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A Conjecture on the Nature and Evolution of Consciousness

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Abstract:

The profound importance of consciousness in everyday life suggests that it is a natural and necessary outgrowth of our biological heritage. In this paper we offer a conjecture that consciousness is a deep property of biological life itself.

We propose a specific model of how a form of core consciousness could be present in all life forms, and subsequently how each species could create a unique form of consciousness from that common core. We formulate the first

consideration as the Core Consciousness Conjecture, and the extension to all animals as the Extended Core Consciousness Conjecture.

Keywords: consciousness; evolution;

Introduction

The discussion of human consciousness is a rich tapestry of interwoven threads from many disciplines. From the Greek philosophers we can trace a line through Aquinas (*Summa Theologica*) to Descartes (1985) and his theory of Dualism, and most recently to Chalmers (1995) and his formulation of the “easy and hard” problems of consciousness. In the nineteenth century a new thread emerged in psychology, exemplified by the works of James (1890/1981) and Freud (1953-1974), each trying to understand the mind scientifically from the observation of human behavior, without the benefit of the tools to examine the underlying mechanisms of the brain. In the late twentieth century, with the advent of the “neural correlates of consciousness” approach, exemplified by the work of Crick and Koch (1992, 2003), a surge of activity occurred, trying to identify those neural correlates, especially in subdomains such as visual awareness. This activity has generated an enormous literature and fascinating insights into detailed components of consciousness, such as attention (Koch, C., & Tsuchiya, N. 2007).

This wealth of detail has prompted several authors to formulate book length overviews that attempt a more unified explanation of how consciousness evolved and how it fits into a more general model of the mind. We are thinking particularly of the works of Edelman (1992, 2003, 2004), Damasio (2010), Llinas (2001), Baars (2001) and Dehaene (2014). In what follows, we outline our underlying model of the mind/brain which is based

on some of the common elements in their proposals, especially those underlying the “global workspace” model of Baars and Dehaene.

The richness of our current picture of human consciousness points in a tempting direction: consciousness as a special characteristic of humans – if not in absolute terms, certainly relative to all other animals. We find that the framing of many discussions still treats consciousness as essentially *human* consciousness, far removed from any consciousness we may glimpse in other animals. It is easy to see humans as the ultimate result of evolution, rather than as one of its many successful results, and thus to see consciousness, and other capabilities such as language, as evidence of our specialness.

However, we take the opposite perspective: we argue that human consciousness is a *variation* on a form of consciousness that is present in *all* animals and, possibly, in all sufficiently complex multicellular organisms. This is consonant with the growing chorus of support for assuming that many non-human animals are also conscious (Declaration at The Francis Crick Memorial Conference, 2012). We believe our perspective complements prior approaches, and perhaps even integrates the apparent dichotomy in the question of the uniqueness of human consciousness: we assert that all animals are conscious (so consciousness is not *uniquely* human), but that humans have a particular expansion of consciousness, given our neural architecture (human consciousness has unique *aspects*).

We hope our contribution offers at least two advantages: if validated by experiment, the proposed model places the study of human consciousness on a firmer footing by deepening its connection to the consciousness of other animals; secondly, it establishes a way to think

about the consciousness of each species of animal that allows for its uniqueness within a common framework.

In what follows, we briefly summarize the approach and its rationale, then make two specific novel conjectures about consciousness, and elaborate how the consequences of those conjectures connect to current theories of consciousness, especially those of Edelman, Damasio, Llinas, Baars, and Dehaene, noted above.

Overview of the Proposal

As Llinas emphasizes (2001), the evolution of multicellular life took a long time. It required each cell in the ensemble to evolve a specialized role, while becoming dependent on other cells. For such an ensemble to survive and prosper, there had to be mechanisms by which the cells coordinated their actions, so that the ensemble could behave as a single entity with a stable identity. For example, ensembles of cell needed to be able to coordinate together to monitor the internal needs of the organism, register external stimuli, and initiate motor activity. We propose that those mechanisms and the resulting ability of the multicellular ensemble to act as a unitary entity was the beginning of consciousness.

While we believe this to be the first time that consciousness has been directly tied to the evolution of multicellularity, we see it as a natural extension of Llinas' observation of the challenges involved in forming multicellular lifeforms. The author who comes closest to framing a similar point of view is Damasio (2010), and we are particularly indebted to his discussion of homeostasis and biological value, which we incorporate in a later section. Tononi's theory of consciousness as integrated information can also be seen as a way to present a similar idea in an information theoretic way, with the potential advantage of finding a numerical measure of

consciousness. Butler (2012) has also expressed a view which is very much aligned with our own: “consciousness is a biologically generated phenomenon that requires, at minimum, a population of cells that has the ability to detect sensory stimuli, such as light, sound, or chemicals, and to communicate among each other—i.e., a set of neurons within a multicellular organism.”

We should also point out that more and more authors (see for example Boly et al. 2013) share the conviction that consciousness exists in non-human animals, and Edelman and Seth (2009) have set out one framework for such an investigation. We see our conjecture as the beginning of a framework for investigating consciousness in all multicellular lifeforms.

With these considerations as context, we now can proceed to lay out the details of our model. We propose that, in the process of multicellular ensembles acting as a unitary entity, this particular mechanism included the formation of a sequence of particular states of the ensemble, each state bringing together the subassemblies of cells – for example, internal and external monitoring, and specific motor behavior – required for that instant. We call each of these instants, in which the ensemble is in a particular state, its conscious state. The rapid succession of such states produces the effect of being continuously conscious. At this point in the argument we do not hypothesize the particular character of each conscious state: we only require that it represents the coherent coming together of those parts of the entity needed for its survival at that instant. It provides the entity with a coherent, dynamic but stable identity.

We argue that this particular architecture had a significant survival advantage. It enabled the entity to respond to changes in its internal or external environment with actions that benefitted the whole entity, not with actions benefitting the particular

subassembly that initially processed the stimulus. To posit a simple example: it might benefit an overheated animal to relax in a cool watering hole, but not if there is a tiger nearby who is about to pounce. This coordinated capacity was particularly important when the stimulus presented a novel situation, requiring a novel response. Furthermore, the rapid sequential production of new (conscious) states, having the appropriate particular interconnection of subassemblies, allowed the entity to try out new solutions, particularly solutions not already available from any subassembly as prior fixed action patterns. It was and is a beautiful learning and adapting mechanism.

