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The QBIT theory of consciousness

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Abstract

The QBIT theory is an attempt toward solving the problem of consciousness based on empirical evidence provided by various scientific disciplines including quantum mechanics, biology, information theory, and thermodynamics. This theory formulates the problem of consciousness in the following four questions, and provides preliminary answers for each question:

Question 1: What is the nature of qualia? Answer: A quale is a superdense pack of quantum information encoded in maximally entangled pure states.

Question 2: How are qualia generated? Answer: When a pack of quantum information is compressed beyond a certain threshold, a quale is generated.

Question 3: Why are qualia subjective? Answer: A quale is subjective because a pack of information encoded in maximally entangled pure states are essentially private and unshareable.

Question 4: Why does a quale have a particular meaning? Answer: A pack of information within a cognitive system gradually obtains a particular meaning as it undergoes a progressive process of interpretation performed by an internal model installed in the system.

This paper introduces the QBIT theory of consciousness, and explains its basic assumptions and conjectures.

Keywords: Coherence; Compression; Computation; Consciousness; Entanglement; Free-energy principle; Generative model; Information; Qualia; Quantum; Representation

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Introduction

The problem of consciousness is one of the most difficult problems in biology, which has remained unresolved despite several decades of scientific research. The hard core of the problem of consciousness is in fact the problem of qualia.

Qualia (plural for quale) refers to subjective conscious experiences such as a red color, a sharp pain, a particular smell, or a specific taste. As an example, when we see a red flower, the redness that we experience is a quale. Our consciousness at any moment consists of several different qualia. In fact, "To be conscious" means "to have qualia", and unconscious perception means "qualia-less perception".

To resolve the problem of consciousness, empirical evidence alone is not sufficient; we also need an appropriate theory to select and put together diverse (and sometimes seemingly unrelated) empirical evidence to reveal a hidden pattern. In this context, the QBIT theory is an attempt toward solving the puzzle of consciousness with pieces of evidence collected from different scientific disciplines including quantum mechanics, biology, information theory, and thermodynamics.

The QBIT theory formulates the problem of consciousness in the following four questions: (1) What is the nature of qualia? (2) How are qualia generated? (3) Why are qualia subjective? (4) Why does a quale have a particular meaning?

In sum, the QBIT theory is based on the following assumptions and conjectures:

(1) Consciousness requires Maxwell demon-assisted quantum computation.

(2) When information-theoretic certainty within a cognitive system about an external stimulus exceeds a particular level, the system becomes conscious of that stimulus.

(3) A quale is a superdense pack of quantum information encoded in maximally entangled pure states.

(4) When a pack of quantum information is compressed beyond a certain threshold, a quale is generated.

(5) A quale is subjective because a pack of information encoded in maximally entangled pure states are essentially private and unshareable.

(6) A pack of information within a cognitive system gradually obtains a particular meaning as it undergoes a progressive process of interpretation performed by an internal model installed in the system.

Consciousness requires computation

As Stanislas Dehaene and his colleagues[1] nicely argue, although centuries of philosophical dualism have led us to consider consciousness as unreducible to physical interactions, scientific evidence is compatible with the proposition that consciousness arises from nothing more than a particular type of computation. But what is computation, and what kind of computation is required for consciousness?

In cognitive science, computation could be regarded as transformation of one internal representation into another.[2,3] Here, “internal representation” is defined as a pack of information that stands in for an external stimulus.[4,5] As Cyriel Pennartz[6] argues, it is widely accepted in neuroscience and cognitive science that consciousness requires formation and transformation of internal representations by the nervous system. In the next section, I will explain how computation could give rise to consciousness.

How does the brain generate qualia?

To explain how brain computations could give rise to consciousness, I use an oversimplified model of sensory processing. Obviously, the brain operates in a much more complex manner than what is depicted in this model. However, this oversimplified model captures the essence of sensory processing by the brain, and clearly explains the basic idea underlying the QBIT theory of consciousness.

