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## *On Evolution and the Quantum and Classical Regimes in Brain Function*

**Abstract:** As species evolved, consciousness (awareness) manifested at different levels: physical, mental, and subtle. But why different species exhibit different grades of consciousness continues to intrigue researchers. A plausible reason could be that adaptation to environmental changes, and hence survival and evolution, all depend on the level of consciousness species possess. This could be the reason why evolutionarily older species (with lower order consciousness) only implicitly (slowly and unconsciously) adapt, whereas evolved species (with higher order consciousness) explicitly (quickly and consciously) adapt to unforeseen situations gaining tremendous survival advantage. This ability requires exploring innumerable possibilities including representations that may not have been experienced before and requires faster, brain-wide computations. We argue that the transition from slow adaptation to fast learning can be explained by considering two different regimes of computation in the brain: a Classical Regime based on slow neuronal signalling, and a much faster Quantum Regime marked by subtler quantum computations at the sub-neuronal level. We conjecture that as brains of species increased in size, a threshold was reached, beyond which species could volitionally control attention and exploit the Quantum Regime which not only enabled them to quickly perform non-local computations, develop dynamic brain-wide neural associations, and adapt very fast, but also be

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*mentally aware, observe themselves, and hence speed-up their own evolution.*

**Keywords:** evolution; attention; Quantum Zeno Effect; neural assemblies; Quantum Hebbian Learning.

## Introduction

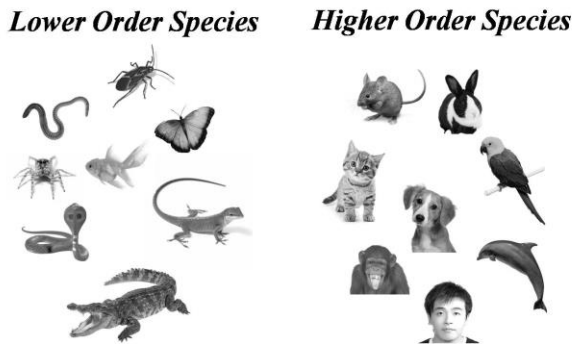
As life evolved from the prebiotic world to complex multicellular organisms, to reptiles, mammals, and current day humans, the most significant change that came about was the manifestation of different grades of consciousness. These different grades of consciousness depended on the level of awareness a species had of its environment, i.e. external stimuli, and of internally generated signals such as hunger, pain, etc. Evolutionarily older species only had primitive sensory systems like touch and smell that enabled them to respond to basic instinctive needs such as finding food, averting danger, and procreation. These senses were slow and only worked in close proximity. As the species evolved, vision and audition got added which were faster and had a broader reach. The species with these new senses could appreciate different dimensions of the same environment that the lower species failed to detect (Kaas, 2008). More senses meant more awareness. Some species even developed specialized body sensors according to the environment in which they thrived, e.g. night vision in nocturnal birds, infrared sensing in some snake species, supersensitive hearing in dogs and whales, heightened sense of touch in certain rodent species, etc. With growing environmental complexity, it became necessary that species created certain representations or associations in their brains that could help them better address threats. In some species more mental faculties developed, like the capacity to introspect and plan. Some even developed mathematical and analytical abilities. Creativity flourished, they developed skills and made tools, as a result of which different arts, cultures, and civilizations prospered. Therefore, we hypothesize that, as the brain evolved, consciousness manifested at three different levels — *Awareness of Body* (awareness of sensory states, internally generated signals such as hunger, pain, urge to procreate, and the capacity to avert dangers through certain pre-programmed body reactions or reflex actions), *Awareness of Mind* (self-awareness, ability to plan and introspect, ability to think, imagine, and develop mental associations), and *Awareness of Subtle States* (such as intuition, telepathy, premonition, meditative states, etc.), more commonly referred to as Anomalous

Cognition (term coined by Science Applications International Corporation (SAIC)) due to the inexplicability of these states under existing scientific understanding. While all sentient beings possess awareness of the body, only some evolved species have awareness of mind and only human beings seem to have the capacity for awareness at all three levels. *The question is, what evolutionary changes made the human brain so unique and enabled it to be conscious at all three levels?*

In this paper species have been divided into two broad categories — *Lower Order Species (LOS)* and *Higher Order Species (HOS)*. The LOS are the evolutionarily older species with small brains that work through pre-wired fixed modes or *reflex actions* in response to different situations. These species show very slow adaptation to changes and can survive only in specific environmental conditions. They have a very primitive form of memory and only seem to have awareness of body. On the other hand HOS are evolutionarily more recent, have larger brains and demonstrate the ability to acquire complex skills and show very fast learning. They can survive in diverse environments and have very complex associative memories. These species seem to have awareness of both body and mind. Human beings are the only HOS with awareness of all three kinds: body, mind, and subtle states.

As the environments became more complex and threatening for survival, more sensory systems got added in the body. The need for larger capacity to process this additional sensory information caused the brain to increase in size (Niven and Laughlin, 2008). With this cortical expansion a large part of the cortex turned into areas that were primarily responsible for forming associations between different brain regions, giving the brain a new kind of flexibility (Buckner and Krienen, 2013). In 1970 MacLean (e.g. 1982) proposed an interesting model of the brain called the Triune Model. In this model, the mammalian brain can be understood as a three-layered structure comprising the Reptilian Brain, Limbic Brain, and Neocortex. According to MacLean the Reptilian Brain, consisting of the brainstem and cerebellum, formed the most primitive and innermost layer of the mammalian brain. It was responsible for carrying out autonomous body functions and was rigid and compulsive. Then came the Limbic Brain consisting of the amygdala, hippocampus, and hypothalamus, forming a second layer around the Reptilian Brain that was responsible for bringing in emotions such as maternal love and fears or joy based on past experience that unconsciously influence our judgments. Then came the Neocortex, with its two large hemispheres that became

responsible for the development of language, abstract thought, creativity, imagination, and brought with it an infinite learning capacity. The most remarkable feature of the Neocortex was to facilitate formation of brain-wide dynamic neural assemblies/associations between different sensory, motor, and planning areas in the brain, giving the human brain its unique flexibility and adaptability (Beggs and Plenz, 2003; Gireesh and Plenz, 2008; Petermann *et al.*, 2009; Thiagarajan *et al.*, 2010). *The question is, what brought about this increased adaptability and infinite learning capacity in the Neocortex and how is it related to consciousness (awareness)?*



*Figure 1.* Categorization of species into Lower Order and Higher Order. LOS have smaller brains, fixed responses to stimuli, show very slow adaptation, and only have awareness of body. HOS have larger brains, they adapt or learn very fast, and have awareness of both body and mind.