We believe that the connection - between learning and the evolutionary advantage of creating a unitary state - offers a new perspective on the role of consciousness, and later we propose that it plays a major role in how all animals learn. In this regard, our model resonates with others who have suggested that a critical function of consciousness is to mediate learning (e.g., Solms, 2013; Baumeister et al 2011). It offers an additional insight into why consciousness can be expected to play an essential role in many or all animals.

In summary, we propose that the ability of a multicellular entity to dynamically create a sequence of states, each optimally interconnecting the parts of the entity to respond to the needs of that instant, was a design for multicellular organisms that gave them a huge evolutionary advantage, and resulted in that design being used by many, if not all, animals. In dynamically creating a state that optimally represented the unitary stable nature of the entity, the mechanism gave rise to a type of organism that could evolve to fit in many niches, and, when we see that design operating in humans today, we call it human consciousness.

While this starting point may seem to reduce consciousness to a basic biological mechanism, we need to keep in mind that the richness that we associate with human consciousness is to be found in the conscious states produced by the mechanism: the relative simplicity of the mechanism allows it to be a candidate for use in many or all life forms, while the complexity of resulting conscious states comes from the complexity of each life form.

Defining a Core Consciousness

Authors such as Edelman (2003), Seth (2005) and Zeman (2001) have posited a dozen or so characteristic features of human consciousness. However, our focus is the possible commonality of consciousness across biological life forms, so we must be careful not to load the definition of consciousness with so many properties that we have virtually guaranteed its uniqueness to humans, primates, or a small subset of the animal kingdom. We propose that certain aspects of human consciousness are present in many or most life forms, and thus can be considered a “core consciousness”. We then explore how different life forms can have their own unique form of consciousness, by extending this core consciousness with characteristics derived from their unique anatomy.

We propose a core consciousness with the following five features:

- (1) Consciousness is a process that creates a particular type of state of the entity - called the conscious state.
- (2) The conscious state is a unitary state, representing the entity as a whole.

- (3) The conscious state is a special state among many other putative states: for humans these include sleep states, unconscious or preconscious states, and states of coma. Each entity has a mechanism for creating or selecting this state from all other possible states.
- (4) The conscious state is the preferred state for assessing (“making sense of”) inputs and preparing outputs. It brings focus and context to select the most important inputs and the most appropriate actions, from the many inputs and potential actions that can be processed out of conscious awareness.
- (5) The apparently continuous flow of consciousness is made from a rapid succession of states, much as a movie comprises a sequence of still frames that gives the illusion of continuous change.

The first two features correspond to the first general feature of consciousness listed in Table 1, by Edelman (2003) - “Conscious states are unitary, integrated, and constructed by the brain.”

The third property is also implied by Edelman and many other discussions of consciousness. We derive the fourth feature from models of human conscious awareness, such as Dehaene (2013).

The fifth property has been part of the literature on consciousness at least since William James (1890).

Furthermore, we believe that our conjecture is consonant with the model of human consciousness and of the brain that we see as underpinning the ideas of many authors, either explicitly or implicitly. At its simplest, the model sees the human brain as a complex system, capable of existing in many possible states, but repeatedly creating an evolving unitary state –

consciousness –that best enables the brain to interpret stimuli and take actions to ensure the person’s survival.

With this model in mind, and the five properties given above defining our use of the term “core consciousness”, we can now elaborate on our specific conjecture.

The Core Consciousness Conjecture

All multicellular sentient life forms have core consciousness.

In this section we discuss several points of our conjecture in more detail.

First, we are restricting the conjecture to multicellular life forms because we hypothesize that consciousness originated in the need to bring coherence to the interactions between cells, such that they form a genuine multicellular unity: cells participating in this unity forgo some independence and collaborate to form a new entity with emergent properties, and the consciousness property describes a particular feature of that collaboration.

An objection could be raised that it is possible to regard a single cell as a homeostatic system and consider what gives the cell its unitary characteristic, but this is a description at a different level, and we have much less reason to suspect that any form of consciousness at that level has a useful connection to human or animal consciousness. We believe that the argument that an individual (eukaryotic) cell is also a unitary complex entity formed from multiple components, and therefore is a good candidate for having consciousness, is not convincing (Note 1 and Butler, 2012.) There are many levels at which one could make such a general argument, but the mechanism for achieving a unitary unicellular state and the nature of the resulting state would generally not provide a base

for evolving towards consciousness as we observe it in humans. Judgment is required to select the appropriate level at which to apply the general argument. Although much remains to be explored, and future evidence may demonstrate otherwise, at this time we propose that the most appropriate level for positing the emergence of consciousness is with the unifying of multiple cells into a coherent entity.

An analogy might clarify this argument. To model chemical interactions it is vital to incorporate the electromagnetic interactions of electrons, ions and nuclei, but it is not generally useful to try to include the strong interactive forces that bind quarks into the nucleus. Chemistry operates at a level that regards the nucleus as an elementary component, and chemical properties do not generally require knowledge of those strong forces. The chemical properties arise from the interactions of electrons and nuclei, and are best modeled by treating nuclear particles as fundamental. To the extent that we are primarily engaged in model-building in this contribution, we propose to treat the individual cell similarly. (For a contrary view see Note1). Specifically, we propose that consciousness arose as a solution to the challenges of unifying multiple cells into a unitary, stable structure, not as a solution to unifying the components of a cell into a coherent entity. Ultimately the usefulness of the definition of consciousness in guiding our understanding, and the extent to which this understanding is supported or contradicted by empirical evidence, will determine whether the single cell or multi-cell level is the better choice.

A similar issue arises when trying to establish the minimum complexity of multicellular life forms needed to support core consciousness. Although the focus of this paper is to develop a framework of core consciousness that can be naturally extended to

include human consciousness, we expect that the basic ideas are applicable to very primitive life forms, and in principle to life forms with very few cells. However, while examining this lower boundary of complexity for core consciousness could provide additional insight to its essential nature, this is outside the scope of our paper. A similar question arises concerning the nervous system: how many neurons with what degree of connectivity are required before the properties of a nervous system emerge (Satterlie, R. A. 2015)? Again, we leave this question to a later forum.