A sensory system contains a hierarchy of computational nodes. At the lowest level of this hierarchy, there is a sensory receptor (node 1 or N1) that converts the energy of an external stimulus into a pack of information. This pack of information is the lowest-level internal representation (representation 1 or R1) that the system creates to represent the stimulus. This internal representation is transmitted up the hierarchy to the next computational node (N2), where the representation undergoes a series of computational operations and, as a consequence, transforms into a higher-level representation (R2). This representation is then transmitted up the hierarchy to the next node (N3), where it is transformed into a representation (R3) that has a higher status than the previous one. This progressive transformation of representations continues until the highest-level internal representation is created at the top of the hierarchy.

Each computational node (for example, N3) receives at least two packs of information: a bottom-up input which is the representation sent forward from the preceding node (N2), and a top-down input which is sent backward from a higher-level computational node (for example, N4). The N3 integrates these packs of information to form a new representation. This new pack of information is compressed by N3, and the compressed representation is then transmitted to N4 for another round of "integration and compression". In the terminology of the QBIT theory, this hierarchical consecutive transformation of representations is called "representation distillation".

The whole computation performed by each node is somewhat similar to what is known as "local operations and classical communication" or LOCC. In quantum information theory, LOCC is a method of information processing in which a local operation is performed in a node of a system, and then the result of that operation is communicated classically to another node where another local operation is performed conditioned on the information received. LOCC, and its relation to the QBIT theory, will be discussed later in this paper. Now, let's return to the oversimplified model.

As a representation ascends the hierarchy, its mutual information with the external stimulus that it represents is increased. Mutual information is in a sense the converse of entropy.[7] Therefore, the representation generated by the sensory receptor (i.e. R1) has minimal mutual information and maximum entropy, while the representation generated at the top of the hierarchy has maximal mutual information and the least entropy. An idea similar to this has been recently proposed by Daya Shankar Gupta and Andreas Bahmer.[8] They argue that an increase in mutual information occurs as sensory information is processed successively from lower to higher levels in a cortical hierarchy. They suggest that this gradual increase in mutual information contributes to perception.

Mutual information between two variables (X and Y) is the average reduction in uncertainty about X that results from knowing the value of Y. In the oversimplified model discussed here, X is a pack of energy (i.e. an external stimulus) and Y is a pack of information (i.e. an internal representation). An increase in mutual information is equivalent to an increase in certainty of the sensory system about the external stimulus. In this sense, the QBIT theory suggests that when certainty of a system about an external stimulus exceeds a particular level, the system becomes conscious of that stimulus. To attain such a high level of certainty, quantum information is required. As Patrick Hayden[9] nicely mentions, "with quantum information, it is possible not just to be certain, but to be more than certain." This wonderful effect of quantum information inspires the idea that in order to become conscious, we need to go beyond the limits of classical physics. Consciousness requires quantum phenomena, including entanglement and coherence. These quantum phenomena and their role in the emergence of consciousness will be explained later in this paper. Let's turn back again to the oversimplified model.

Computations performed at each stage of the hierarchy could be regarded as a kind of "interpretation" that gives a particular meaning to the representation before being sent to the next stage. As a representation ascends the hierarchy, it becomes not only more compressed but also simpler and more meaningful for the system. When the representation becomes compressed beyond a certain level, it transforms into a quale. Therefore, a quale is the most compressed, the simplest, and the most meaningful representation sitting at the top of a hierarchy of internal representations for an external stimulus.

Is there any scientific evidence in support of this oversimplified model of sensory processing? Yes. To some extent, literature on "predictive coding", "the simplicity principle", "Bayesian inference", and "the free-energy principle" supports this model. These are discussed briefly in the following sections.