Various theories have attempted to explain different aspects of consciousness. These theories can be broadly classified as *Neurobiological Consciousness Theories (NCT)* (Tononi and Edelman, 1998; Edelman and Tononi, 2000; Edelman, 2003; Baars, 1993; 2002) and *Quantum Consciousness Theories (QCT)* (Hameroff and Penrose, 1996; 2014; Penrose and Hameroff, 2011; Stapp, 2004; 2005; 2006; Bohm, 1990; 2002; Jibu and Yasue, 1995; Jibu, Pribram and Yasue, 1996; Vitiello, 1995; Beck and Eccles, 1994; 2003). NCT assume that consciousness arises from the complexity of the nervous system (emergentism). These theories are unable to provide an account of how consciousness arises in primitive organisms with low neural complexity and also lack success in providing an explanation of how causality between mind and brain ensues or how volition arises. They treat consciousness as an adult phenomenon that can only occur in

developed brains and do not consider the prolific conscious experiences that infants and children have as they explore the world around them (Trevarthen and Reddy, 2007; Koch, 2009; 2013). QCT on the other hand are equipped to deal with uncertainties in the brain and seem to have the potential to explain mind–brain causality (Stapp, 2006) and therefore might lead to unravelling aspects related to higher-order consciousness. Some QCT (Penrose and Hameroff, 2011) have attempted to provide an explanation for the presence of consciousness in organisms that do not even have a nervous system.

A vital ingredient for any theory of consciousness and mind–brain interaction, based on the foundations of quantum theory, would be to have an avenue for mental causation. Consciousness, mind, or any other subtle description must have a relevance in the classical world and may be serving some evolutionary advantage to the organism and that is probably the reason consciousness also evolved and manifested at different levels. Therefore, theories that consider consciousness to somehow emerge as a second-order phenomenon disregard the potential role consciousness might serve in neural development and hence survival and evolution. For any quantum or subtle description, that is essentially a state of all possibilities, to have any relevance in the classical world these possibilities should reduce to a definite classical outcome, generating a unique conscious experience. And in the brain it should lead to the activation of a corresponding neural assembly and this assembly should be stable at least for as long as it takes learning mechanisms to form structural changes in the connectivity between the neurons. Only then can it have any physical significance. We evolve only through the various experiences we engrave in our brains as memories and therefore experiencing, engraving, and evolving seem to be the three tenets through which consciousness operates. Some of the prominent QCT are compared in Table 1. As can be inferred from Table 1, not all theories in their current form seem to have an avenue for mental causation. However, it appears that Penrose-Hameroff's Orch-OR proposal and Henry Stapp's Von Neumann-Stapp Interpretation are some of the theories that do give a clue as to how this could be happening.

<b>Theory</b>	<b>Quantum Mechanical Basis</b>	<b>Salient features</b>	<b>Benefits</b>	<b>Drawbacks</b>
Henry Stapp	<ul style="list-style-type: none"> <li>i. Von Neumann Interpretation of QM</li> <li>ii. Quantum Interactive Dualism</li> </ul>	Processes 1, 2, and 3 (Choice, Causation, and Chance) causally connect mind and brain	<ul style="list-style-type: none"> <li>i. Quantum brain state can be maintained by Quantum Zeno Effect therefore does not need long coherence times</li> <li>ii. Consciousness causes collapse hence consciousness is treated as superior than mental processes</li> </ul>	Concrete details as to how quantum superpositions and their collapses are supposed to occur in neural correlates of conscious events has not yet been worked out precisely
Penrose & Hameroff	<ul style="list-style-type: none"> <li>i. Quantum Gravity (non-algorithmic)</li> <li>ii. Godel's incompleteness theorem</li> <li>iii. Quantum computation in microtubules</li> </ul>	<ul style="list-style-type: none"> <li>i. Based on Orchestrated Objective Reduction of quantum states in the microtubules</li> <li>ii. Conscious experience is associated with abrupt changes in quantum state (or collapse)</li> </ul>	<ul style="list-style-type: none"> <li>i. Sound experimental evidence of anaesthesia causing changes in conscious states directly affecting microtubules</li> <li>ii. Supported by experiments that have shown the existence high frequency quantum vibrations in MTBs</li> </ul>	<ul style="list-style-type: none"> <li>i. Quantum Gravity is not yet established</li> <li>ii. Thoughts are not causal but an outcome of quantum state reduction under quantum gravity</li> </ul>
Eccles & Beck	<ul style="list-style-type: none"> <li>i. Quantum effects at nerve terminals</li> <li>ii. Quantum state reduction</li> </ul>	<ul style="list-style-type: none"> <li>i. Conscious action is related to quantum state reduction</li> <li>ii. Quantum (10–12 sec) and thermal processes (10–9 sec) in the brain are distinguishable</li> <li>iii. Quantum Trigger mechanism based on electron tunnelling</li> </ul>	<ul style="list-style-type: none"> <li>i. Empirically concrete and theoretically detailed</li> <li>ii. Exocytosis can be influenced by mental intentions</li> </ul>	Not explained how processes at single synapses are correlated with mental activity
Umezawa, Jibu, Yasue,	Quantum Field Theory	<ul style="list-style-type: none"> <li>i. Memory states are treated as representations of vacuum states of quantum fields</li> </ul>	<ul style="list-style-type: none"> <li>i. Takes dissipation, chaos, and quantum noise into account</li> </ul>	<ul style="list-style-type: none"> <li>i. Describes the brain, not mental states</li> <li>ii. Relevant brains states them-</li> </ul>

