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A Three-Layered Model for Consciousness States

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ABSTRACT

This paper presents a general three-level framework to represent different states of consciousness. Although awareness, by itself, is an all-or-nothing phenomenon, the state of consciousness depends on the degree to which preconscious and memory states are accessible to awareness. The relative ability to recruit these states and integrate distributed neural activity has a corresponding effect on the state of attention which can, therefore, be measured on a spectrum. Research in anesthesiology showing an uncoupling of perception from sensory inputs supports the idea of the disembodied consciousness state. We propose a three-level hierarchical model to explain these findings. The higher level nodes in this model are non-physical and they leave their trace in the non-local binding of activity across regions that are far apart. The activity across the brain can be quantified using an entropy-based metric and the non-physical nodes corresponding to consciousness states may be governed by quantum dynamics.

Key Words: consciousness states, neural correlates of consciousness, hierarchical processing, perception sensation decoupling, quantum neural processing

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Introduction

The mapping of distributed brain processes to behavior and cognition must include the influence of social context and history that also contribute to our subjective feel of the world. The neurophysiological component of this equation is provided by activity in the neural circuitry of the brain and in the functional modules that map to specific conscious states. The mapping is further complicated by the self-organization of the brain since activity and behavior have implications for structure. This indicates that the idea of mind/brain identity based on a classical computational framework is incorrect, which is consistent with the finding that there is no unified neural correlate of consciousness (NCC) (Zeki, 2003).

There exist *many* different neural correlates for different kinds of consciousnesses, which is supported by the fact that there are specialized modules for particular perceptions. Furthermore, conscious experience is selective: some neural activity generates it whereas other activity doesn't. If consciousness is equated to attention, there appears to be greater overlap between mechanisms of memory and awareness than between those of attention and awareness (Lamme, 2003; Zeki, 2003). When considered as activity in specific areas of the brain, consciousness appears to depend on the activity of the thalamus and brain stem (Paus, 2000), or in higher prefrontal and parietal association areas (Marois and Ivanoff, 2005). The claustrum, along the underside of the neocortex, has also been identified as the region where widespread coordination of the activity occurs, resulting in

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the seamless quality of conscious experience; the claustrum synchronizes the activity between both the cortical hemispheres and between cortical regions within the same hemisphere (Crick and Koch, 2005).

In the case of the visual system, information comes through the primary visual cortex V1, which creates a well-defined map of the spatial information in vision. After this, information flows to the secondary areas V2, V3, V4, and V5. Neurons in V1 and V2 respond selectively to bars of specific orientations and they are believed to support edge and corner detection. In V2, neurons are tuned to basic properties such as orientation, spatial frequency, and color. In V3/V3A, they process global motion. V4 neurons are like V2 but they are tuned to features of intermediate complexity; faces are recognized in the inferotemporal cortex; and the area V5 plays a major role in the perception of motion and in eye movements. If V5 is damaged there is no perception of motion. If V1 is damaged but V5 is intact, then signals in V5 are correlated with the stimulus, but the subject has no conscious awareness of that fact. Figure 1 shows these areas in which face and object recognition regions (blue), receive their input largely from V1 (yellow) and V2. In short we find that sub-tasks in the vision process are distributed over several regions. (Zeki *et al.,* 1991; Zeki, 2003)

If we consider language, the complex manner in which aphasias manifest suggest that its production and processing are a tangled process. Certain components of the language functioning process operate in a binary fashion. These components include comprehension, production, repetition, and various abstract processes. Viewing each as a separate module is not quite correct due to subtle interrelationships mediating between these capabilities which all come into operation in normal behavior. The explanation of counterintuitive disorders such as alexia without agraphia can only be understood by postulating decision nodes that do not have physical neural correlates.

From the point of view of anesthesia, two states of consciousness may be postulated for the patient who is not fully anesthetized: (i) the patient seems to be cognizant responding to commands but with no postoperative recall or memory of the events; and, (ii) the patient can recall events postoperatively, but was not necessarily conscious enough to respond to commands. Our understanding of these cases must be addressed by the model of consciousness states that is developed, and reconciled with the hierarchy of conscious, preconscious, and subliminal processing that is well understood (Dehaene *et al*., 2006).