Predictive coding

Predictive coding was first developed as a data compression strategy in signal processing.[10] It is an encoding strategy by which only unpredicted elements of a signal are transmitted to the next stage for further information processing.[11] In fact, predictive coding compresses a signal (or a representation) by removing the predictable, and hence redundant, elements of that signal.[12]

In a hierarchical model of predictive coding, as described by Rajesh Rao and Dana Ballard,[12] a pack of sensory information in a computational node (for example, the primary visual cortex or V1) is compared against a prediction received from a higher-level computational node (for example, V2). As a result of this comparison, deviations from such predictions (called the prediction errors) are identified and only these elements are fed forward to the next computational node. In this context, the prediction error is the difference between a pack of sensory information and a higher-level prediction that both enter a computational node.

In predictive coding, feedback and feedforward connections allow the serial, reciprocal exchange of predictions and prediction errors.[13] Signals (or packs of information) descending the hierarchy via backward connections (i.e. top-down inputs) contain predictions, while signals ascending the hierarchy via forward connections (i.e. bottom-up inputs) contain prediction errors.

In general, a computational node at any given stage attempts to predict the representation (or the pack of information) generated at the stage below. Furthermore, the same computational node also attempts to improve (or update) the representation at the stage above by reporting its errors of prediction.[13] As a representation ascends this hierarchy, its errors are gradually minimized. The representation generated at the top of the hierarchy, has the least prediction errors, and hence is the most accurate prediction that a sensory system has about the associated external stimulus.

Daniel Little and Friedrich Sommer[7] argue that the predictive accuracy of an internal representation could be measured by its mutual information with the sensory input. In this context, mutual information is the amount of information an internal representation contains regarding the associated sensory input. On the basis of these arguments, the QBIT theory suggests that a quale is an internal representation generated at the top of the hierarchy of predictive coding. Therefore, a quale is the most accurate representation, with the least prediction errors, and maximal mutual information.

The simplicity principle

The simplicity principle is a powerful unifying principle in cognitive science capable of explaining a wide range of phenomena including perception as well as learning.[14] The simplicity principle states that a primary goal of sensory processing is to create the simplest possible internal representations of external stimuli.[15] The tendency of a cognitive system to create the simplest possible representations is due to the fact that simplest representations allow the most accurate predictions and provide the best basis for decision-making, both necessary for survival in a challenging environment.

To create the simplest possible representations, a cognitive system should be endowed with the capacity to compress information. There is a variety of techniques for information compression that a cognitive system (such as the brain) can exploit

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to maximize simplicity of its internal representations. One of these techniques is the "matching and unification of patterns" as described by Gerard Wolff.[16] This kind of information compression is accomplished through a series of computational operations that search a pack of information to find patterns that match each other, and then merge or unify them so that multiple configurations of the same pattern are reduced to one. Wolff[17] argues that compressing a representation (or a pack of information) via the matching and unification of patterns increases both the simplicity and the explanatory power of that representation. He suggests that this kind of information compression via the matching and unification of patterns is an essential part of perception, cognition, and learning in the human brain.

The simplicity principle is closely connected to the concept of "Bayesian inference".[14,18,19] Jacob Feldman[20] argues that, in cognitive science, complexity minimization and Bayesian inference are regarded as profoundly intertwined, if not practically the same thing. It is noteworthy that Bayesian inference has a built-in tendency towards representations with fewer parameters (i.e. simpler or lower-dimensional representations) over those with more.[21] But what is Bayesian inference, and how is it related to the QBIT theory of consciousness.

Bayesian inference

Bayesian inference is a statistical method of reasoning in which information already available in a system (i.e. prior knowledge) together with new evidence (i.e. incoming information) are used to generate, test, and update a hypothesis (or a belief) about the hidden causes of an event. Bayesian inference can be realized using a variety of strategies, one of which is the hierarchical predictive coding.[22] Both predictive coding and Bayesian inference agree upon the importance of integrating external inputs with internal signals (i.e. predictions, priors, or hypotheses).[22]

Predictive coding could be regarded as a kind of hierarchical Bayesian inference, in which, top-down predictions play the role of "empirical priors".[23] However, at the top of the hierarchy, there is no top-down prediction, and expectations become "full priors". These expectations are usually associated with instincts and prior beliefs that are selected by evolution as necessary for survival.[23]