Vitiello		ii. Symmetry breaking processes lead to long range correlations	ii. Describes how the system–environment interaction causes infinitely many differently coded vacuum states, offering the possibility of many memory contents without overprinting iii. Explains how memory is temporally limited	selves are decidedly viewed as classical states. Similar to a classical thermodynamical description arising from quantum statistical mechanics iii. Do not suggest how quantum dynamical level interacts with electrochemical activity in the brain iv. Consciousness emerges from memory retrieval process and is non-causal
Bohm	i. Mind and matter are inseparable (like electron and field around it) ii. Defends a version of holism which embraces the non-separation of observer from the observed, therefore doing away with the need of collapse	i. With Active Information or quantum potential, even weak quantum field has strong effect on particle therefore distant features of the environment can strongly affect the particle ii. Active Information also implies the possibility of a certain sort of wholeness of the particle with distant features of its environment iii. When particles interact, it is as if they are all connected to each other by invisible links consisting of a single whole	i. Both mind and matter are conceived as processes rather than things, so the conventional mind–matter problem, with matter as a thing, but mind not, is dissolved ii. Active information can be viewed as the underlying reality, both physical and mental, from which both mind and matter emerge	i. Does not suggest how either mind or matter arise from the implicate order, or how they relate to one another

Table 1. Comparison of different quantum consciousness theories.

In Penrose-Hameroff's proposal, microtubules seem to be interestingly placed at the interface between the quantum and classical worlds, both in terms of their size and their function, and could have the potential to affect neuronal activity. On the other hand, Henry Stapp in his theory gives a unique role to attention for stabilizing neural responses through the Quantum Zeno Effect (QZE). Therefore, the reconciliation of Penrose-Hameroff's proposal that microtubules are the quantum mechanical substructures where quantum superposition and quantum computations take place and where collapse happens when the self energy of the system reaches a critical threshold (Penrose and Hameroff, 2011) determined by the Penrose-Diósi relation  $E = \hbar/T$  (where  $E$  is the self energy of the system,  $T$  is the time of collapse, and  $\hbar$  is the Planck's constant) leading to a moment of conscious awareness (of the mental kind), with Henry Stapp's ideology (Stapp, 2005) that we could maintain the brain in a particular state through attention incited QZE, we could have a proposal that has strong neurobiological support and that could work around the decoherence problem. Guided by this philosophy, a novel attempt to explain how experience-based learning happens in the brain has been put forth by us in Gupta and Markan (2013).

In this paper we proposed Quantum Hebbian Learning (QHL) as a new paradigm that looks at how neural assemblies could be created. The stimulus orchestrates a quantum state, the collapse of which activates a coherent neural assembly and leads to a conscious experience. Depending on the intensity of this experience, attention is drawn towards it. This attention invokes the QZE that biases the probability of subsequent collapses to happen to the same neural substrate and hence in a way holds the brain state for a sufficient duration that allows Hebbian learning to take place. However, this attention-based QHL (or explicit learning) can take effect only in species that have the capacity to direct and sustain attention (HOS). Species that do not have the capacity to voluntarily modulate attention (LOS) also exhibit learning, but their learning is a slow adaption process commonly known as implicit learning (or *as we term it* Classical Hebbian Learning (CHL)). The attention-based QHL is evolutionarily more recent as compared to CHL. Interestingly, the human brain exhibits both these forms of learning, but *the question is what benefits does this attention-based explicit learning have over its implicit counterpart and what necessitated this change?*

Based on the frequency of Diósi-Penrose's self collapses (objective reduction of quantum superposition maintained in microtubules)



(Diósi, 1989; Penrose, 1996; 2000) determined by  $E = \hbar/T$  (where  $E$  is directly proportional to the size of neural assembly), this paper explores the possibility of having two distinct regimes in brain function, a slow *Classical Regime* and a fast *Quantum Regime*, that are separated by the limit of axonal communication speed (maximum processing speed achievable in classical neuronal networks). As evolution brought about an increase in the brain to body ratio of different species (Barton and Harvey, 2000; Roth and Dicke, 2005), it led to the possibility of faster collapses since larger areas of the brain could now be involved in processing information. Therefore, in this paper we hypothesize that with an increase in brain size and the evolution of the brain's structural capacity to form large neural assemblies, there was a gradual transition from a slower classical regime to a faster quantum regime of information processing in the brain. By taking this fresh outlook towards evolution and neural processing, different aspects of consciousness, learning, and attention can be more intuitively understood. Moreover, this approach opens up the possibility of viewing in a new light some of the open-ended problems in the area of consciousness studies like implicit and explicit learning, bottom-up and top-down attention, self-awareness, volition, and mind-brain interaction.

### **Quantum Collapse, EEG, and Quantum and Classical Regimes**

According to the Diósi-Penrose relation  $T = \hbar/E$  (Diósi, 1989; Penrose, 1996; 2000), the time after which a quantum superposition collapses is dependent on the size of the system. Therefore, a system with a lesser number of particles in superposition would take longer to collapse than a system with a larger number of particles in superposition. It has been conjectured that this collapse of the superposition of microtubule conformational states would lead to the activation of a coherent neural assembly (Hameroff and Penrose, 2014) or in the words of Henry Stapp a 'template for action' (Stapp, 2004; 2005; 2006) and generate a moment of conscious awareness (mental awareness) (Hameroff and Penrose, 2014). In evolutionarily older species or LOS with smaller brain sizes, since the number of microtubules that can get involved in any computation is limited, these conscious collapses would be infrequent. On the other hand, in evolutionarily recent species, or HOS, as the brain becomes large and structurally equipped to form large neural assemblies, the number of microtubules

that can participate in any computation becomes large, and as a result the moments of conscious awareness would become more and more frequent. Assuming that these collapses trigger widely spread coherent neuronal activity (possibly through gap junction connected neurons as is discussed below), faster collapses would mean faster neuronal processing or interaction across wide areas of the brain. Hameroff conjectures that these conscious collapses or moments of conscious awareness (of the mental kind) are what give rise to gamma rhythms (>30 Hz) that are observed in EEG recordings of conscious subjects.

