central role in signal transduction pathways and have been experimentally well related to cognitive processing (e.g., calmodulin-sensitive protein kinase II - see a study on the role of CamPK II in Frankland et al., 2001).

There is empirical evidence by Warren and his group (Warren, 1997) that MRI could trigger and detect correlation between protons in biological macromolecules. Trugenberger (2001) goes one step ahead to propose the use of entanglement for the encoding of mnemonic patterns. If these possibilities turn out to be mechanisms that occur spontaneously in biological systems, one day the "lock and key" view should be broadened by adding that proteins can also interact non-locally. In this perspective, it is possible that Ca2+ ions specify the state of the neuron's internal proteins such that a network of these proteins could perform quantum computations to control biological functions. Therefore, a classical/quantum interface can be conceived as:

a) membrane channels controlled by electrical activity manipulate Ca2+ ions;

b) these ions select a sub-state of CaM and/or other proteins pertaining to signal-transduction pathways involved in cognitive processing;

c) electrons/protons, which define different sub-states of proteins (these proteins being internal to neurons, in several parts of the brain), perform quantum communication and computation in a given time interval (around 100 ms);

d) the result of the computation influences the sub-states and therefore influences the patterns of binding of such proteins with a variety of agents, thus controlling classical processes responsible for the generation of behavioral patterns.

8) Creating Correlations Instead of Merely Preserving

Our quantum mind model (abbreviated "RPC", for Rocha, Pereira Jr. and Coutinho, 2001) is fundamentally different from the proposal of Penrose-Hameroff (abbreviated "PH" - see a review of their proposal in H. Morais' paper in this journal) and therefore cannot be rejected based on the criticisms directed to the latter. The main differences are:

a) in the PH model, "transitions from pre-conscious possibilities into unitary choices or experiences may be seen as quantum computations in which quantum superpositions of multiple states abruptly collapse (reduce) to definite states at each 'quantum moment' " (Hagan and Hameroff, 2000). In the RPC model unitary conscious experiences correspond to quantum computing epochs when systematic entanglement occurs. In summary, conscious states correspond to collapsed states in the PH model, and to coherent (entangled) states in the RPC model;

b) in the PH model quantum superposition (corresponding to "pre-conscious" states) depends on the *maintenance* of coherence in tubulins (neuronal microtubules proteins) by means of isolation, e.g., by means of water molecules shielding microtubules from the (relatively) hot and noisy cellular environment. In the RPC model, quantum coherence is *created* (or, using a technical term, *prepared*) by macroscopic mechanisms (recurrent processing, oscillatory synchrony, gating Ca ions through NMDA receptor-controlled membrane channels);

c) in the PH model the quantum computing system is composed of tubulins and is assumed to propagate mechanically through cellular gap junctions. In the RPC model the system is composed of particles/waves of intra-neuronal proteins that participate in cognitive processing (as possibly calmodulin, calmodulin-dependent protein kinases, protein tyrosine kinase, etc.), and the communication between such particles/waves is non-local.

The major difficulty for both models is to explain how quantum coherent processes (including superposition and/or entanglement) could occur in the brain. Most XXth-century physicists (and also Osvaldo Pessoa Jr., in the study published in this journal) were inclined to accept the existence of quantum macroscopic effects in only two kinds of cases: materials kept at ultra-cold temperatures, or quasi-isolated systems composed of a small number of particles. One of the first quantum mind hypotheses (Marshall, 1989) was inspired by the existence of Bose-Einstein condensates, but as this phenomenon occurs at ultra-cold temperatures its biological feasibility is low (see comment in Cairns-Smith, 1998). The PH model chose the second possibility, arguing that microtubule systems could be adequately isolated to avoid decoherence. This hypothesis was seriously criticized by Tegmark (2000), who estimated the available time interval for quantum computation in microtubules to be too small (from 10^{-13} to 10^{-20} seconds), and by Seife, who wrote in *Science* that Tegmark's calculations "unmake the Quantum Mind" (Seife, 2000).