Experimental evidence shows that the visual system uses a hierarchical Bayesian inference to interpret sensory information.[24] This is apparently not restricted just to visual perception. In general, perception could be considered as a kind of hierarchical inference or successive rounds of hypothesis testing and updating.[25,26]

Hierarchical Bayesian inference gradually minimizes uncertainty in a series of hypotheses about an event. This is achieved by accumulating (or maximizing) Bayesian evidence toward the top of the hierarchy. The QBIT theory suggests that when accumulation of Bayesian evidence (and hence certainty) within a cognitive system about an external stimulus exceeds a particular level, the system becomes conscious of that stimulus. This occurs at the top of the hierarchy of Bayesian inference. In fact, a quale is regarded as a hypothesis (about the hidden cause of a sensory input) for which the system has accumulated the greatest amount of Bayesian evidence.

Bayesian inference, predictive coding, and the simplicity principle could be regarded as different manifestations of a more fundamental principle called the "free-energy principle". In the next section, this unifying principle and its relation to the QBIT theory is discussed.

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Free-energy principle

The free-energy principle states that any self-organizing system (such as a biological organism) that is able to resist decay and maintain its integrity over time must constantly minimize its internal entropy by minimizing its variational free energy.[27] In this context, variational free energy is an information theoretic analogue of the thermodynamic free energy, and entropy is the long-term average of surprisal (or uncertainty).[28,29] Therefore, minimizing free energy is equivalent to reducing entropy and uncertainty.[30] Shannon entropy (also called uncertainty) quantifies how much is not known about something.[31] In other words, entropy is a measure of the amount of information needed to eliminate all uncertainty about a variable.[32]

According to the free-energy principle, all biological organisms are forced to generate internal models of their environments.[33] They must create hierarchical generative models of the world in order to become capable of minimizing their free energy, and consequently minimizing their internal entropy.[29] Minimizing free energy is roughly equivalent to maximizing the evidence for a model.[33] Therefore, an organism must constantly maximize evidence for its generative models of the world through Bayesian inference and active sampling of sensory information.[26,34]

The free-energy principle proposes that adaptive fitness of an organism corresponds to minimization of sensory uncertainty, which is the average of surprisal.[35] According to this principle, when an organism is stimulated through its sensory receptors, it instantly (and automatically) initiates an attempt to minimize sensory surprisal by means of active inference .[35]

Variational free energy is roughly equivalent to prediction error.[23] Therefore, minimizing free energy increases the accuracy of predictions of a cognitive system. Furthermore, minimizing free energy gives rise to reduction of complexity of accurate predictions.[36] In fact, free energy can be expressed as complexity minus accuracy.[37] Therefore, minimizing free energy corresponds to minimizing complexity, while maximizing accuracy.[38] Here, "complexity" is used in the sense of algorithmic (or Kolmogorov) complexity.

Kolmogorov complexity measures the amount of statistical regularity, and not the amount of information, within a representation.[39] Statistical regularity is a kind of redundancy.[40] Any regular or predictable element of a representation reduces its simplicity. In fact, the degree of simplicity of a representation is inversely related to the amount of statistical regularity it contains.[40] Therefore, minimizing free energy of a representation gives rise to redundancy reduction and hence compression of the representation.

A cognitive system (such as the brain) could minimize its variational free energy by recurrent information passing through a hierarchy of computational nodes, so that each node minimizes uncertainty in the incoming information by receiving a prediction (or a prior) and responding to errors in that prediction.[41] In fact, the brain attempts to reduce the probability of being surprised by an external stimulus by reducing errors in its representations of that stimulus.[30]

On the basis of all these arguments, it is plausible to suggest that, in the brain, the overall drive of the free-energy principle is to (1) create an internal model of the external world, (2) maximize Bayesian evidence for that model, (3) reduce uncertainty in internal representations, (4) increase the accuracy of internal representations, (5) maximize simplicity of internal representations, and (6) make the internal representations more compressed.