Interestingly, in recent years gamma rhythms have been shown to derive not from axonal spikes and axonal-dendritic synapses, but from post-synaptic activities of dendrites (Hameroff and Penrose, 1996; Penrose and Hameroff, 2011). To be more specific, gamma rhythms are driven by networks of cortical interneurons that are connected by dendro-dendritic ‘electrotonic’ gap junctions. Groups of neurons connected by gap junctions share a common membrane and fire synchronously, behaving ‘like one giant neuron’ (Kandel, Schwartz and Jessell, 2000). Gap junctions have long been recognized as prevalent and important in embryological brain development (Hormuzdi *et al.*, 2004; Bruzzone and Dermietzel, 2006) and recently they have also been shown to precede chemical synapse formation (Todd, Kristan and French, 2010). Until some years ago gap junctions were seen as irrelevant to cognition and consciousness. However, more recently, relatively sparse gap junction networks in the adult brain have been appreciated and shown to mediate gamma synchrony/40 Hz (Bennett and Zukin, 2004; Buhl *et al.*, 2003; Dermietzel, 1998; Draguhn *et al.*, 1998; Friedmann and Strowbridge, 2003; Galaretta and Hestrin, 2001; Gibson, Beierlein and Connors, 1999; Hormuzdi *et al.*, 2004; LeBeau *et al.*, 2003). They facilitate the formation of transient neural assemblies through opening, closing, and reforming mediated by intraneuronal activities. Therefore, gap junction connected neurons and glia form continually varying ‘hyperneurons’ whose membranes depolarize coherently and may span wide regions of the cortex. Since the cytoplasm of hyperneurons is also continuous, there is a possibility that they host brain-wide quantum states. Therefore, gap junctions appear to be a strong candidate for propagating brain-wide coherent neural activity.

It may be conjectured on the basis of the above discussion that neurons in the brain function in two distinct modes. The *classical mode* in which the activity of the neurons is through the build-up of action potentials through slow neurotransmitter based chemical

processes, and a *quantum mode* which works through a much faster gap junction based electrical channel in which the neurons depolarize and fire together because their cytoplasm is continuous and possibly their microtubules are entangled. Neuronal firing through the quantum mode could therefore be the outcome of collapse of the superposition of microtubule states. Ongoing research in microtubules suggests a strong possibility that they could be capable of modulating neuronal firing (Hameroff and Penrose, 2014; Sahu *et al.*, 2011; Bandyopadhyay, 2014; Mavromatos and Nanopoulos, 1998; Nanopoulos, 1995). While processing speeds achievable through the classical mode are limited because of the speed of axonal communication ( $\sim 10$  Hz) (Dalal *et al.*, 2010; Preston, 1962), and it may not be possible to have synchrony across wide areas of the brain with this mode, the processing speeds achievable through the quantum mode would be much higher because of extremely fast non-local interactions leading to coherent widespread neural activity. Moreover, as discussed above, the role of the proposed quantum mode of neuronal firing (through gap junctions) in creating local as well as brain-wide synchrony is now being recognized. Also recently, gamma rhythms, as well as some slower rhythms like alpha, have been shown to be generated by gap junction connected interneurons (Hughes *et al.*, 2011).

Various groups have extensively studied EEG rhythms to understand various aspects of brain function (Freeman, 2004a,b; 2005; 2006; Buzsáki and Draguhn, 2004; Buzsáki, 2006). While it is known that EEG records the extracellular potential differences that give rise to the extracellular field, it is difficult to pinpoint which type of transmembrane current contributes to the extracellular field at any instant of time since the field is the superposition of all ionic processes, from fast action potentials to the slowest fluctuations in glia. Some of the sources that contribute to the extracellular currents are synaptic activity, calcium mediated spikes, intrinsic currents and resonances, spike after-hyperpolarizations, gap junctions, and neuron–glia interactions and other ephaptic effects (Buzsáki, Anastassiou and Koch, 2012). Therefore, in the complex neural set-up, EEG depends on various factors that cannot be isolated from each other and is a reflection of the most predominant activity of a very large number of neurons in a particular brain area. Therefore, based on the available evidence, it seems that the EEG recorded at any time could be either due to the neurons firing in the classical mode (chemical synaptic activity) or in the quantum mode (possible collapse of superposition

leading to coherent activity in gap junction connected neurons). Under this premise, we can hypothesize that the slower EEG rhythms like delta and theta are an outcome of the classical mode of neuronal firing whereas the faster rhythms like alpha, beta, and gamma are due to the quantum mode of neuronal firing.

Different states of human consciousness are associated with different EEG frequency bands, e.g. delta rhythms (0.1–3 Hz) are associated with slow-wave sleep in adults, theta rhythms (4–7 Hz) are associated with adult dream state and drowsiness, alpha rhythms (8–15 Hz) represent the relaxed or reflecting state in adults, beta rhythms (16–31 Hz) are associated with active thinking, whereas gamma rhythms (>32 Hz) are observed during cross-modal sensory processing, information binding, memory matching of recognized objects, sounds, or other sensations, and other high-level complex cognitive tasks (Freeman, 2004a,b; 2005; 2006; Buzsáki, 2006). In growing children, these rhythms appear at different stages of development, e.g. when a child is born the delta activity predominates during the first year of life. However, in the first three months, there is notable increase in the theta and alpha activity as well (Vladimirova, 1990). During further development of resting state activity, there is reduction in the amplitude of slow-wave (delta and theta) rhythms, while faster rhythms (alpha, beta, and gamma) increase during childhood and adolescence (John *et al.*, 1980; Matoušek and Petersén, 1973). These are signs of maturation (Clarke *et al.*, 2002).