In positing that the multicellular life form requires for its survival to be sentient, we are emphasizing that a crucial role of the consciousness architecture is to manage the interactions between the life form and its environment. Of course we do not restrict the term “sentient” to the human senses; rather we mean the general ability to respond to one or more physicochemical stimuli (Butler, 2012).

However, it is worth pointing out that we specifically have not restricted the consciousness conjecture to life forms with a nervous system or a brain. We only require that the life form has a mechanism for coordinating the action of its cells to provide a coherent stable form, which implies an adequate internal mechanism for communicating between cells and cell clusters, but not necessarily a nervous system. An interesting example is provided by the only surviving representatives of the Placozoa (a basal group of multicellular animals), namely *Trichoplax adhaerans*: very flat organisms lacking any internal organs. Jékely, Keijzer, and Godfrey-Smith use the *Trichoplax* anatomy and behavior to discuss the possibilities for early neural evolution (Jékely, 2015) and in the process demonstrate that unitary complex behavior does not require a nervous system.

Another point we wish to highlight: We have specifically used the word “core” to make clear that we mean consciousness in the very specific sense described above: namely the property of generating a sequence of dynamically evolving unitary states - the conscious states - that provide the life form with a stable coherent structure capable of interpreting stimuli and generating appropriate actions. Later we will consider whether some other features that are typically included in the term consciousness can be added to our base definition without unduly limiting the usefulness of the conjecture. Ultimately, we aim to reach a new formulation of consciousness that explicitly takes into account the diversity of life forms while capturing a shared property that may be instantiated differently.

Finally, we stress that we need an additional concept - biological value (Damasio, 2010). For any homeostatic system to function it must have a way to decide which new state best serves its goals, so this feature has to be present in our model of core consciousness or almost any model of consciousness. One way to do this is to assume that embedded in the architecture of core consciousness is a way to assign a value to any possible state and the conscious state produced at any time is the available state with the highest value. In biological systems this value will probably represent an estimate of the best chance of survival both in the short and the long term.

The Conscious State is a Particular State

A question arises naturally at this point: why would evolution have favored a dynamically reconstructed state to be singled out from all other states and to use it as the critical decision-making state? Why not evolve a structure that selects fixed action patterns to

respond to external stimuli, without creating a special state, or alternatively evolve a structure with a slowly changing master state. For example, a guided missile can dynamically adapt its trajectory by constantly updating its program with information about the terrain and its target, but this is a limited form of dynamic adaptation that leaves the master control program unchanged. It corresponds to the adaptation of the movement of an arm as it tries to catch a moving ball, which does not require consciousness.

We argue that the underlying reason for creating a special conscious state and requiring it for many decisions must have something to do with novelty, as suggested by Dehaene (2001) for example. However, we will take a metaphor used by Dehaene (2014) to illustrate why we have to clarify the basic idea of dealing with novel situations. He suggested that consciousness acts like the staff to the CEO of a company, sifting the results of the labors of a multitude of lower workers (processes operating outside of consciousness) to produce a specific perspective and evaluation (the conscious state) based on which the CEO takes an action. However, within that metaphor, the outcome is still limited by the capabilities and biases of the CEO, and we propose that a slightly different analogy represents the true power of the dynamically reconstructed state of core consciousness.

We replace the CEO by a council whose members collectively take decisions for one day, but every day a new council is elected. In our metaphor, each day corresponds to the period of about 200 - 500 msec that it takes the human brain to form a new conscious state (Note 3). We suggest that this is a much more potent way of dealing with novel situations, but also much more dangerous, and more expensive in energy. The council model allows for greater flexibility in at least two directions. The nature and number of

candidate councillors can evolve over time, representing the evolution of different organs in the body or different sensory capabilities. Secondly, depending on the flexibility of the rules governing how the council makes decisions, a totally new decision can arise from a small change in which councillors are present. Solutions can more easily evolve as days pass, and novel solutions can more easily occur. In this design more fundamental changes can occur while maintaining the coherence of the life form.

However, metaphors are just that and shouldn't be taken too literally. Our point is that *dynamically* creating the state that *fundamentally* represents the life form is extremely powerful and dangerous (e.g., vulnerable to dysregulation), and goes beyond those types of solutions that adapt to novelty by adaptations to out-of-consciousness processes.

Unconscious Processes and States

In our model, at any given moment during its waking hours, the consciousness architecture of the animal will produce a dominant set of processes that instantiate a particular conscious state that represents the particular organization of its resources required for that moment. Many of the animal's processes will not participate actively in this state at any given moment, but may be functioning "in the background" or "out of consciousness" (Dehaene 2014). Some of these processes will never be part of the conscious state, because they play no part in defining the animal as a whole: they may, for example, be specific to a particular subsystem, such as controlling stomach acidity. Some processes will be sometimes part of the conscious state and sometimes out of consciousness. Dehaene and others have shown that processes functioning outside of conscious awareness are capable of many cognitive functions, including recognizing words, doing limited arithmetic, binding

multiple sensory inputs, and distinguishing the value of a stimulus (Dehaene (2014).

Since Freud introduced his topographical system - dividing the mind into the conscious, the preconscious and the unconscious - non-conscious processes have played an important role in many psychodynamic models of the human mind. In our model, many of the issues that arise in those psychodynamic models can be subsumed under the question, "What are the rules governing which processes and data are incorporated into any specific conscious state?" We have suggested earlier that there must be a general mechanism that evaluates the biological value of any possible conscious state and selects the state with the greatest value. However, that still leaves many ways in which that assessment could be refined or biased. For example, Freud made significant use of the idea of repression, implying in our model that certain potential contributions to the conscious state are forbidden or assigned a negative biological value. This in turn raises the question whether such a "repression" mechanism is part of core consciousness, and applies across the animal kingdom, or is restricted to human consciousness.

We suggest that clarifying the architecture and rules for including processes or data in the conscious state will be one of the most important requirements for understanding animal consciousness. In particular, it is important to understand the "core" rules applying to all animals, how those rules evolved, and how they apply to the different components of consciousness described later (Somatic, Sensory and Remembered Consciousness.)