Allan Hobson and his colleagues[42] argue that when the brain reduces complexity, it also reduces its thermodynamic free energy, and hence reduces the work needed to attain that state. In fact, a brain state with minimum complexity is also the state with minimum thermodynamic free energy. In other words, a maximally simple brain state is in an energetic minimum. The QBIT theory of consciousness suggests that a conscious state corresponds to a state with the minimum possible variational free energy. Therefore, in a hierarchy of internal representations, a quale is the representation that is in an energetic minimum.

Consciousness and meaning

Information on its own has no intrinsic meaning. It is "interpretation" that adds a meaning to information. The same pack of information can have different meanings, depending on how it is interpreted by a system.[43] The QBIT theory suggests that, in a cognitive system, what interprets a pack of information and assigns a particular meaning to it is an internal model that has been installed in the system. This internal model is in fact a hierarchical generative model. A pack of information (i.e. an internal representation) undergoes interpretation at each stage of this hierarchy, and thus gradually becomes more meaningful as it ascends toward the top of the hierarchy. Consistent with this conjecture, Stephan Tschechne and Heiko Neumann[44] argue that computations in early and intermediate stages of visual hierarchy transform local representations into more meaningful representations of contours, shapes and surfaces.

For each quale that the brain can generate, there is a specific internal model installed (or encoded) in the brain. To generate a quale, its associated internal model should be activated. However, bottom-up activation of an internal model does not necessarily give rise to generation of a quale, unless its activation is strong enough to reach the top of the hierarchy. If not, activation of the internal model results in a quale-less (or unconscious) perception. Even in the absence of consciousness and sensory inputs, internal models can guide the behavior of a system.[45]

Internal models are created as a cognitive system observes and interacts with its environment for a long enough time. In other words, internal models gradually form as the system repeatedly acts on the environment through its actuators and receives feedback through its sensors.[45] When the environment or the tasks that should be performed to survive in the environment are complex enough, the cognitive system reacts to this challenge by developing internal models.[45] Expectations and needs are two factors that shape internal models of an animal. As animals evolve to behave appropriately and survive in a dynamic environment, internal models of the environment emerge within their nervous systems. Internal models are hierarchical, nonlinear and dynamic. They could be shaped by learning, and become updated during the lifetime of an animal or over the course of evolution.[45]

Information compression

The QBIT theory assumes that the key to solve the problem of consciousness is the concept of "information compression". Sometimes the phenomenon of consciousness appears so enigmatic that one cannot stop thinking that the emergence of consciousness requires something like a magic. According to the QBIT theory, if emergence of consciousness actually requires a magic, this magic is performed by information compression. In nature, we have a good example of the magic of compression: extreme compression of matter creates an enigmatic entity, called the "black hole". Likewise, extreme compression of information might create another enigmatic entity, a quale. The QBIT theory suggests that packing too much quantum information into a small space causes something like a gravitational collapse, giving rise to the creation of a quale. Roughly similar to a black hole (which is a superdense pack of matte), the QBIT theory considers a quale as a superdense pack of quantum information.

The QBIT theory assumes that, for extreme information compression, quantum phenomena (such as entanglement and coherence) are required. Classical physics cannot perform the magic. Consistent with this assumption, it has been shown that entangled quantum states can be compressed much more than what is possible via classical lossless compression.[46] Furthermore, quantum entanglement is the most important resource for superdense coding.[47]

A benefit of information compression is a decrease in the computation requirements by a factor equal to the compression ratio. Such a decrease might be important for systems in which the computing power is limited or too expensive.[48] In fact, any system with limited resources that is located in a challenging environment and solve complex problems need to compress information.[49]

Information available to our sensory receptors is highly redundant. Information compression via the reduction of redundancy appears to be a major goal of computation in the earliest stages of sensory systems.[50] For example, lateral inhibition in the retina could be viewed as a process of removing local correlations in retinal input, thus providing a less redundant and hence more compressed representation of that input.[15] Therefore, a main goal of computation in the retina is to transform the visual input into a statistically independent form as a first step in creating a compressed representation in the cerebral cortex.[51,52] A computational benefit of information compression for the cerebral cortex is that the transfer and utilization of a huge amount of sensory information would become much easier and less costly. Furthermore, information compression causes a significant reduction in the amount of memory required to store a pack of information.