Animal Consciousness has also been widely studied with an aim to understand what gives rise to human consciousness (Dennett, 1995; Edelman and Seth, 2009; Griffin and Speck, 2004; Vitti, 2010). Interestingly, animals belonging to different evolutionary classes show different EEG rhythms. For example, the EEG recordings in reptiles in a wakeful state are dominated by delta rhythms (0.5–3.5 Hz). These delta rhythms are observed in humans only during the state of deep sleep. This prompted Rial *et al.* (1993; 2010) to consider reptilian waking as evolutionarily antecedent of mammalian sleep. Slightly higher frequencies in the theta range (6–10 Hz) are observed in rodents when they are in the wakeful or exploratory state. These theta waves are observed in humans during dreaming state. As we go up the evolutionary tree, as the cognitive abilities of the species grow, higher frequency EEG rhythms are recorded in the wakeful and alert states, e.g. birds show even higher frequency EEG recordings during their wakeful and active states — for example, pigeons and chickens show activity between 12–60 Hz (Ookawa and Gotoh, 1965; Vyssotski *et*

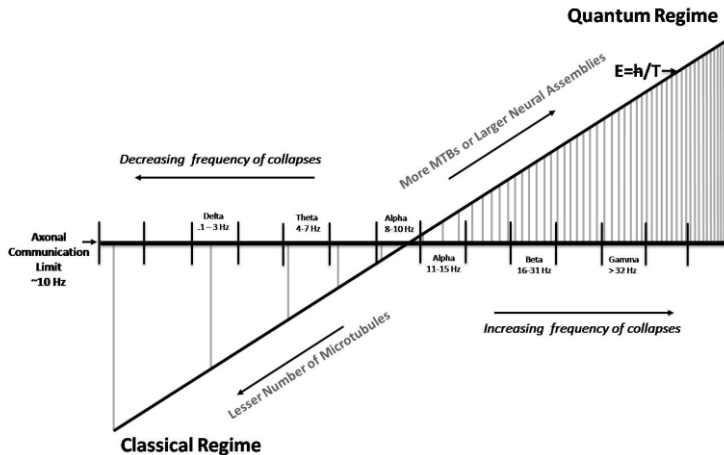
*al.*, 2009; Martinez-Gonzalez, 2008). However, an important thing to observe is that while evolution moved to higher frequencies (evolutionarily newer mechanisms) the lower frequency states (evolutionarily older mechanisms) were preserved since they proved to be useful at some stage. In fact, much evidence shows that when advanced brain mechanisms are suddenly rendered functionless, the lower rise in activity (Jackson, 1958). It has also been speculated that the return to lower frequencies (i.e. rest and sleep) is necessary for reconciling the acquired experiences during the high frequency or active or wakeful states with fundamental biological mechanisms.

Human EEG recordings, particularly of patients under the influence of anaesthesia, show that the transition from a conscious to an unconscious state is marked by a transition from higher alpha to lower alpha rhythms (Purdon *et al.*, 2013). However, when the patient undergoes a transition from a minimally conscious to persistent vegetative state, alpha rhythms disappear completely (Lehembre *et al.*, 2011). Therefore, the transition from unconscious to conscious processing in humans happens around the alpha frequency range. If we look at the limit of axonal communication (~10 Hz) (Dalal *et al.*, 2010; Preston, 1962), that is also in the alpha frequency range. Therefore, it may be possible to divide the mode of operation of the brain into two distinct regimes, with a cross-over at the alpha frequency or the upper limit of axonal communication (~10 Hz). A *Classical Regime*, where processing speed is at or below the classical axonal limit, and a *Quantum Regime*, where much higher processing speeds are achievable (Figure 2). In the classical regime, neurons would predominantly function in the classical mode of neuronal firing. Here quantum (conscious) collapses would be so infrequent that processing in this region would be slow and may not be accompanied by mental awareness. On the other hand, in the quantum regime, activity of neurons would primarily be driven by collapse of superposition of microtubules (quantum mode) and therefore be accompanied by mental awareness.

### **Quantum vs. Classical Regimes**

The previous section explored the possibility of having two distinct regimes of brain function, the classical regime and the quantum regime (Figure 2). The quantum collapses (moments of mental awareness) although present in the classical regime are so infrequent that they fail to influence the functioning of the brain, whereas in the quantum regime the brain is primarily driven by these collapses.

Different animal species can be placed at different levels of the quantum and classical regimes according to their brain size (or number of available microtubules) (more specifically their capacity to involve a large number of neurons in processing) (Figure 3). Evolutionarily primitive organisms like single cellular organisms that do not have a nervous system, or worms that barely have a few neurons, will have very infrequent quantum collapses (once in a few days or more). These organisms can only be purely instinctive (or driven by pre-programmed body responses). Slightly higher organisms like fish or reptiles, that have somewhat larger brains but not a very large brain to body ratio, could have collapses in the delta or theta range and display slightly more complex behaviour, however their actions would still be limited to sensory responses.



*Figure 2.* Represents the quantum and classical regimes in the brain. The black lines represent the limit of axonal communication and the grey lines represent the quantum collapses. In the classical regime the frequency of quantum collapses ( $T = \hbar/E$ ) is lower than the limit of axonal communication, whereas in the quantum regime the frequency of quantum collapses is higher than the limit of axonal communication. The classical regime is marked by slow processing speeds whereas the quantum regime is marked by fast processing speeds.

These organisms, in other words, would be driven purely by sensory needs. Therefore, the level of consciousness exhibited by them would be limited to the body (physical awareness). Their wakeful state can be considered homologous to the sleeping state of humans (Rial *et al.*, 1993; 2010). With increase in the brain to body ratio, in rodents, birds,

and higher mammals like primates and humans, the frequency of quantum collapses would become higher and higher and so would mental awareness, and therefore these organisms move more and more into the quantum regime (Figure 3). Therefore, species in the quantum regime would be aware at both physical and mental levels. It may be hypothesized that different physical and mental phenomena manifest at different levels of the quantum and classical regimes, e.g. *physical* phenomena such as instinct, autonomous body functions, and sensory awareness may be associated with different levels of the classical regime whereas *mental* phenomena like mental awareness, thoughts, cognition, and volition seemingly manifest at different levels of the quantum regime.