A third, still not discussed possibility, is *to mechanically create correlations* that generate quantum entanglement, *instead of just preserving* the correlations that spontaneously occur at the micro level. This would be the way to understand how classical mechanisms as recurrent neuronal networks and oscillatory synchrony could be necessary for the existence of consciousness. The theoretical basis for this reasoning is the association between (macroscopic) irreversibility, entropy increase and decoherence (see the *Introduction* to Halliwell, Pérez-Mercader and Zurek, 1994). If the decoherence process is always accompanied by a increase of entropy and macroscopic irreversibility, it becomes possible that, when lowering the entropy of a partially closed macro system, *"anti-decoherence" processes* occur, having the effect of generating quantum entanglement (as originally argued in Pereira Jr. and Rocha, 2000, based on a previous research reported in Pereira Jr., 1997) and making reversible quantum computations possible. In this view, recurrent neuronal circuits, synchrony and coordinated entry of Ca2+ in different neurons are considered to be mechanisms that lower the entropy of the brain, thus generating quantum coherence between particles/waves at the endpoint of such processes.

This proposal helps to understand why artificial neural networks fail to generate consciousness. Such networks can have recurrent circuits and synchronize the activity of different nodules and layers, but they lack an essential ingredient: a quantum-classical interface, as membrane ion channels in the brain, that manipulate individual atoms to create entanglement in protein networks. As far as artificial networks are able to locally decrease entropy and create classical coherence they can in principle generate *rudimentary minds*. In fact, all living tissue can do a similar job and therefore all living beings should be considered as having a rudimentary mind. However, modalities of consciousness as the one available to human individuals would certainly require a variety of sensors and effectors, and the workings of a efficient quantum-classical interface able to generate systematic entanglement and to use it to interpret sensed data and to control consistent action.

Once the idea of creating correlations is taken seriously, a new paradigm emerges for quantum computation. It becomes free of temperature or isolation constraints. A closer look at the work of one of the Physics Nobelists of 2001, Wolfgang Ketterle, reveals that even working with systems at ultra-cold temperatures to get quantum effects as the atom laser (a laser made of whole atoms and not only photons; see Ketterle, 1997, 1999), his methodology *also* makes use of a mechanical device to control this laser. The device is based on the existence of the *Feshbach resonance* (see Inouye et al., 1998), a mechanism by which a Bose-Einstein condensate submitted to a variable magnetic field is shaped by the frequencies present in this field.

The result obtained by Warren (1997), producing spin correlation between a few protons by means of a nuclear magnetic resonance (NMR) coil, is the best example of the strategy of *creating correlations* instead of just preserving them. Of course it is objectionable that the brain's magnetic fields don't possess such "tesla power", but why would the NMR technique be the only option for generating correlation?

The brain possesses a unique way of distributed information processing, and also possesses distributed energy sources that make possible the performance of two crucial steps:

a) to highly coordinate the information being processed by billions of units (neurons);

b) at each unit, the information controls a switching mechanism (gated membrane channels) that directly manipulate atoms (Na, K, Cl and Ca ions).

Regarding conscious processing, the role of Na, K and Cl ions is to depolarize the neuron's membrane, thus controlling the entrance of Ca2+ through NMDA channels to trigger quantum computing. As their flux is a necessary condition for the opening of the NMDA channel, the weak electromagnetic fields they generate (as measured by the electroencephalogram - EEG) often - if not always - is a companion of conscious processing. Besides this fact, as the lowering of entropy always requires consumption of free energy, and such energy is conveyed by sugar carried in arterial blood, the flow of oxygen-rich blood to brain regions mobilized for conscious processing (as measured by the blood oxygenation method - abbreviated "BOLD" - largely used in current functional magnetic resonance imaging - fMRI) coexist with consciousness. According to the RPC model, these would be reasons why appropriate measurements by EEG (as well as by magnetoencephalography - MEG) and fMRI are good indicators of consciousness.

The RPC model predicts that any factor that disturbs the normal function of membrane receptors in the CNS - not only the NMDA channel - have a direct or indirect effect upon conscious processing. If the NMDA channel is perturbed, the flux of Ca2+ is disturbed and then the triggering of the quantum coherent state is directly perturbed. If muscarinic or other acethylcholine-binding receptors are affected, the awake state and attention are disturbed and therefore the electrical patterns that gate the NMDA channel are affected; in this case, there may be no conscious processing of the stimulus, as in non-REM (rapid-eye movement) sleep (i.e., the larger part of sleeping periods, where no dreaming occurs), or in cases of attentional neglect. If AMPA-kainate receptors function is altered, the depolarization that removes Mg from the NMDA channel is also impaired, possibly leading to unconsciousness as in general anesthesia. If the ion currents in a (small) brain region are massively disturbed by transcranial magnetic stimulation, illusory perceptions as well as localized unconsciousness may occur. Finally, if metabotropic receptors function is changed (e.g., by altering the concentrations of transmitters as serotonin and dopamine, that bind with them), complex interactions in internal signaling pathways can occur, directly affecting the processing of emotions closely related to consciousness.