Here, we restrict ourselves to a few comments about non-conscious processes. The effects of non-conscious processes could appear in the conscious state in many different ways. For example, the early stages of visual processing of a face may have matched several people and triggered several associated emotions. Subsequent processing to select the

resulting conscious state may eliminate some specific faces but leave traces of their associated emotions. There is nothing in our proposed model that determines this level of detail; many psychodynamic models will be consistent with our core conjecture.

Since conscious awareness is the selection or creation of a particular set of processes and outputs from the many processes continuously monitoring and regulating the various subsystems, it is expected that conscious mental activity will constitute only a small percentage of the total mental activity and energy consumption. This is certainly true of the human brain, and has given rise to it being characterized as the “restless” brain (Raichle, 2011). Most of the models of consciousness referenced in this article have this characteristic either explicitly or implicitly. Many unconscious processes are simply processes that happen not to be incorporated into the current state: they are not different in kind from those that do participate.

However, there is one major difference between a process acting within consciousness or outside of consciousness. By its nature, our concept of the conscious state requires consistency between the cooperating processes to produce a state that “makes sense”. So, for example, when dreaming, there are mental states that represent possibilities inconsistent with normal sensory input, such as unaided flying or time travel. In our model, we attribute the possible “strange” states produced by unconscious processes to them being freed from the “making sense” conditions required for the conscious state, not to any inherent difference between conscious and unconscious processes.

Most animals are not perpetually awake or in a conscious state, so there are clearly non-conscious states which can survive for lengthy periods, but most of them do not enable the animal to perform many of the functions necessary for long term survival, such as

eating or reproducing. Also there are states that are not fully or stably unitary, and there are states that do not represent the body as a whole, so we need to accept that the definition of consciousness may always have fuzzy boundaries or allow states of partial consciousness. For this paper we are assuming healthy adult consciousness.

An Evolutionary Perspective

The evolutionary origin of consciousness has attracted the attention of several authors, and those who use the neural correlates of consciousness (NCC) approach typically identify a required property of consciousness and look for the evolutionary origins of the neural correlates of that property. We agree that looking at the evidence on the nervous system in the context of the evolutionary record enriches the exploration of the origin and function of consciousness, both in generating hypotheses and also refining or correcting them.

Edelman took this approach (Edelman, 2003), identifying the key evolutionary step for consciousness as new neural correlates linking sensory information to the frontally located systems responsible for “value-category memory” (p. 5522). These new thalamocortical circuits enabled a level of perceptual discrimination not available through the sensory systems alone, enabling an animal to compare a current complex sensory input to its categorization of previous sensory inputs in a more detailed way, and thus conferring a significant evolutionary advantage. Edelman dates this evolutionary step to some time around the divergence of reptiles and mammals, during the earlier part of the Mesozoic era. This is compatible with the fact that the 6-layer neocortex is a mammalian structure. However, this would obviously restrict consciousness to mammals, and thus is not a candidate as a mechanism for the core consciousness that we are hypothesizing.

Edelman asserts that the level of neural complexity appropriate for consciousness was only reached with the arrival of reentrant corticothalamic circuits, but this is by no means obvious or supported by strong evidence. The fact that animals navigated the world with their “less complex” sensory capability for the 300 million years prior to the arrival of the corticothalamic circuits suggests that either a selectionist design can be made to work within a less complex system, that other neural correlates can do an adequate job of supporting the selectionist approach, or that the selectionist approach is not the only approach.

These alternatives are particularly important for birds and reptiles, and in recent years a major re-evaluation of avian and reptile behaviors has led to a new understanding of the structure and capabilities of their brains (Emery, 2006; The Avian Brain Nomenclature Consortium, 2005). While these studies typically focus on the cognitive or behavioral capabilities of birds or reptiles, they suggest that we should broaden our thinking on consciousness, and interpret Edelman’s proposals as just one candidate for an elaboration of the machinery of consciousness that allows for richer conscious states, but does not constitute an origin of consciousness.

Another milestone in the evolution of consciousness is offered by Feinberg and Mallet (Feinberg, 2013). In their words, they offer “the first hypothesis that dates the origin of consciousness....” and argue that the necessary neural correlates probably appeared between 560 and 520 mya. A crucial part of their argument is the existence of a central mechanism (using the thalamus and the visual tectum) for translating most sensory inputs into isomorphic maps that can be integrated. They assert that such a capability conferred at

least a minimal form of sensory consciousness. They also propose the lamprey as the first animal capable of sensory consciousness.

However, the same argument applies to this proposal as to Edelman's proposal: even if the proposed neural correlates constitute a major evolutionary milestone, we should not consider it as an origin of consciousness, nor as a reason for excluding other animals from having consciousness. We suggest that a better interpretation is that the proposal identifies a particularly interesting *adaptation* of the conscious states of certain animals, not a fundamental step distinguishing the existence of consciousness itself.

In contrast to these positions, our definition of consciousness requires that we go all the way back to the origin of multicellular organisms, and seek a neural correlate of consciousness in the critical ability of a multicellular structure to create an integrated assessment of multiple external stimuli and from that to generate a coherent response. This integration ability requires at a minimum two neural correlates: a suitable sensory input mechanism, and an internal signaling mechanism between the cells. In our proposal, these could be extremely primitive and still yield a (primitive) form of conscious state.

A brief summary of when the required multicellularity and neural correlates appeared is given in Hille (1987). By 700 million years ago (mya), three multicellular kingdoms - fungi, plants and animals - had started their diversification from the precursor unicellular eukaryotes, and by 500 mya the major animal phyla (chordates, arthropods etc.) had been differentiated during the Cambrian Period. Earlier complex multicellular eukaryotes (the Ediacara) died out, and current multicellular life forms are generally considered to derive from this Cambrian period. We therefore consider these Cambrian

multicellular life forms to be our first possible carriers of core consciousness with an unbroken link to modern species.

Despite the appearance of the fungi and plant kingdoms during this same period, their evolution followed very different paths compared to the animal kingdom, and we do not examine here the conjecture that they have core consciousness. Nor do we address the question of whether non-biological systems can have core consciousness. We prefer to understand more thoroughly the application of our conjecture to the animal kingdom, leaving open the question of how fruitful it is to apply the same term (core consciousness) to plants and fungi, or whether this adds understanding or confusion.