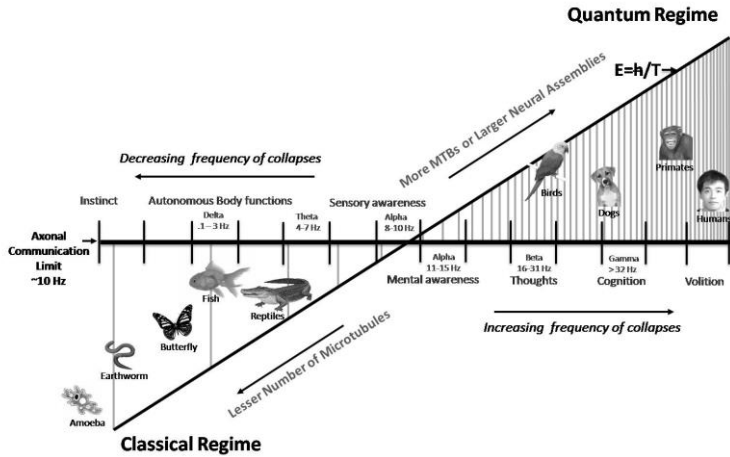


Figure 3. Different species can be placed at different levels of the quantum and classical regimes. Different physical and mental phenomena appear at different levels, e.g. instinct, autonomous body functions, and sensory awareness are associated with different levels of the classical regime whereas mental awareness, thoughts, cognition, and volition appear at different collapse frequencies in the quantum regime.

Some evolutionary theories hypothesize that the newer parts of the brain closely supervise the older parts (Jackson, 1958). If we consider quantum collapses or moments of conscious (mental) awareness to be supervisory signals (or interrupts) that provide additional meaningful information to the classical brain for faster development, we can reconcile some of these ideas (Figure 3). In the classical regime, these supervisory signals are infrequent, so they do not make substantial

changes to the normal course of body function. However, in the quantum regime, as the brain size increases, species are able to involve larger parts of their brain in processing and therefore these collapses become more and more frequent and they possibly gain the capacity to alter the normal course of body function. These species are able to take benefit of the quantum processing in the brain. What the possible information content of these interrupt signals/quantum collapses would be is an aspect that needs further investigation, however for now we could consider that these collapses have a rich information content that encompasses certain aspects of subjective experience. An interesting aspect to consider here is the benefit accrued by this quantum processing. According to a recent paper (Alfaro *et al.*, 2009), most modern birds (including songbirds, parrots, doves, eagles, hummingbirds, and pigeons) and most mammals successfully evolved and diversified into hundreds of species. Whereas crocodiles and alligators (even after being more than 250 million years old) have diversified into only 23 species. From our model it appears that for the species in the quantum regime, that are able to exploit the quantum processing, evolutionary processes are somehow speeded up. Hence, we can conjecture that mental awareness or being conscious at a mental level indeed had a survival advantage and the species that took advantage of this could speed up their own evolution. It could be that evolution is driving species to take advantage of more and more subtle senses.

### **Attention and Learning in Classical and Quantum Regimes**

In this section we discuss the implications of having two distinct brain regimes on learning and attention, two very important aspects of consciousness. Literature cites two forms of learning: *implicit* and *explicit* (Reber, Allen and Reber, 1999; DeKeyser, 2008; Willingham and Goedert-Eschmann, 1999; Dienes and Berry, 1997; Sun, Slusarz and Terry, 2005; Squire, 2004). Implicit learning happens in the absence of awareness of the aspect being learnt or is ‘cognitively unconscious’ and is unavailable for verbal recollection. On the other hand, explicit learning happens in complete awareness where we have volitional control over what we are learning and can verbally recollect it. Some examples of implicit learning are grammar acquisition of native language, sequence learning, unintentional learning of repetitive tasks such as dialling a particular phone number, social and behavioural



skills, etc. Whereas everything that is intentionally learnt, such as complex sensory-motor tasks, academic concepts, skills such as typing, learning any sport, etc. all constitute explicit learning. Even though the underlying mechanisms of these two forms of learning are unclear, they seem to be related and it has been found that implicit learning can facilitate explicit learning in patients suffering from memory related disorders (Cermak *et al.*, 1988; Polster *et al.*, 1993). While the study of implicit learning has gained increased significance for medical rehabilitation of amnesic patients, from a cognitive science perspective it is believed that understanding implicit and explicit learning mechanisms might shed light on issues related to higher order consciousness (Cleeremans and Jiménez, 2002; Cleeremans and French, 2013).

The importance of attention in the learning process has been indisputable, however the growing evidence on implicit learning has raised questions on the role of attention in learning. Attention is known to be of two types: *bottom-up* or sensory driven, also known as exogenous attention, and *top-down* or volitional, also known as endogenous attention (Connor, Egeth and Yantis, 2004; Sarter, Givens and Bruno, 2001; Buschman and Miller, 2007). Bottom-up attention is driven by object properties like sudden loudness, motion, brightness, etc. and we do not have any control on it. The parts of the brain that are involved in this kind of attention are evolutionarily older, e.g. parietal and temporal cortices and brainstem (Posner and Petersen, 1989; Posner and Rothbart, 1998). Therefore, this form of attention came first and is an older mechanism. Top-down attention on the other hand is something over which we have full volitional control and it is driven by factors such as intention, taste, interest, and so on. This form of attention is mediated primarily by the frontal cortex and basal ganglia, which are evolutionarily more recent parts of the brain (Posner and Petersen, 1989; Posner and Rothbart, 1998; Corbetta and Shulman, 2002).