As Gerard Wolff[17] argues, compressing a pack of information could be considered as a process of reducing informational redundancy and consequently increasing its simplicity, while retaining as much as possible of its non-redundant predictive information. In fact, compression of information is a cognitive ability that allows predicting the future from the past and estimating probabilities. By this cognitive ability, an animal, for example, can predict where food may be found or where there may be dangers. The better and more efficiently an organism can compress information, the more accurate its predictions will be.[53] All successful predictive systems, including the human brain, could be regarded as approximations of an ideal information compressor.[54]

Based on these evidence and arguments, it seems plausible to suggest that information compression is an important part of cognition.[14,16] The QBIT theory suggests that it is also an important and necessary part of consciousness. The idea that consciousness requires information compression is not new. Phil Maguire and his colleagues[54] as well as Giulio Ruffini[55] have proposed a similar idea previously.

Phil Maguire and his colleagues[54] propose that consciousness can be understood in terms of "data compression", a well-defined concept from computer science that acknowledges and formalizes the limits of objective representation. They suggest that information compression occurs when information is bound (or integrated) together through the identification of shared patterns in a pack of information. Maguire and his colleagues further argue that data compression is not just something that happens when a pack of information is reduced in size. Due to its connection to induction and prediction, information compression can be considered as a process that provides reliable proof of (or evidence for) understanding or comprehension. The higher the level of compression that is achieved by a system, the better the predictions of the system will be, and the greater the extent to which it can be said that the system has understood the information. This is very similar to the idea proposed by Gregory Chaitin[56] that "compression is comprehension".

Giulio Ruffini[55] proposed that consciousness is possible only in computing systems that are capable of creating compressed representations of the external world. He argues that the brain is a model builder and a compressor of information. Ruffini suggests that the brain builds a compressive model and uses it to perform information compression with simplicity as a guiding principle.

Consciousness requires quantum phenomena

The QBIT theory suggests that consciousness requires quantum phenomena, including entanglement and coherence. Quantum entanglement and coherence are real physical resources which are indispensable for certain computational tasks that cannot be performed using classical resources such as energy.[57,58] However, these resources are very fragile at physiologic temperatures as compared to cryogenic temperatures, since the environmental noise increases with increasing temperature, resulting in rapid decoherence and loss of useful entanglement.[59] In fact, decoherence is a common obstacle for all phenomena that depends on the capacity of preserving and using quantum coherence and entanglement.[60]

Although coherence and entanglement are so fragile at physiologic temperatures, there is strong evidence that these two quantum phenomena play important roles in certain biological processes, including photosynthesis in plants and bacteria as well as magnetoreception in birds.[61-64] Furthermore, there is a growing body of literature in support of the idea that entanglement and coherence are also involved in some aspects of cognition.[65-68]

The QBIT theory suggests that quantum entanglement and coherence play an essential role in consciousness. This idea is also the basis of the Orchestrated Objective Reduction (Orch OR) theory of consciousness, developed by Stuart Hameroff and Roger Penrose.[69] The Orch OR theory suggests that, for consciousness to occur in a system, it is necessary that a sufficient amount of material (e.g. microtubule) be kept in a coherent (or pure) state for a long enough time.