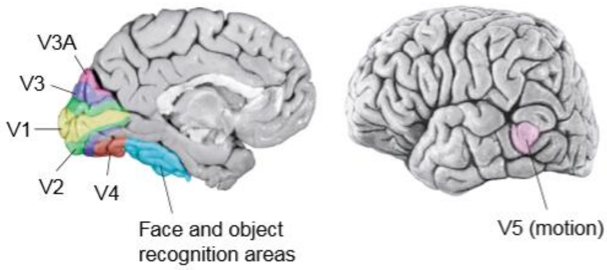

Figure 1. Areas of the visual brain

The mechanisms associated with consciousness are often very dissimilar both spatially and temporally and may be associated with different perceptions. This is so, for example, for the specific cases of color and visual motion awareness. The disparate and multiple mechanisms of perception and comprehension suggests that consciousness has no single neural correlate (Zeki, 2003).

But if there is no single neural correlate, how do distributed lower-level consciousnesses relate to each other, and how does the integration of the neural activity take place, as in the network hub research of van den Heuvel and Sporns (2013)? The general view is that the communication between preconscious states somehow maps to a single consciousness (Gilbert and Sigman, 2007) although a conceptual framework within which this communication may be addressed is not defined.

In this paper we take up this question by advancing a model of different hierarchically-defined consciousnesses which are mediated by languages and metalanguages with varying capacity to recruit lower level consciousness states. It is further assumed that some of these languages are quantum in character. The highest node in this hierarchical model, which is located in a non-physical space, represents the unitary consciousness but it does not have a single neural correlate, and, in this sense, it agrees with the available evidence.

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A Hierarchical Model of Consciousness

The idea of consciousness requires not only an awareness of things but also the awareness that one is aware. If awareness is some kind of a measurement, it should have a reference. This, in turn, poses two problems: Firstly, what is the reference for awareness? Secondly, how does consciousness choose between various possibilities?

The problem of the referent in awareness is an old one. The Vedic sages of India solved it by postulating a single universal, transcendental consciousness. In this view, the individual's empirical consciousness is a projection and the referent for it is the universal. The analogy of the same sun reflecting in a million different pots of water as little suns is provided to explain the empirical consciousness of the individual. The Māṇḍūkya Upaniṣad speaks of four basic states of consciousness: waking, dreaming, deep-sleep, and a fourth, which transcends these three. The waking state is primarily concerned with the embodied self and sensations. In the dreaming self, not all memories associated with the autobiographical self are available to the conscious agent. In deep-sleep where there is no dreaming, the conscious self is dormant; and in the fourth state, the conscious self is in a transcendent state.

In a somewhat similar way, Plato invokes an object in a cave that cannot be seen directly and whose shadows on the wall represent the accessible phenomena. In this view, truth is an abstraction and universals exist independent of particulars.

In Western philosophy, René Descartes proposed that consciousness resides within an immaterial domain of *res cogitans* (the realm of thought), to be contrasted from the domain of material things, or *res extensa* (the realm of extension). He assumed that the two realms interact in the brain, but this dualist Cartesian position is no longer taken seriously. Immanuel Kant arrived at a resolution similar to that of the Vedic tradition by arguing that empirical consciousness must have a necessary reference to a transcendental consciousness (a consciousness that precedes all particular experience). The universal or transcendental position is generally unacceptable to mainstream scientists who insist on reductionist models.

William James spoke of two kinds of selves: the self as knower (the "I"), and the self as known (the "me"). Each person's self is partly subjective (as knower) and partly objective (as known). The objective self may be described in its three aspects: the material self, the social self, and the spiritual self (James, 1890). Narrative self-reference is in contrast to the immediate knowing "I," that supports the notion of momentary experience as an expression of selfhood.

James believed that, as knower, the self is comprised of different mental states. Thought has no constant elements and every perception is relative and contextualized. States of mind are never repeated, and whereas objects might be constant and discrete, thought is constantly changing and mental states arise out of choices that are made by the mind. James believed that thought flows, and thus he could speak of a stream of consciousness.

If one were to find the boundaries between the "me" and the "I" of consciousness, it becomes essential to find a "minimal" sense of self. It is easy to speak of the intuition that there is a basic or primitive something that is the true self, and much harder to provide evidence for such belief. Conceptually, there must be something permanent – a bed rock -– underlying the stream of consciousness. It is known that medial prefrontal cortex (mPFC) supports self-awareness by linking subjective experiences across time and this function is of special importance to human social cognition and behavior. Additionally, the mPFC plays a role in decision making, executive control, reward-guided learning, and recent and remote memories. Cortical midline processes support narrative self-reference that maintains continuity of identity across time. It has been proposed that the function of the mPFC is to learn associations between context, locations, events, and corresponding adaptive responses, particularly emotional responses (Euston *et al.*, 2012). Therefore, neuropsychological case studies of episodic memory or loss of memory can help to define the neural bases of the narrative self.