Hille concentrates most of his evolutionary analysis on the appearance of signaling mechanisms, particularly ionic channels, noting that voltage-gated potassium and calcium channels were a key part of early eukaryotic cells, and probably arose to coordinate cellular responses to external stimuli: one of the neural mechanisms critical to our conjecture. However, those two ion channels were not well adapted to the needs of longer distance electrical signaling, and during the early development of animals the sodium channel evolved: a channel more suited to the sending of action potentials over axons. This was quickly followed by the development of the chemical synapse, which added an important capability to the signaling repertoire - inhibitory signaling. Early electrical signaling was excitatory, and the addition of inhibitory signaling is a fundamental requirement for the production of oscillations and the central nervous system. The development of these neuronal and neurochemical mechanisms clearly afforded additional structural and functional complexity. Thus, although not required by our definition for the *origin* of core consciousness, it is clear that the evolution of the nervous system played a central role in

the further evolution of consciousness and initiated a significant surge in the diversity and capabilities of animals. A useful introduction to the current understanding of possible early evolutionary trees and the associated evolving nervous systems can be found in Strausfeld and Hirth (Strausfeld, 2016), and Schneider provides another detailed modern account (Schneider, 2014.)

Given that our model posits core consciousness for any multicellular organism that coordinates activity between cells, we think it is worth stressing that this does not imply any requirement for a *specific* kind of system. Brains themselves do not appear necessary for core consciousness, in our estimation. It seems clear that prior to the emergence of the vertebrates, when organisms settled on or crawled about the sea bed, some of them made do with simple neural nets arranged in a diffuse plexus with no preferred directional flow of information. Over time, aggregations of neurons occurred, sometimes becoming ganglia, and eventually giving rise to centralized structures that could be called brains. In their paper on Xenacoelomorpha, Gavilan, Perea-Atienza and Martinez discuss many of the factors governing the evolution of a central nervous system, including why a brain should evolve at all, despite its high energy demands, and whether it arose once in an early bilaterian or multiple times in different taxa (Gavilan et al , 2016.)

It may even be that neurons themselves are not required for consciousness. In this regard, it is worth noting that it is still not established whether the neuron evolved once or more than once from different cell lineages. Moroz and Kohn hypothesize that the ancestor of all animals was an organism lacking neurons and synapses, and that the Ctenophore evolved a neural system independently of all other animals (Moroz and Kohn, 2016).

Overall, our sense of emerging work on the origin of the nervous system is that, although findings on nervous systems may shed light on the origin of consciousness, the two issues may not be synonymous. For example, Jékely, Keijzer, and Godfrey-Smith point out that conceptual models typically stress either the effects of the sensory motor system or the role of the nervous system in coordinating muscle activity (Jékely, 2015.) These are also two of the major models proposed for the origin of consciousness, suggesting that the two disciplines can learn much from each other.

Thus, in keeping with our goal to provide a framework for investigating the widest possible role for consciousness, we suggest that the emergence of synaptic driven ganglia or nervous systems marked a significant milestone in the evolution of conscious states, while allowing that earlier more primitive life forms may also have had the properties of our conjectured core consciousness.

Other major perspectives on the evolution of consciousness include those of Llinas (2001), Damasio (2010), Panksepp (2005) and Baars (2005) , all of whom have made major contributions to our understanding of the structure and operation of the brain. Mashour (2013) provides a useful review of many theories from an evolutionary perspective.

Llinas (2001) has discussed in detail the evolution of multicellular structures and the evolution of the brain as a central communication and control center, designed to bring coherence to a potentially chaotic system. He has emphasized movement as a key driver of the evolution of the central nervous system and the brain, and prediction as the “ultimate function of the brain” (Llinas, 2001, p. 21). Nothing in this work contradicts our conjecture, though he does say “cognition and consciousness *probably evolved from the emotional*

states that trigger FAPs [fixed action patterns]" (p. 168, emphasis in the original). He also argues that consciousness underlies our ability to focus and choose, which parallels our property #4 of core consciousness. We note that although his papers often emphasize the role of the thalamocortical circuits (see Llinas 2006, for example), this is usually in the context of human consciousness.

Panksepp (2005) has argued that psychology and neuroscience have overly focused on cognitive consciousness compared to affective consciousness, and he proposes consciousness as "a multi-tiered process that needs to be viewed in evolutionary terms, with multiple layers of emergence". Additionally, he proposes that a primitive form of affective consciousness may have served as the evolutionary platform for the emergence of more complex layers of consciousness. Both of these points fit well with our conjecture and with other hypotheses about how consciousness evolved.

Finally, we note that transient synchronization of different brain areas into a "global workspace" is a crucial aspect of several recent theories of consciousness (Baars 2005, Dehaene 2001). Provided we interpret the "workspace" as a metaphor, a part of our conjecture can be reinterpreted as the assertion that the mechanism of core consciousness is the formation of a dynamic global workspace using the signaling capability of the multicellular life form.

We think all of these ideas fit within our conjecture, provided that we slightly change perspective. Where other authors speak of the origin of consciousness at later stages in the evolutionary tree, relying on certain structural developments of the nervous system, we identify the origin of consciousness in the fundamental integrative mechanisms, guided by homeostatic imperatives, that support the stable, unitary existence of the life

form, and recategorize the other authors' proposed origins of consciousness as later stages in the evolution of levels or types of consciousness.

The Extended Conjecture of Core Consciousness

We have thus far laid out the central claims of our conjecture, and discussed it in an evolutionary context. We have deliberately omitted specific additional ideas that usually flesh out a model of consciousness, but might detract from its general applicability. However, in focusing on animals, we are now able to discuss some extended aspects of our conjecture, and we discuss three extensions in this next section. In each case we take a property that we believe plays a significant role in core consciousness and expand our interpretation to more directly bridge to significant elements of human consciousness.

The first idea is that the conscious state plays a particular role in the way an animal develops novel responses to stimuli: i.e. how it learns. The second idea is that it is possible to see every conscious state as a blend of three components, which we call the somatic, the sensory and the remembered components. The third idea is that inherent in our interpretation of a conscious state is the concept of a self.

We consider each in turn and then summarize our extended proposal.

Consciousness and Learning

In an earlier section ("The conscious state is a particular state") we stressed the vital role of novelty in forming the core conscious state and here we wish to elaborate on the connection between novelty and conscious processes and states.