In quantum mechanics, every system has a set of states. A state is called pure if it contains maximal information about the system.[70] The Orch OR theory suggests that different states of a tubulin represent information in the brain. The theory considers tubulin bits (and quantum bits, or qubits) as entangled coherent states. These coherent (or pure) states of microtubules in one neuron can extend by entanglement to microtubules in adjacent neurons, potentially extending to brain-wide syncytia.[69] In line with this theory, evidence shows that long-lived quantum coherence is possible in microtubules as well as in some other molecules within the brain at physiologic temperatures.[71,72]

Maximally entangled pure states

The QBIT theory proposes that a quale is a superdense pack of quantum information encoded in maximally entangled pure states. But why maximally entangled pure states?

Maximally entangled pure states are ideal resources for quantum computation, while mixed states are not very useful for this purpose.[73] Some unique and wonderful effects of quantum computation arise only when maximally entangled pure states are available for use. From a thermodynamic point of view, production of maximally entangled pure states is costly, meaning that it requires consumption of energy and production of entropy. However, for some computational tasks such as estimating a given parameter with a high precision, it is more cost effective for a system to use maximally entangled pure states rather than using already available mixed states.[74] Therefore, above a certain level of precision, the cost of computation will be reduced if maximally entangled pure states are used.

Since consciousness requires quantum computation with maximally entangled pure states, a conscious agent should be endowed with a mechanism that constantly produces and preserves such states. The QBIT theory proposes that, in the brain, the task of producing and preserving maximally entangled pure states is partly performed by something like a Maxwell demon. In thermodynamics, a Maxwell demon is an entity that couples to a system, and improves thermodynamic efficiency of that system.[75] In fact, a Maxwell demon extracts work and removes heat from a target system in a cyclic process. Work extraction and heat removal (which is a thermodynamic process) is equivalent to converting mixed states to pure states (which is an information theoretic process).[76] In quantum mechanics, there is a special kind of Maxwell demon which is able to transition a qubit into a purer state.[77] In other words, it can inject pure states to an ongoing quantum computation. This kind of Maxwell demon is in sharp contrast to locally operating classical Maxwell demons. It can purify a target qubit over macroscopic distances on the order of meters and tolerates elevated temperatures of the order of a few Kelvin. Such a spatial separation between the system and the demon has practical benefits because it prevents undesired heating of the system during the demon's memory erasure. In fact, this particular demon not only purify a qubit but also makes the environment surrounding the qubit slightly colder. Furthermore, in contrast to the classical demon, this quantum demon utilizes its purity or coherence as a thermodynamic resource.[77]

Although the concept of Maxwell demon was first introduced in thermodynamics, it gradually found applications in other scientific disciplines including information theory and biology. In biology, for example, it has been demonstrated that the action of a Maxwell demon is necessary for chemotaxis in Escherichia coli.[78,79] In this case, the Maxwell demon attempts to reduce the effects of the environmental noise on the target system. The QBIT theory proposes that consciousness is another biological process in which a Maxwell demon could play important roles. One of these roles is production and preservation of maximally entangled pure states for quantum computation.

Quantum computation will be more efficient if maximally entangled pure states are used.[80] Furthermore, some computational tasks, such as dense coding, generally require pure maximally entangled states.[81] However, due to the effects of decoherence, practically available states are most likely to be non-maximally entangled, partially mixed (i.e. not pure), or both.[80] To counter this problem, different methods of entanglement distillation as well as state purification have been proposed and realized experimentally. Entanglement distillation is a process that increases entanglement, but not purity; while, state purification is a process that increase purity, but not entanglement.[80] Entanglement distillation converts a number of less entangled qubits into a smaller number of maximally entangled qubits.[82] While, state purification converts mixed states into maximally coherent (i.e. pure) states.[83]

Both entanglement distillation and state purification can be realized by a sequence of "local operations and classical communication" or LOCC.[82,84] Therefore, a sequential series of LOCC can potentially generate maximally entangled pure states.[85]

Why are qualia subjective?

A prime feature of qualia is that they are subjective. This means that they are private and unshareable, accessible only to the system that is generating them. Observation or measurement of qualia generated within a system is not possible for any other system.