In the RPC model conscious states and processes are directly supported by quantum coherence, and such quantum coherence depend on several dassical mechanisms in the brain. Therefore, the model allows the explanation of a series of phenomena studied in cognitive neuroscience, where a correlation between brain activity and conscious processing has been detected. Some examples of such explanations are given in the next section.

9) What Does a Quantum Mind Model Could Explain?

Some aspects of conscious experience that could be explained by the quantum mind hypothesis are:

a) '*qualia*'

Recent discussion in the philosophy of mind has been centered on the possibility of a physical explanation of 'qualia' (the qualities present in conscious perception, as color, sound, taste, etc.). Pessoa Jr.'s paper, in this journal, identifies four alternatives for an explanation of 'qualia' based on quantum theory: theories based on the collapse of the wave function (as Penrose-Hameroff's), on the phenomenon of entanglement, on the formation of quantum condensates, and on holographic phenomena allowed by quantum field theory. The RPC model, as stated in the last section, chose the entanglement alternative, but we still have to make clearer how quantum entanglement supports the experience of 'qualia'.

Physicists and science journalists usually describe entanglement in terms of mechanical metaphors. As Johnson (2000) puts it, "a subatomic particle can spin clockwise or counterclockwise like a top — but with a quantum twist. As long as it remains isolated from its environment, it lingers in a state of limbo, rotating both clockwise and counterclockwise at the same time [the phenomenon of quantum superposition - APJ]. Only when it is measured or otherwise disturbed does it randomly snap into focus, assuming one state or the other [the phenomenon of decoherence - APJ]. 'And' becomes 'either/or'. Stranger still, two subatomic particles can be linked so that they must rotate in opposite directions. Force one to spin clockwise and the other instantly begins spinning counterclockwise, no matter how far they are separated in space [the phenomenon of entanglement - APJ]". Rough as the picture can be, this is the basic material currently available to the quantum mind hypothesis defenders, to show a similarity or even an isomorphism with mental relations.

The above metaphor is limited to a *particle model* of quantum reality. It says that particles have internal states, conceived in terms of rotational properties, and that the internal state of one particle can be non-locally correlated with the internal state of others. Conceiving such internal states as merely rotational doesn't help much to approximate to perceptual qualities. This goal can be better achieved in a *wave model* of quantum reality. Waves can have internal states as frequencies and other temporal patterns of activity, which (once they are known) could find close correspondence with perceptual qualities. In other words, colors, sounds, tastes, etc. would correspond to different waveforms at the quantum level in the brain.

Surely the progress into a more detailed understanding of the relations between quantum particles/waves will help to draw this correspondence. One more step would be to consider the behavior of larger populations of entangled particles/waves, as observed in a recent experiment (Julsgaard et al., 2001), and the next step may well be theorizing on quantum information about qualitative states (as colors) carried by populations of particles/waves (see Brian Flanagan's paper in this journal). In this perspective, what reaches the eyes cannot be conceived as merely a wave frequency. Quantum information carried by the photons also brings *the pattern of the objects* that interacted with white light before the result of such interaction reached the eye. In other words, the qualitative aspects of visual perception (the visual 'qualia') shouldn't be considered as a pure creation of the conscious mind, but constructed from a quantum coherent pattern encoded in the flux of photons that stimulates the retina, and supported by quantum entanglement between intra-neuronal proteins.

Following the above guidelines, the RPC model makes possible the formulation of testable hypotheses about 'qualia'. It predicts the existence of different quantum computations in different sensory cortices (visual, auditive, somatosensorial, etc.). Such different computations imply the existence of different mechanisms supporting them. As the proposed mechanisms are based on substates of intra-neuronal proteins, the model makes possible the prediction that internal proteins as CaM would assume different sets of preferential states (or different "attractors") in different neocortical regions. This hypothesis can be tested using crystallographic methods available in the current "proteomics" era, or new techniques as atomic structure holography.

b) *meaning*

While the understanding of grammatical structures and brain mechanisms responsible for them had a considerable advance since the work of the Chomskian school, *linguistic meaning* - as well as other modalities of meaning - seems to be an ineffable matter hardly tractable by science. However, there are two aspects of meaning that suggests a possible explanation in terms of quantum relations associated to classical processes in the brain. First, meaning is always *meaning of a sign*: meaning of a word, a sentence, a perceived object or a retrieved mnemonic pattern. The external sign may be transduced to a classical pattern generated in brain activity, while the meaning would be the quantum pattern associated to the classical pattern. Second, while signs are combinatorial structures (a word being composed of letters, a sentence being composed of words, etc.) the meaning itself appears as an indivisible whole. This would be because meanings are supported by quantum relations, while signs are supported by classical relations.