Our extended conjecture is that every animal uses core consciousness as its primary learning state.

We posit that, starting from the earliest days of multicellular organisms, there had to be a learning mechanism to allow the migration of function from the individual cell to the organism as a whole. That was the very origin of genuine multicellular life (as opposed to a collection of cells). We can view this as cells having started with inbuilt reflexes or fixed action patterns or subroutines and a multicellular organism learning how to create new more “organic” responses by integrating and sharing responsibilities differently among the constituent cells. Eventually these new responses would become reflexes and transmitted genetically to subsequent generations.

We propose that building these new responses required a particular state in which multiple elements of the organism could be combined in novel ways, with novel rules for their use, and that this state needed to be the state which represented the coherent identity of the organism, so that the integrity of the organism was maintained. Allowing significant changes to be made to one part of the organism “out of consciousness” would run the risk that those changes would be incompatible with other parts of the organism. We think this forms the foundation for the critical link between the unitary nature of the conscious state and its role in learning new strategies.

We therefore extend our model to include the following process: any stimulus is assessed against an existing set of rules and is dealt with by those rules if that is possible. There is an attentional mechanism that decides whether a sufficient match has occurred and whether the situation needs to be escalated to become part of a new conscious state, where different rules can be applied. Changes that require coherent modification of multiple parts of the animal can only be carried out within the conscious state or based on information arising within the conscious state, but a limited form of learning can occur out of consciousness, especially if it is honing a

skill that already exists. As noted earlier, we think this suggestion is consonant with others who have posited a critical connection between consciousness and learning (e.g., Solms, 2013; Baumeister et al 2011). This is not a novel suggestion for how ontological learning occurs: we simply wish to firmly associate it with the core conscious state and expect to see it in all animals.

Core Conscious States have Three Components

Having conjectured that conscious states are generated to process stimuli in a coherent unitary fashion, we now use this idea to propose the major components of any conscious state. We suggest that the stimuli fall naturally into one of three possible categories depending on their origin. (See note 2.)

We categorize them first into internal and external stimuli. External stimuli come from the external environment and give rise to a component of consciousness we call the sensory component of consciousness. Internal stimuli can come from two sources: the body and secondly the brain's memory and management system. We call the component of consciousness that arises from moment-to-moment body stimuli the somatic component of consciousness, and those that arise from the brain's memory and management system the remembered component of consciousness.

Our Extended Conjecture Is That Every Animal Has Three Components to its Core Consciousness: the Somatic, Sensory and Remembered Components

The somatic component of core consciousness, which arises from the experience of the animal's own body, can probably be regarded as "primordial" and the most likely candidate to exist in all life forms. It represents the "tip of the iceberg" of the essential homeostatic system that regulates the body, and we think it corresponds approximately to Panksepp's affective consciousness (2005), Damasio's proto-consciousness (2003, 2010)

and Solms' "conscious id" (2013). From our perspective it is particularly important as the main source of biological value, and we believe that some form of Damasio's somatic marker hypothesis (Damasio, 2003 and 2010) will be found as the means to express in concrete form the most basic drives for survival.

In this component, we conjecture that every instance of the core conscious state contains summarized information about the somatic state of the animal: in some instances this will dominate the conscious state and be paramount in deciding on any actions; in other instances it will apply a "coloring" to the state and contribute to its subjective quality. We expect this to apply to all animals. In a sense it is why we have subjective feelings: to guide our conscious state in its choice of actions (Damasio, 2003; Solms, 2012).

The second component of core consciousness comes from the sensory subsystem, which detects the external environment, comprising some combination of vision, audition, touch, smell, taste, nociception, balance, chemical detection and sonar. The neural implementation of this subsystem shows remarkable similarities across most animals, and this has been used to suggest a very early origin for something that could be called consciousness (see Butler 2008, Feinberg 2013). We argue that this sensory subsystem has its own integrative consciousness architecture and contributes to the conscious state by creating a coherent interpretation of incoming sensory stimuli in the context of the other components of consciousness. How, for example, should the animal integrate the pressure sensation from its foot with the vestibular balance sensation and the visual sensation to form a coherent interpretation of its environment? A human infant takes years to acquire a reasonably complete form of this sensory consciousness. It has to use its inbuilt sensory consciousness architecture to interpret its experimental interactions with the environment

to form a package of interpretations that it can use reliably to navigate the world. At the same time the infant has to integrate this component of consciousness with the somatic component of consciousness described earlier.

We presume that for the vast majority of animals, the combination of the sensory and somatic components of consciousness appear to dominate their primary state of consciousness, with very little contribution from the remembered component of consciousness, described next.

This is a third source of stimuli that we believe contributes to the conscious state: we call it the memory and management system. Just as responding in a coherent manner to the external environment generates a sensory component to the conscious state, so responding to our memories generates another component - the remembered component - of the integrated conscious state. We justify including this third component in our enhanced model of core consciousness as follows.

At any particular level of development an animal has in its subsystems some form of memory that enables it to execute reflex or fixed action patterns to respond to any particular stimulus (Kandel 2005, 2006). If our learning conjecture above is valid, in addition we hypothesize that there needs to be associated with the formation of the conscious state, and accessible by it, some memory that lies outside (at least logically) any particular subsystem and is used for the ultimate level of integration. This memory would be used to store either the intermediate results of the process of integration - for example from one instance of the conscious state to the next - or a pending form of a pattern that could later become a fixed pattern to be activated outside of consciousness.

We think it is reasonable to presume that animals with a limited amount of this memory are limited to living in the “remembered present” as described by Edelman (2003). However, a larger neocortex can contribute to the brain in at least two distinct ways: it can significantly enhance already existing functions, such as vision, and expand the available memory for new capabilities. We think the ability to record massive numbers of autobiographical events, and to carry out complex processing on those memories, is particularly significant for the experience of human consciousness. This was related to the relative expansion of the prefrontal cortex, which is intimately involved with the avalanche (Dehaene 2014) of activity that ignites conscious awareness: also with the Baars’ workspace and with the rules that govern the content of conscious thoughts.