A quale could be regarded as a private key. In terms of information theory, a private key is a string of bits which has two important features. First, it is perfectly correlated. Second, it is inaccessible to any other person.[73] The first feature is due to maximal entanglement. The second feature is due to maximal coherence (or purity), because an eavesdropper who attempts to obtain knowledge about the private key will unavoidably disturb it, introducing a phase error into the system, which destroys purity.[73]

"Entanglement is the quantum equivalent of what is meant by privacy." This nice statement, and the argument behind it, in a paper by Ryszard Horodecki and his colleagues[73] provided insight for the QBIT theory to propose that quantum entanglement might be able to explain the subjectivity of consciousness.

Quantum entanglement has limited shareability. In the case of pure states, it can even be absolutely unshareable.[86] All these arguments can be expressed in terms of the monogamy of entanglement. According to the monogamy of entanglement, maximally entangled pure states are not shareable.[87,88] Since qualia are encoded in maximally entangled pure states, they should be private and unshareable.

Consciousness and quantum information

The QBIT theory proposes that qualia are quantum information in nature, and emergence of qualia requires quantum computation. Most physical phenomena in nature can be formulated and better described in terms of quantum information and computation.[89] Gravity is a prominent example. Reconciling quantum mechanics with gravity is a hard and yet unresolved problem in physics. Recently, quantum information theory and concepts like entanglement and quantum error correction have come to play a fundamental role in solving this problem. For example, it has been suggested that gravity comes from quantum information.[90] Furthermore, recent evidence from theoretical physics imply that entangled qubits are not only the origin of gravity, but also the origin of matter and space.[91] It seems that, at some level, everything reduces to information.[92] This inspires the QBIT theory to propose that, at a fundamental level, qualia are quantum information or entangled qubits.

As our knowledge about the nature of quantum information increases, we would gain more insights about the nature of qualia. At present, we know that quantum information is nonlocal. It does not make sense to ask where quantum information is at any given time; it is nonlocally distributed in the entangled state.[88] Since quantum information is nonlocal, qualia should also be nonlocal. Furthermore, there is some evidence that quantum information is physical.[93] If this turns out to be true, then qualia must also be physical.

In general, information cannot exist without a physical substrate that encodes it.[94] Therefore, information that we retain in our brains should also have a physical substrate. This physical substrate is a kind of qubit. But what plays the role of qubits in the brain? There are, at least, two potential candidates: the "tubulin bits" described by Stuart Hameroff and Roger Penrose,[69] and the "neural qubits" described by the physicist Matthew Fisher.[95]

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Matthew Fisher[95] suggests that, in the brain, nuclear spin of a single phosphorus atom residing on a Posner molecule can serve as a qubit, called a "neural qubit". A Posner molecule is a kind of calcium phosphate molecule with a unique chemical structure that can protect phosphorus nuclear spins from decoherence for very long times. Phosphorus nuclear spins in different Posner molecules can become entangled and remain so for relatively long periods of time.[72]

In the brain, the Posner molecule seems to be a promising platform for quantum computations based on phosphorus nuclear spin. The nucleus of a phosphorus atom is an extremely weak magnet. It can be thought of as a compass needle that can point toward either north or south. These north or south positions are equivalent to zeros and ones of binary codes which form the basis of classical computation. In classical computers, information is encoded in zeros and ones, which themselves are represented by different voltages on semiconductors.[96]

Conclusion

According to the QBIT theory of consciousness, a quale (or a subjective conscious experience) is the end-product of "representation distillation". A quale is a maximally compressed representation that is most meaningful for the brain. It is the simplest, the most accurate, and the most efficient representation that could be generated to represent an external stimulus within the brain. When the brain generates such a representation, its uncertainty about the external stimulus becomes as minimum as possible.

The QBIT theory of consciousness is in its first stage of development, attempting to absorb relevant evidence from various scientific disciplines. Apparently, it is not a complete and comprehensive theory, but I think it is on the right path toward solving the problem of consciousness.

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