To understand how the brain codifies signals is the easiest part of the task of understanding the neural basis of language and animal communication: temporal patterns of neuron firing, and also a biochemical syntax (Rocha, 1997) have been proposed. But how does meaning emerge from the individual properties of signs and the syntax? A possible analogy - one that I will only suggest here - could be between the classical behavior of particles, corresponding to the structure and grammatical rules of language, and the associated quantum behavior (i.e., quantum entanglement in appropriate conditions), corresponding to the emergence of meaning.

c) *unity and projection of content*:

Conscious content is a unitary mix of patterns from the environment, memory, sensations from the body and abstract concepts. Each part of the content - that is always undergoing dynamical changes - is processed by different brain subsystems (each one matching endogenous and afferent patterns). In conscious experience a variety of informational patterns are integrated into a coherent, meaningful whole. Such patterns are transduced to intra-cellular signaling by calcium ions entering the neuron's membrane through NMDA channels or by G-proteins activation by metabotropic receptors. In the RPC model, the integration of informational patterns is performed by quantum communication and computation based on entanglement between intra-cellular proteins activated by Ca2+ or G-proteins. The unity of content of conscious experience would then be directly supported by the entanglement of particles/waves that carry a diversity of informational patterns (relative to the environment, memory, body sensations and abstract thought).

The workings of the brain (the neurons themselves) are never (or almost never) a conscious content, because consciousness is *intentional*. As the objects, which are interesting for the survival of the organism, are outside the brain, evolution of the species has led to strong habituation to signals endogenous to the brain. Such signals became not perceptible if not matched by afferent signals. A classical problem is how signals internal to the brain are "projected" (Velmans, 1993) to appear as existing outside the brain? Of course, this "projection" mechanism cannot be explained by classical information theory or classical physics, but requires a different concept of information as the one provided by quantum theory.

d) *conflict-solving*:

We intuitively know it, and it has been corroborated by cognitive neuroscience, that conscious processing implies solutions to perceptual and behavioral conflicts. Underlying them is *computational* conflict, i.e. neuronal networks simultaneously processing different (and/or opposite) perceptual and behavioral demands. As Penrose (1994) argued, this kind of conflict cannot be solved by classical processing, but could be solved by quantum computation. Differently from Penrose and Hameroff, the RPC model proposes that the quantum computational system is composed of intra-cellular proteins activated by the entering Ca2+ or G-proteins activated by metabotropic receptors, instead of microtubule proteins (tubulins), which are not directly participating in cognitive processing.

In any distributed and non-hierarchical system, conflict between the subsystems makes the whole system stop working. In von Neumann machines conflict between two programs makes the computer stop working. How does this kind of catastrophe never happen to the brain? Considering that each of billions of neurons is like a autonomous processor, brains should stop working every moment when they are awake and processing signals from many modalities, each one having many degrees of freedom. It has been known for some time in cognitive neuroscience that every connection between sensing and behaving that doesn't imply systemic conflict (i.e., every automatic response) is made unconsciously. All responses that imply systemic conflict (binocular rivalry is one of the most studied of such situations) require consciousness. Based on these observations, the conclusion that conscious processing appeared in the evolution of the brain as a useful mechanism to solve systemic conflict (Pereira Jr. and Rocha, 2000) is very appealing.

e) *reliability*:

A thesis held by philosophers of perception (e.g., Chisholm, 1981) is that our percepts are reliably related to what "external reality" is likely to be. Of course, there is a bootstrapping at work here that suggests the falsity of a sharp distinction between "objective" and "subjective", or "first" and "third-person" perspectives. Any third-person knowledge is also first-person, since the subject who has the knowledge is a person; on the other hand, every first-person knowledge is also potentially third-person, since the informational patterns that constitute the content of this knowledge are directly supported by brain processes that can be observed by another person.