From an information theory perspective, the quantification of the spatiotemporal distribution of current evoked in the brain using a transient magnetic field, can measure the level of consciousness. The idea behind this measure

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is that when the brain is unconscious, the evoked activity is either localized, or widespread and uniform, as during slow wave sleep or epileptic seizures (i.e., "lack of differentiation"). The conscious state, on the other hand, corresponds to differentiated but structured activity in the brain (Llinas *et al.*, 1999). This hypothesis requires an appropriate measure to be associated with the activity and one could use an entropy-based function for this (as seems logical). But the computation of such entropy required to create a three-dimensional map of the brain will be problematic, given the difficulty of accessing this activity, although one may instead consider the entropy of suitable evoked one-dimensional signals.

To deal with the empirical pre-conscious or conscious awareness, we postulate independent and distributed neural structures at the lowest Level 1, which may include subliminal and preconscious nodes. The nodes in the next higher Levels, 2 and 3, do not possess specific neuronal correlates and there is aggregation of several of the lowest consciousnesses, and the unitary consciousness is defined at the highest Level 3. This is shown in Figure 2 where it may be noted that the hierarchy has a tangled structure and cross-dependence that goes beyond what is shown in the sketch.

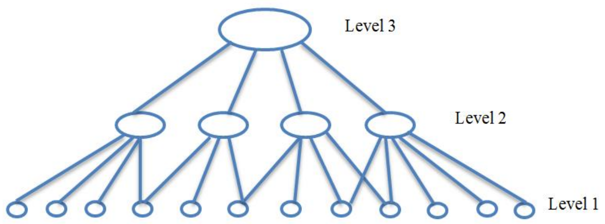

Figure 2. A hierarchical model of autonomous agents

The nature of the conscious experience would depend on what other nodes are accessible to the node at Level 3. The hierarchical details of the centers of consciousness will vary across different individuals. If more of the processing is done in Levels 2 and 3, one would expect faster response, and this may explain why chimpanzees appear to have a superior working memory for numerals compared to humans (Matsuzawa, 2013).

The speed of attribute binding would depend on the complexity of the communications and the relationships. Therefore, it is natural to assume that the binding of the attributes in Level 1 will be the fastest, and correspondingly slower in Level 2, and yet slower in the cumulative aggregation in Level 3. Due to the interference between various levels and the tangled nature of the information flow, one has illusions of perception as given by the example of Figure 3.

Since the idea of a transcendental consciousness cannot be reconciled with the reductionist position, Zeki (2003) argues that Level 1 agents are ontologically more fundamental and there is no need to invoke a transcendent entity. Speaking of the visual systems, he believes that the Level 1 cortical programs that construct visual attributes must precede any entrainment by experience. He therefore believes that Level 1 micro-consciousnesses precede the unified consciousness and they are present at birth.