However, we suggest that the new human capabilities came at a potential cost: a dramatic increase in the possibility of chaos. After eons honing the response system managed by the existing somatic, sensory, and remembered consciousness, this new “autobiographical” animal had many more possibilities for constructing a conscious response in any situation. In the case of humans, the new capabilities were so rich and so powerful that they could easily have played a dominant, but potentially inappropriate part in the response to any situation. There needed to be an evolved consciousness mechanism incorporating this new “autobiographical” form of remembered consciousness with the existing somatic and sensory consciousness, a challenge that still leaves visible the differences in priorities, response times, and styles of the three components.

Although we have emphasized autobiographical memory as a major source of interactions generating the extra level of higher consciousness, we do not imply that this new (neocortical) system is simply a memory device. We propose that processing

autobiographical memories either triggered or co-evolved with a new set of capabilities. Language may have evolved as the internal mechanism for categorizing, managing and retrieving this complex new data type (analogous to billions of video clips). The human sense of time expanded both backwards and forwards, giving us a unique sense of history and future possibilities. A trove of historical records provided us with the basis for predicting the future. The extra memory provided space for the construction of alternate imagined possibilities, and eventually self-awareness. And, we should expand this list to include subsequent developments, such as the interactions with the societal and cultural environment that surrounds humans, and how this new level of conscious thought enables conflicts originating from society and culture to be resolved (Masicampo, 2013).

There is no accepted theory as to how these major capabilities caused or influenced the evolution of each other. We are making the most parsimonious assumption: that currently it makes sense to regard them as one set of capabilities - an evolved remembered component of consciousness. This provides us with a common framework for looking at other primates, who also enjoyed substantial growth in brain capacity during the same two million years, and assessing how their consciousness evolved. Did they also show a relatively larger increase in their remembered component, or was that a uniquely human evolutionary path?

In our model each organism can have a contribution to its conscious state from each of these three components (somatic, sensory and remembered sources), with the wide variety of conscious states found in nature reflecting the different internal, sensory and memory capabilities of different animals, and the different ways in which these three capabilities have evolved to cooperate to form the coherent stable entity.

It is not surprising that this line of reasoning rediscovers forms of human consciousness that are well discussed in the literature, since we purposely advanced the core consciousness framework to be able to accommodate human consciousness. Our goal was not to invent new aspects of human consciousness, but to suggest how the major types of human consciousness could have arisen naturally from a core consciousness mechanism common to all animals.

The Conscious State Implies a Self.

A much discussed (see Fabbro 2015, Feinberg 2011, Panksepp 2009) concept associated with consciousness is the idea of the self. Many of those discussions conclude that the ideas of consciousness and self are closely intertwined, and we agree.

Our extended conjecture is that every animal has a self

We define the self as the internal representation of the animal's coherent stable existence, confirming to the animal that it is separate from the environment and any other animal. Damasio (2003) has expressed this idea of self when writing, "the key to the self is the representation of the continuity of the organism." In our view, the self is a *creation* arising from the animal's internal and external interactions, and we can expect a contribution to the organism's sense of self from each interaction. The self is expressed in the conscious states of the animal according to the nature of the interaction. A part of the self (the somatic self) will come from the internal bodily sensations, because the conscious state must be able to represent the specific in-the-moment bodily existence of the animal and the requirements that derive from that bodily existence (such as the need for food.) A second part (the sensory self) comes from the sensory interactions, in which the animal is

sometimes the actor, the observer, the recipient, the attacker, the defender or playing any number of roles. In each conscious state the animal plays at least one of those roles, and from the sequence of interactions the animal creates a coherent sense of the attributes of its unitary stable sensory self. A third part comes from memories, as part of remembered consciousness, and gives rise to a remembered self. Solms (2013) discusses a similar view of different contributions to the self, emphasizing that the core self (roughly our somatic self) is “the font of all consciousness.”

However, we must be careful not to anthropomorphize this idea of self. The sense of self of any animal comes from the nature of its conscious state: only at that level, in that way, and with those same capabilities can it have a sense of self. An animal would need language capability to give the self a name; it would need a certain type of awareness of the external world to be self-aware; it would need certain perceptual capabilities to have a bodily self anchored in the physical world. In short, we propose that each animal has a sense of self that matches the richness of its possible conscious states, because in our model that sense of self is built from how its unitary nature occurs in the succession of its conscious states.

This is particularly important as people research consciousness in non-human animals. We cannot know directly the nature of the self created by each animal. Edelman and Seth (2009) explicitly consider “animal selves” and possible experiments for demonstrating their properties. Panksepp (2005, 2009) has long argued for studying affective consciousness in animals, and has specifically proposed models of the self that are “trans-species.” With respect to our own selves, we humans make an assumption—one that

is verified by most interactions—that other people have a similar mind to our own, and that we live in an objective world that we experience similarly, and we deduce that their selves and our self have essentially the same nature. However, scientifically we have to proceed cautiously when applying the same approach to animal consciousness. Even when we might guess from repeated patterns of behavior that they have parallel experiences, such as hunger or fear, we cannot assume very much about those experiences. We assert this because even people have very different responses to experiences, such as normally painful events, including feeling no pain at all. We therefore are quite cautious in asserting anything specific about the actual nature of the consciousness of other animals.

Discussion

We think it may be worthwhile to comment on the consistency of our conjecture with prevailing models of the mind and clinical practice. The two foundational models of the mind in psychology remain the topographical (Freud, 1915) and tripartite (Freud, 1923). Ideas about the self, cognitive-behavioral theory, and other contributions inform and enrich these basic models. The topographical model divides the human psyche into its principle parts of conscious, unconscious and preconscious with the phenomenon of repression as a dominant defense mechanism. The tripartite model lays out the dynamic tension between principle aspects of mind, namely id, ego and superego. Contributions by Zellner and others (e.g., Zellner, 2012) have tried to unify these models of mind with contemporary principles in neuroscience and brain functioning, as proposed by Kandel (Kandel, 1998 and 1999.)

Perhaps the most obvious connection between our conjecture and these two foundational

models is the idea that consciousness evolved to ensure the unitarity of multicellular organisms. Initially this was required to allow cells to specialize and to become interdependent, but we are proposing that this mechanism evolved to maintain a unitary existence as organisms became more complex, and particularly as the multifunctional vertebrate brain evolved. Such a role always involved balancing competing requirements from different parts of the organism, and we proposed that the maintenance of a stable unitarity implies that a self is created from the repeated interactions of the organism with its internal and external environment. We advance the idea that the ego is a particular form of this self, required to keep the balance between pleasure and pain. Such a notion has been present present from the beginnings of psychoanalysis and the development of self psychology.