From the perspective of the classical and quantum regimes present in the brain, it seems implicit learning is the kind of learning that is present in the classical regime. While it is a common notion that implicit learning happens in the absence of attention (Dienes and Berry, 1997; Cleeremans and Jiménez, 2002; Sun, Slusarz and Terry, 2005; Squire, 2004), it may be that sensory driven or bottom-up attention is indeed present during implicit learning. However, this form of attention may not reach the threshold of awareness. It is known that only small neural assemblies are involved in implicit

cognition and that they are generally restricted to a particular sensory modality (Baars, 2002). The species that operate in the classical regime only have a few neurons and are only able to slowly adapt to their environment. Hence, implicit learning is the only form of learning that they would demonstrate. These species cannot modulate their attention. On the other hand, in the quantum regime (particularly around higher collapse frequencies) the ability to voluntarily control attention comes in. This top-down or volitional attention brings in interesting phenomena. Top-down attention seems to be regulating the quantum mode of brain functioning, which is faster and more efficient. Through top-down attention, large neural assemblies can be recruited for processing information especially during multi-modal sensory or sensory-motor tasks (possibly by microtubule entanglement and gap junction coupling). Top-down attention could also have a role in sustaining these large neural assemblies through the QZE (Stapp, 2005) (wherein a quantum system can be maintained in the same state by frequently observing it; Misra and Sudarshan, 1977) allowing Hebbian learning mechanisms to hardwire (create chemical synapses) the connections between neurons involved, creating what are called ‘*zombie modes*’. These zombie modes are complex sensory/motor tasks (skills) that can be performed without attention once the skill has been mastered (Crick and Koch, 2003; Gupta and Markan, 2013; Penrose and Hameroff, 2011). Therefore, species in the quantum regime seem to have the capacity to modulate their attention, and using this they are able to dynamically recruit, sustain, and hardwire neural assemblies for unforeseen or threatening situations through the QZE. This enables them to form representations in their brains within a very short duration that help them tackle those situations effortlessly in future. These species are also able to develop complex skills that not only help them in survival, but also help them lead a better quality of life. This fast attention-based explicit learning involves the quantum brain and therefore has been termed *Quantum Hebbian Learning* (Gupta and Markan, 2013). Not all species in the quantum regime have equal capacity to modulate their attention or have equal brain size. Therefore, there is gradual increase in this capacity and it becomes most pronounced at high gamma frequencies.

The human brain exhibits both these forms of learning. In the absence of top-down attention (but the presence of bottom-up attention) few neurons are stimulated through the sensory channels. These neurons function in the classical mode. With recurrent activity these neurons form synaptic connections amongst themselves leading

to what we call implicit learning. On the other hand, in the presence of top-down or volitional attention, large widely spread neural assemblies of the brain are activated in the quantum mode. Through attention mediated QZE (or stabilization of a neural assembly), Hebbian learning takes place and this leads to what we call explicit or QHL. Therefore, it seems evolution brought in the quantum regime to enable much faster learning. This speed-up in learning enabled rapid responses to changes in the environment ensuring better survival. However, it still preserved the more primitive implicit learning, possibly because of its robustness and resilience to injury (Reber, 1996).

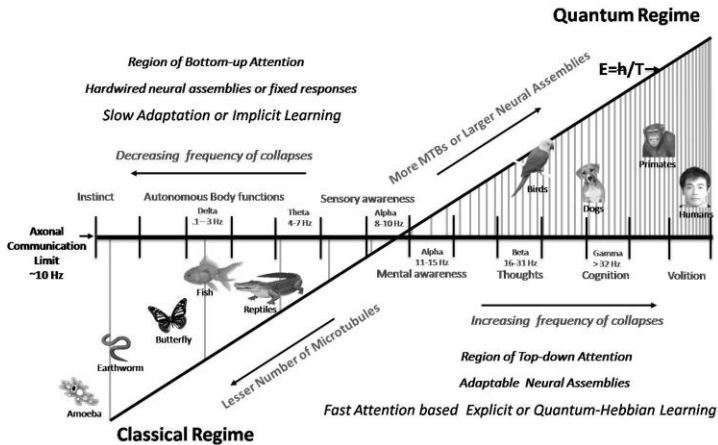


Figure 4. The classical regime is the region of bottom-up or sensory driven attention. In this regime species do not have control on their attention, have pre-wired responses or reflex actions to stimuli, and show very slow adaptation. The quantum regime is the region of top-down or volitional attention. In this regime species can voluntarily control attention, adaptively form neural assemblies (using attention and QZE) for unforeseen situations, and learn very fast.

### Perspectives on Higher Level Consciousness: Self-Awareness, Mind–Brain Interaction, and Volition

As discussed, the brain seems to be governed by two different processes, classical processes in neurons and subtler quantum processes possibly in the sub-neuronal microtubule cytoskeleton. The classical processes are slow, they work at low frequencies, whereas the quantum processes are fast and they work at higher frequencies.

Therefore, we have two systems almost coalesced with each other but operating at different frequencies. An interesting analogy for such a system can be drawn from the principle of sampling in digital communication (Marks and Robert, 1991). According to sampling theorem, a signal can be truly observed and understood if the observing signal has a frequency that is more than twice the frequency of the observed signal. In the brain, such a situation gets created when the quantum subsystem starts working at a higher frequency (faster collapses) than the classical subsystem (classical neuronal firing) and this happens in the quantum regime. Therefore, an observer (with 'mind-like' qualities) gets created within the brain. Being at a higher frequency than the classical processes, this observer is able to observe the classical processes in the brain, e.g. the observer can monitor different parts of the physical body. The phenomenon of *self-awareness* could be a possible outcome of the observation of the coarser neuronal networks by the subtler quantum (microtubular) networks. As the frequency of operation of the quantum subsystem (observer) increases further, it reaches a point where the QZE may be actualized. At this frequency of operation (>30 Hz), the quantum processes start to have a causal effect on the classical processes. Top-down attention has a major role in stabilizing this process. Therefore, it can be conjectured that the covert mind-brain interaction could have its origin at these high collapse frequencies where quantum processes begin to have a causal effect on the classical processes. It may be noted that the collapse frequencies here refer to the transition from quantum to classical processing which are proposed to be at 'beat' frequencies of much higher quantum vibrations in microtubules, as has been discussed in detail in Hameroff and Penrose (2014).