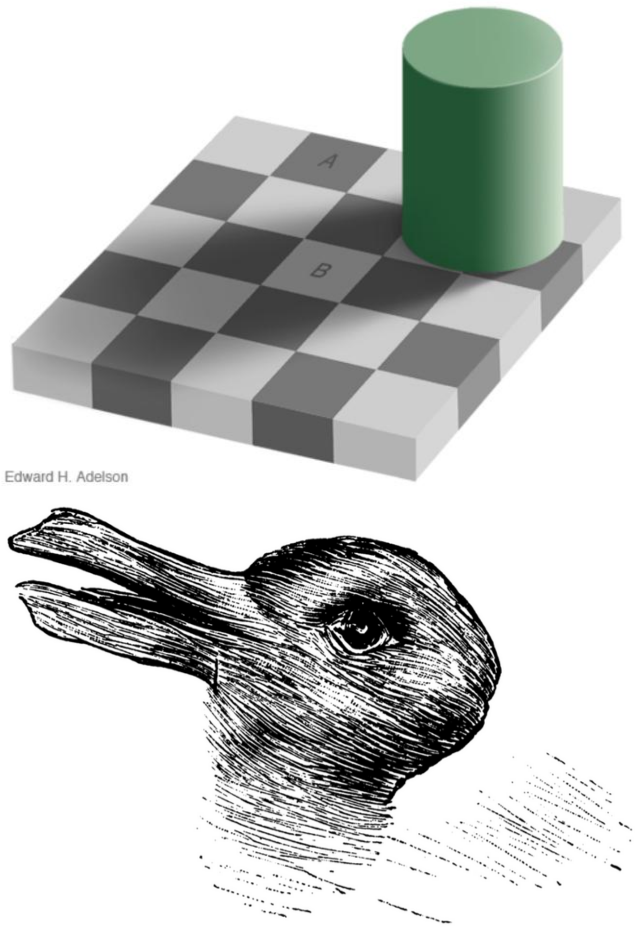

Figure 3. The checker shadow illusion by Edward H. Adelson (A and B have identical shades), and the rabbit and duck illusion from the 23 October 1892 issue of *Fliegende Blätter.*

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Zeki (2003) does not consider the possibility that the entrainment of the Level 1 consciousnesses may have occurred within the species in earlier generations. Our proposed model of Figure 2 is different from Zeki's in that nodes of Level 2 and Level 3 do not have neural correlates, and, therefore, they are located in a non-physical plane. It is because of this non-physical nature that these "virtual" nodes are able to synchronize activity in distant modules.

Recruitment of Consciousness and Preconsciousness States

The mind must select from the pool of memories in the emergence of any specific consciousness state that the subject can communicate to others. This selection may not be made consciously and it may be determined by the stream of previous consciousness states and the emotional state of the subject. It is to be expected that the executive control processes play an important role in the selection.

Furthermore, repeated selection of certain memories at the expense of others may affect the recall process, causing unwanted memories to be pushed back into the unconscious. Thus mechanisms can be recruited that prevent unwanted declarative memories from entering awareness, and this cognitive act may have enduring consequences for the rejected memories (Anderson and Green, 2001).

Executive control can influence the degree to which memories are being recruited to assist awareness. The performance of the executive control, even in the presence of awareness, will define the spectrum of awareness states. On the other hand, pathologies that prevent the recruitment of memories will degrade the states of consciousness and thus the consciousness of an Alzheimer's disease patient is of a lesser quality than that of a healthy individual. One may also speak of a person being only partially awake or fully awake using the same criterion.

If one were to refer to mindfulness as the state in which executive control can recruit memories with the greatest ease, we face the question of how to define it. Vago and Silbersweig (2012) describe mindfulness in terms of systematic mental training that develops meta-awareness (self-awareness), an ability to effectively modulate one's behavior (self-regulation), and a positive relationship between self and the other that transcends self-focused needs and increases prosocial characteristics (self-transcendence). They call their approach self-awareness: regulation and transcendence (S-ART). But there are consciousness states that are not associated with the subject's autobiographical self.

Entropy Metric for Consciousness States

Entropy is a commonly used mathematical measure for information and represents the degree of surprise associated with a given event or state. To determine the entropy of a three-dimensional structure associated with the brain is computationally impractical due to the difficulty of accessing the internal states of the brain and we must not only access the physical state of the neurons (if it were even possible), but also of the virtual nodes.

Since the inner states are mapped to behavior and this may be seen either in the ambulatory behavior, which may be two-dimensional for certain organisms, or in the behavior associated with the accessed mental states, which may be seen as one-dimensional.

The commonly used information entropy function for a one-dimensional system is:

$$S = -k_B \sum_i p_i \ln p_i$$

where p_i is the probability that the state i is occupied, and k_B is the Boltzmann constant in Joules/Kelvin, and the amount of energy required to erase one bit of information is $kT \ln 2$ (Landauer, 1961). The energy requirements for the physical processing of information by the brain are important in their own right, but this issue does not concern us here.

Although in thermodynamic systems all the states of the same energy are taken to have the same probability, this is not the case in information networks which are associated with decisions at various hierarchical levels. Experiments, as well as theoretical considerations, show that such networks are characterized by self-similar or recursive behavior (Bressler, 1995).

A network consisting of N nodes, labeled 1, 2, … n, may be represented by a graph where the connection between the nodes i and j is shown by a link between the two. A network may be valued for the function it performs to nodes outside of it, or it may be valued for the function it serves to the nodes within. Unlike engineered networks whose function (to nodes outside the network) is well-defined, goodness of the networks inside the brain cannot be quantified because of the elusiveness of the inner experience of well-being. Nevertheless, for the entire network one speaks of some general function such as value, utility, well-being, or welfare, whose definition is driven by extraneous considerations of theory.