Another close connection between our conjecture and Freud's models is the significance of the unconscious. In our understanding, most of the mental activity of the organism occurs "out of consciousness," (Dehaene et al., 2014 and Dehaene, 2014) and a specific conscious state has to be created and recreated to provide the necessary homeostatic unitary control. In creating this state most stimuli have to be "repressed" -- in other words, filtered or barricaded from access to consciousness to facilitate efficiency and unitarity. We put the words in quotation marks here to note that we are using the term in a broader sense than the specific psychoanalytic sense of repression against specific contents of consciousness; indeed, we suggest that one could see psychoanalytic repression as a special case of a more general phenomenon of the "repression" or filtering that is required for consciousness. The brain can only deal with a fraction of the information available at any instant, and a great deal of the organism's learning is about making this repression or selection wisely. Repression therefore has to occur at many levels, including sensory processing, but particularly in

selecting which memories can influence the current conscious state. In our model all conscious states have somatic, sensory and remembered elements, and memories of prior conscious states will generally have all three components, and, in some sense, each memory will be tagged by the potential impact or value of these three elements. It is then natural to assume that in forming future conscious states, the consciousness mechanism will take into account these tags and repress or include the memories accordingly. The phylogenetic learning of how to do this was likely honed through evolutionary selection over hundreds of millions of years. With the addition of major new cortical function during the last few million years, we should not be surprised to find poorly adapted choices being made in the balance between neocortical inputs and more ancient drives, and we suggest that these poor choices often show up as a conscious state with a poorly designed compromise between the needs of the id and restraints of the superego. Such ideas about conflict and compromise are well established in the psychoanalytic literature, although their origin from an evolutionary standpoint, has not been thoroughly considered.

Dreaming is a very important state of the mind not subject to some requirements of the conscious state. What Freud called the “censor” is not as active during dreaming, and primary process in mental functioning more clearly emerges. We suggest that this state is similar to a hypnotic or anesthetized state or, more generally, to when attention may turn away from the environment and focus more on preconscious or internal thoughts. A recent study shows how as a monkey’s brain is anesthetized, awareness is lessened in stages, and neuronal networks desynchronize and then resynchronize as sleep sets in (Ishizawa et al., 2016). Such studies allow us to see an important characteristic of consciousness, namely its boundaries are not so clear cut. We have appealed to the requirement for unitarity of

consciousness in a given organism, but in certain states of consciousness, it may not even be clear what is real and imagined. We can see manifestations of this in psychiatric conditions such as psychosis and mania, which by definition blur the boundaries of internal and external reality. It also shows up in the challenge of evaluating patients in some level of coma. (Gerard, 2014; Dehaene, 2014). We should not expect to find a simple clear boundary between a person being conscious and being unconscious. Likewise, in terms of the dynamic unconscious, there may be some fuzziness between what is conscious and unconscious in an individual. Clinically speaking, it is not unusual for repressed material in an individual to partly break through into conscious awareness. For example, this occurs in traumatized states, when past experiences have not been fully metabolized psychologically.

Obviously, there is much more to examine and understand about the nature of brain functioning and its manifestation in mind. However, we believe that the same fundamental principles of the mind are still operative in mental functioning whatever the state, albeit not engaged or active in the same way. We think that primary and secondary processes are both ways the brain has developed, evolutionarily speaking, to adapt and to increase the chance for survival, which has not been made explicit in the relevant scientific literature. The first links things in an associational manner, and the second in a rational and logical way. With mammalian brain development, and especially in humans, secondary processes came to predominate our awareness in waking life. Still, both states are integral, indeed even essential, to the mind making sense of the world around it.

Summary

Our goal was to find a way to conceptualize consciousness so that it could meaningfully be applied at least to all animals, and perhaps to all multicellular life forms, while preserving a plausible way to view human consciousness as an important special case. The key step was to strip the generalized ideas of human consciousness to a few key elements - the core - and to match those elements to the basic idea of biological homeostasis of multicellular organisms. Seen this way, consciousness is the architecture that confers stability and coherence (unitarity) on multicellular life forms.

From this approach we offered the following conjecture:

All multicellular sentient life forms have core consciousness.

Furthermore, three additional properties appear to us to fit naturally within the core framework without diminishing its potential applicability to all animals, and therefore we made the following extensions:

Our extended conjecture is that every animal:

- uses core consciousness as its primary learning state;
- has three components to its core consciousness: somatic, sensory and remembered components;
- has a self.

We propose that every animal will be found to have a form of consciousness that is a specific detailed instantiation of this extended core consciousness.

Notes:

1. In Sacks (2015) several respected authors reaffirmed their view that certain properties of an individual cell could be considered as the starting point for aspects of consciousness. In his reply, Koch respectfully disagreed. While acknowledging the significance of these basic properties of the cell, and the work of Hille, he observed that a property of a component of a system can be vital to the overall functioning of the system without playing any direct role in emergent properties of the system. This paper agrees with the Koch view that we should look to the cooperative properties of the system rather than to specific cell properties for the clue to consciousness.
2. We are emphasizing the role of stimuli in categorizing components of the conscious state, but it is important to recognize that processes are also involved, and a richer system model would have subsystems that managed the stimuli being the contributors to the conscious state. Also we would explicitly recognize that it is a two-way process, neither just bottom-up nor top-down.
3. We are using 500 msec as a proxy for the time evolution of a complex process that is discussed in detail in Chapter 4 "The Signatures of Consciousness" in Dehaene (2014). However, note that recent work on Event Related Potentials (ERP's) associated with visual awareness suggests that Dehaene's P3 signature is too simple an explanation. For a detailed discussion see Railo et al (2011). Our conjecture does not depend on the specific mechanics of how sensory processing starts with unconscious processing and can become conscious. There is a general agreement (see Railo, 2011) that there are one or more mechanisms that create a "binding" between the different parts of the brain processing the sensory signal, and these and their associated ERP's constitute neural correlates of conscious awareness.

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