Another important aspect of higher consciousness is volition or free will. If the quantum processes are assumed to have a supervisory role where they interrupt the classical processes at regular intervals and change the course of the classical processes as required, we can develop a model of how volition might be working. Assuming that the brain has a hardwired response for a given set of stimuli, in the absence of attention the brain will respond to the stimuli exactly as it is wired to do. This process happens at low frequencies, falling in the classical regime. However, in the presence of attention the quantum processes get invoked, and these quantum processes, being supervisory in nature, have the capacity to override the hardwired neural response. We could term this attention-driven overriding of hardwired neural responses *free will*, e.g. in the absence of attention if we are

pricked by a needle, the body would instinctively retract through a reflexive action, however, if the same needle is pricked in the presence of attention, we can choose a more suitable behaviour over the natural or reflex action. The question as to what decides whether this overriding of hardwired neural response is required at any instance is perhaps driven by even higher-order or subtler quantum processes that lead to what we call intentions, motivations, goals, etc. that are beyond the realm of physical matter but could possibly be arising from more subtle quantum fields that surround matter of all kinds as suggested by Bohm (1990; 2002).

What gives rise to various subtle levels of awareness such as intentions, motivations, intuition, telepathy, meditative states, etc. is still regarded as a question outside the purview of scientific investigation. However, it may be that these subtle effects act through some fundamental subtle force field that science is yet to understand. The idea of fields affecting matter is not new. In fact, various kinds of fields like electric, magnetic, and gravitational have been known to cause various effects on matter. These fields have also been shown to have an effect on microtubule self-organization in the brain (Tabony, 2007; Glade and Tabony, 2005; Vater *et al.*, 1998). Similar effects may be extended to subtle fields also, e.g. some recent experiments in the area of psychokinesis (Tiller, 1993; 2014; Tiller, Dibble and Kohane, 2000) reveal that intent has the power to affect matter of various forms (and not just neural processes). For example, it has been shown that intent can affect the pH value of water, germination of seeds, and growth of plants (Tiller, Dibble and Kohane, 2000; Tiller, 1993; McTaggart, 2007). In some other experiments, certain subtle fields affect random number generation in group meditational sessions of students (Radin, 2007; Bösch *et al.*, 2006) and spiritual groups (Satsangi and Sahni, 2007). Hence, the possibility of a subtle quantum field outside the body causing subtle changes in matter, and in particular the brain, should be open to further scientific study. This might help in unravelling mysteries of higher level or subtler aspects of consciousness including cosmic consciousness.

Certain eastern traditions have explained consciousness as an all-pervasive, fundamental quantum force field that is the source of all other forces and matter way back in early 1900s (M. Sahab, 2004; Satsangi, 2010). From their standpoint, the human brain is essentially an intricate broadcasting and receiving station for waves traversing this field. It is said that this all-pervasive quantum force field has energy higher than all other force fields known. Therefore, according

to Einstein's relation  $E = h\nu$  (where  $E$  stands for energy,  $\nu$  stands for frequency, and  $h$  is the Planck's constant), it has the highest frequency. With this frequency, the quantum force field has the capacity to observe all lower frequencies, including the microtubular and neuronal frequencies, creating a hierarchy of observers (Satsangi, 2012). Since this field has the highest frequency it could act as a universal observer. The frequencies at which human brains and human-devised machines work are much lower than the suggested omnipresent quantum field frequency, and therefore human brains are incapable of observing the field. Indirect means could be devised to understand how the field works. Experiments along these lines would not only impart a new outlook to the scientific study of consciousness but also help in bridging the gap between consciousness as a study undertaken by the scientific community and consciousness as an experiential phenomenon as propagated by certain eastern traditions.

### Conclusions

This paper highlights the possibility of having quantum and classical regimes in brain function. There appears to be a threshold marked by the limit of axonal communication creating these two distinct regimes, differentiating higher order and lower order species. The classical regime is where processing speed is at or below the limit of axonal communication and the quantum regime is where processing speed is higher than the limit of axonal communication and is controlled by collapse rate determined by  $T = \hbar/E$ , where  $E$  is the self energy determined by the size of neural assembly. Lower order species (that operate in the classical regime) are the ones in which brain sizes are small and therefore quantum collapses are infrequent. The normal processing of the brain is not affected by the collapses and therefore these species are unable to exploit quantum processing. They function at low levels of mental awareness, only have bottom-up or sensory driven attention, and exhibit very slow adaptation (implicit learning) to their environment. Higher order species (that operate in the quantum regime) have larger brains and hence more frequent collapses and therefore are able to exploit quantum processing. By using volitional attention and QZE they are able to recruit and hard-wire large neural assemblies for unforeseen situations and show extremely fast learning capability (quantum Hebbian or explicit learning).

For the species that exploit quantum processing, the process of evolution speeds up. In a system that can work at two different frequencies (higher and lower), according to principles of sampling, the subsystem working at the higher frequency can observe and possibly supervise the subsystem at the lower frequency. This allows the species to observe its own actions and place itself in past or future and take actions according to the learnt experiences. Therefore, different species have different grades of consciousness based on where they lie in the classical and quantum regimes. The quantum regime can be exploited for increased efficiency in learning and adaptation and hence better survival. Human brains are most suited to exploit the quantum regime and hence are at the apex of conscious awareness by being aware at all three levels — physical (body), mental (mind), and subtle. This paper looks at phenomena related to higher level consciousness such as self-awareness, mind–brain interaction, volition in a new perspective and also proposes a hierarchy of observers in the order of increasing frequency (or subtlety) that could help in understanding the subtler aspects of consciousness.

### *Acknowledgments*

The authors are deeply grateful to Rev. Prof. P.S. Satsangi, Chairman, Advisory Committee on Education, Dayalbagh Educational Institute, for inspiring this research work. We also wish to thank Mr. Prem Prashant, Member Divinity Forum, Dayalbagh, Dr. Shiroman Prakash, Dept. of Physics & Computer Science, for their valuable inputs, and the anonymous reviewers for their observations that greatly helped in improving the manuscript.

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Paper received August 2014; revised February 2015.