In networks where value must be associated with the nodes within, one speaks of Pareto efficiency, or Pareto optimality, which is a state of allocation of resources in which it is impossible to make any one individual better off (in terms of a suitable measure of well–being) without making at least one individual worse off. A state is Pareto efficient or optimal when no further improvements can be made. The allocation, normally in terms of resources, could also be in terms of some property of the connectivity where we ignore the cost of the connections.

If one were considering connectivity as value, the total value of the network is proportional to n (n −1), that is, roughly, n^2, since in a network with n nodes each can make (n −1) connections with other nodes. This ignores the fact that in an evolutionary network the connection capacity of the nodes must vary as new nodes can only gradually get connected with others and some other nodes might leave the network. A careful analysis indicates that the potential value of a network of size n grows in proportion to $n \log n$.

Any theoretical definition of utility for a network is at best arbitrary; therefore, the actual connectivity can provide insight into value. Such connectivity is determined by cognitive or energy considerations with one defining feature of it being self-similarity across different layers, which is driven by the logic of local and hierarchical interactions. The value of the network may be examined from how close it is to self-similarity across many different layers.

Hierarchical modular brain networks are particularly suited to facilitate local neuronal operations and the global integration of local functions. Energy and connectivity considerations constrain functional networks but it is essential for these networks to integrate the broader picture (Kak, 2012). The self-organization of brain networks leads to both redundancy and self-similarity (Park and Friston, 2013).

Conversely, it has been proposed consciousness is a fundamental property possessed by physical systems having specific causal properties (Tononi and Koch, 2015). This approach correlates integrated information of a certain type directly with consciousness without explaining how the capacity for awareness emerges and, therefore, this hypothesis doesn't appear to have the potential of deepening the understanding of consciousness. This view appears to simply be a version of the strong-AI thesis according to which awareness will emerge in any computing system that is sufficiently complex. Consciousness may have specific physical correlates but the correlates are projections which cannot explain the problem of the necessary referent for understanding, or how awareness emerges in a classical system.

Anesthesia, Sleep, and Coma

General anesthesia leads to unconsciousness, amnesia, analgesia, and akinesia, while maintaining stability of the autonomic, cardiovascular, respiratory, and temperature regulatory systems. With the deepening of the level of general anesthesia, a progressive increase in low-frequency, high-amplitude patterns on the electroencephalogram (EEG) occurs. During recovery from coma, the EEG transitions through the patterns characterizing general anesthesia, sleep, and finally the awake state. There is a corresponding sequence of the return of regular breathing, salivation, tearing, swallowing, gagging, and grimacing, and finally the capacity to respond to oral commands.

Brown *et al.* (2010, p. 2644) argue that the "quantitative neurobehavioral metrics used to monitor recovery from coma could be used to track the emergence from general anesthesia from a functional state that can approximate brain-stem death to states similar to a vegetative state and, eventually, to a minimally conscious state." Such a metric would be similar to the one

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that has been proposed to determine the entropy of the activity in the brain as a measure of level of consciousness.

The idea of the uncoupling of perception from sensory inputs seems to support the idea of disembodied Level 3 consciousness. In a model proposed by Pandit (2014), an explicit sensation–perception coupling is incorporated into a macroscopic, functional model of consciousness. According to Pandit:

> The main hypothesis is that the minimum requirement for satisfactory general anesthesia is an uncoupling of perceptual experience from sensory input. The two model elements requiring elimination for this minimally adequate state are at least: (1) the 'perceptual experience' and (2) 'stimulus-evoked thoughts'. Eliminating these will (according to model) reduce attention to the surgical process and so the formation of explicit memories. With use of adjuvant drugs, a considerable proportion of the structures underpinning consciousness can be disrupted (Pandit, 2014, p. 202).

Pandit (2014) calls the drug-induced state in which perception and sensory inputs are uncoupled as dysanaesthesia, and he terms this as a new state between the usual conscious and unconscious states. In such a state, the patient may respond to commands and other stimuli but remain unaffected otherwise by pain or surgery. In his study, surgical patients under anesthesia were placed in a state of paralysis covering the entire body, with the exception of the forearm, which they could use to respond to commands and otherwise signal wakefulness or perception of pain. A third of the patients moved their finger when commanded, although they were under the usual level of anesthesia prescribed for such surgery.

The state where the patient is immobilized and cannot talk, but is still aware, may be dysanaesthesia. It may also be that the patient is paralyzed with neuromuscular blocker agents but has not been administered sufficient anesthesia to decrease the level of consciousness. If the identification of the dysanaesthesia state is true, one can explain it within the framework of our hierarchical model. When modules for language comprehension are not accessible to the consciousness node in Level 3, the subject is able to comprehend the command to move their finger if this node acts as a referent.