The agreement of different minds about a common theme is possible because knowledge can be "inter-subjective" and also "inter-objective". The meshing of subjective and objective derives from our kind of interaction with the environment, by means of perception and action. Such interaction is controlled by adaptive constraints that require for survival at least a partial correspondence (not isomorphism) between knowledge and the world (see discussion in Pereira Jr., 1999). Perceptual reliability is the product of evolutionary processes submitted to such constraints.

The RPC model can explain the reliability of perception in the following way. The physiology of the NMDA channel works in such a way that Ca2+ enters *only if* there is a temporal matching between inputs to distal and proximal parts of the apical dendrite of the neuron (the matching is necessary to remove Mg from the NMDA channels). In perceptual processes, while the subject is in the awake state (in dreaming or hallucinatory conscious states it is different), one of the inputs must be an afferent one (e.g., glutamatergic input from the thalamus to pyramidal neurons in cortical layer IV).

This dynamical processing suggests a naturalistic explanation for the philosophical claim of reliability of perception: a "vivid" (as Hume called it) conscious image of a stimulus is formed only if a matching between the stimulus' pattern and an endogenously generated pattern occurred. Studying the physiology of the NMDA channel and the anesthetic role of NMDA blockers, Flohr (1995) conceptualized a possible relation between the workings of this mechanism (NMDA receptor controlling Ca2+ ion channels) and aspects of self-consciousness. This hypothesis has been experimentally tested and (inductively) proved to be successful. A fruitful line of research has flourished in neuropharmacology, consisting in the blocking of NMDA channel with ketamine or similar drugs (in this case only for medical purposes), leading to a temporary loss of consciousness, or the perturbation of NMDA function by a weaker dose of ketamine in humans (in this case for research purposes with consent of subjects), leading to temporary perturbations in conscious processing, similar to what is observed in schizophrenia.

In dreaming the connection of the CNS with peripheral sensors and effectors is blocked. Substitutive stimulation is made by the pons that plays the role of the afferent signal. As a consequence dreaming is a kind of consciousness but not a kind of perceptual consciousness. While dreaming we still have a feeling of reliability because we don't know that the afferent signal is being mimicked by a endogenous (subcortical) one; however, sometimes we are able to doubt the dream content because of its absurdity and conclude (while still sleeping and dreaming) that it is just a dream.

In hallucination the afferent signals are present but as there is a disturbation in serotoninergic/dopaminergic systems (that modulate the activity of the NMDA channel), or there is a substance directly perturbing NMDA function (as in the case of taking a weak dose of ketamine), then the afferent signal doesn't play the role it usually does. Hallucination is also a modality of consciousness, but is not perceptual consciousness either. The subject who has hallucinations tends to believe in them as if they were perceptions; therefore reliability is still present. But it is not an essential aspect since some schizophrenics who learned that they have hallucinations report being able to stop believing in them (M. A. Pereira, personal communication)

f) *sense of self*:

The dynamical approach to the mind made possible a sophisticated conception of the Self as an invariance in the dynamical processes that constitute the mind of a biological individual. However, "invariance" as well as "attractor" are formal concepts that don't correspond to a definite physical being, but to sets of points in abstract high-dimensional spaces. How to reconcile this abstract concept with the psychological feeling of Self that every conscious being seems to have?

One of the characteristics of the psychological Self is the feeling of having causal powers, i.e., of being able to command or influence the behavior of the biological organism where it is embodied (Fisher, 2001; see my comment in Pereira Jr., 2001b). However, if the Self is just an invariance, or a "natural category" as Fisher puts it, how does it happen to have causal powers? One way to solve this problem is considering the quantum/classical interface in the brain. Classical processes in the synapse and cytoplasm shape the quantum coherent state that makes possible the existence of quantum computations that, a fraction of time later, exert a back-influence on the synaptic processes that lead to the control of behavior. This is, in essence, the solution for the problem of free will advanced by Eccles (1992) and Beck and Eccles (1992). Of course, their proposal is related to a dualistic view of mind and brain that I don't subscribe, but the main idea can be adopted and adapted to the RPC model.

10) Conclusion

The contemporary concept of mind is deeply influenced by the dynamical view. Instead of using terms as "substance" or "representation" to describe the mental domain, philosophers and scientists make use of concepts like "informational patterns" and "temporal relations". In this paper I attempted to show that such concepts make sense only when quantum relations are taken into account, and that quantum relations are indeed generated by the living brain. I also claimed for the similarity of quantum and mental relations, and attempted to reveal a dynamical rapport between the quantum mind and the classical brain.

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