One could hypothesize that the modules are accessible, but networks to form memories are not, which is why there is no recollection of moving the finger in this state. But since there is awareness in the consciousness node of Level 3, we are compelled to postulate that awareness, without the accompaniment of memories, must have independent ontological reality. This is supported by neuroimaging results that show some parts of the cortex are still functioning in "vegetative" patients (Laureys, 2005). Primary sensory cortices in these patients are activated by an external painful stimulus, although these areas are functionally disconnected from the higher associative areas needed for awareness. Likewise, patients surviving severe brain injury may regain consciousness without recovering their ability to understand and communicate (Rosanova *et al.*, 2012).

Quantum Models

Certain broad characteristics of the evolution self-organizing living structures may be described by complex system theory, but analysis of other interactions and activity requires cognitive agents. The biological system functions at different scales of physical organization and there exist layers for which a classical representation is appropriate, and others for which we must describe using not only electrical flow of information, but also electromagnetic fields (Qiu *et al.*, 2015), as well as quantum mechanics.

Although the emergence of these cognitive agents (in Levels 1 and 2 of our model) is generally viewed in the context of the evolutionary history of the biological system that is grounded in classical macroscopic processes, we cannot ignore that underlying these macroscopic processes are physical structures that have a quantum basis at the deepest level of description. Previously, the quantum ground was ignored due to high level of noise in biological systems that would make it hard for any quantum state to maintain coherence, but there are many situations, such as vision and light harvesting, where quantum models appear appropriate (e.g., Pelli, 1985; Anna *et al.*, 2013; Lambert *et al.*, 2013).

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The question of noise in biology becomes irrelevant when we consider virtual nodes, whose existence has been assumed in the proposed model as well as elsewhere (Kak, 1996). Indeed, we need to consider a variety of objects, including quantum ones, in considering a general biological system from the perspectives of attention and high-level consciousness (Gautam and Kak, 2013). Quantum formalism is required to deal with fundamental complementarity in Nature, and it is associated with nonlocality, entanglement, and coherent behavior.

Memories may be modeled as nodes. The state of such a memory node depends on the activity in all related notes and, therefore, memories can never be the same as they are reconstructed each time. Since memories map into distributed activity over many neurons, the memory as a node is virtual and, therefore, it may be modeled as a quantum object (Kak, 2013). Memory nodes may interact with each other as virtual quantum particles and fields that are not affected by material channels within the brain.

If the higher nodes in the model of Figure 2 follow quantum characteristics, that would be an explanation for long range correlations inside the brain and in behavior. It has been proposed that the cognitive system, through its evolution, veils the nonlocal processes of the quantum interactions amongst consciousness states by creating classical narrative for them (Kak, 2014).

Conclusions

The mechanisms associated with consciousness are often very different both spatially and temporally and may be associated with different perceptions. This is so, for example, for the specific cases of color and visual motion awareness. Since there exist multiple mechanisms of perception, we are led to the view that there is no single neural correlate of unified consciousness.

Normal consciousness exists when the brain is in a state of harmony and is able to transmit signals throughout the brain. When this signaling is hindered either by injury or by anesthesia, the experience changes and in certain states the subject is witnessing, but uncoupled from the autobiographical self.

Although awareness by itself is an all-or-nothing phenomenon, the state of consciousness depends on the degree to which preconscious and memory states are accessible to awareness. The uncoupling of perception from sensory inputs supports the idea of a disembodied consciousness state. A consciousness state that is decoupled from specific memories of the individual indicates that such states have an ontological reality.

The degree to which memory nodes have recruited other nodes will have a corresponding effect on the quality of inner dialog and the corresponding experience of reality. We proposed a three-level hierarchical model to explain these findings, and the entropy associated with the consciousness states can, in principle, be estimated by means of experiments based on the nature of activity patterns.

The model of different hierarchically-defined consciousness states that are mediated by languages and metalanguages with varying capacity or ability to recruit memories has explanatory power. In theory, the computed value of the entropy associated with the consciousness states will be a scalar projection of a three-dimensional reality, and it can serve a purpose in identifying abnormal states. The highest node in this hierarchical model, which is located in a non-physical space, represents the unitary consciousness, but it does not have a single neural correlate, and, in this sense, it is consistent with the available evidence.

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