A Heuristic Model of Consciousness with Applications to the Development of Science and Society

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ABSTRACT

A working model of consciousness is fundamental to understanding of the interactions of the observer in science. This paper examines contemporary understanding of consciousness. A heuristic model of consciousness is suggested that is consistent with psycophysics measurements of bandwidth of consciousness relative to unconscious perception. While the self reference nature of consciousness confers a survival benefit by assuring the all points of view regarding a problem are experienced in sufficiently large population, conscious bandwidth is constrained by design to avoid chaotic behavior. The multiple hypotheses provided by conscious reflection enable the rapid progression of science and technology. The questions of free will and the problem of attention are discussed in relation to the model. Finally the combination of rapid technology growth with the assurance of many unpredictable points of view is considered in respect to contemporary constraints to the development of society.

Keywords: Consciousness, Scientific Method, Free Will, Attention, Human Self-Extinction, Space Habitats

INTRODUCTION

A fundamental understanding of the role of the observer in science and the interaction of technology with society requires a working model of consciousness. This paper describes heuristic theory of consciousness that is consistent with psychophysical measurements and suggests that consciousness is an essential element of the scientific process, and the development of technology. These same characteristics of consciousness place certain serious constraints on the development of society.

Consciousness, our awareness of our own awareness, Descartes declared, is equivalent to our unique identity, to the very conception of our own existence. Despite its perceived importance, experimentally testable theories of consciousness have proved elusive, and thus the most fundamental questions remain unanswered. For example: How can we tell if another entity is conscious? Which animals are conscious and to what extent? Why is so much of our brain (as has been demonstrated since the time of Freud) unconscious? How are attention and consciousness related? A testable model of consciousness could add insight towards answering these questions as well as critical sociological questions such as: Would there be a benefit to "expansion of our consciousness?" Do we consciously express free will? Can we reach a "higher state of consciousness," an "enlightenment" that will allow humanity to transcend its ills? These and other questions of obvious significance about consciousness have remained largely unanswered.

There is as yet no scientific consensus on a theory of consciousness; however, as a point of conceptual departure for this discussion, we can sketch (following Edelman's approach [1]) a contemporary view of the brain and conscious mind. The brain is a neural network that continually adapts to model the organism's interactions with its environment in order to confer a survival advantage. There is thought to be a hierarchy of consciousness. The simplest brains (up to about the sophistication of a lobster's brain) probably do not possess consciousness. Most of the higher mammals (including dogs, cats, etc.) are thought to possess Primary Consciousness which can be thought of as "the remembered present." The most sophisticated brains (humans and perhaps others such as chimpanzees and dolphins) possess Secondary Consciousness in which the remembered present can be related to the remembered past and the projected future. Whenever a memory is brought to consciousness, that memory is to some extent changed, because it is altered by the context of the conscious experience at the time it is remembered. The train of (secondary conscious) thought follows a path controlled by "attention." A common metaphor in the literature is that conscious attention is like a "spotlight." Edelman states [1, pp. 141] "Attention is not the same as consciousness, but its relationship to consciousness poses some of the most difficult problems for theory."

Beginning at about 1990, powerful new techniques in neurobiology reinvigorated the effort to establish a neurological basis for consciousness. Some early examples of working hypotheses include Crick and Koch's that 40-hertz oscillations in the cerebral cortex recruit regions of the brain into the conscious state [2] and Edelman's suggestion [3] that re-entrant loops in the thalamocortical system are the neurological basis for consciousness. To test these and other hypotheses, neurological functional imaging and other data has been used to help identify cortical structures that can be correlated with certain conscious experiences [4]. Although, neurological correlations with consciousness are being studied with increasing vigor, the field remains in a very early stage of development with many competing models [5]. Even with modern neural imaging tools, the unparalleled complexity of the human brain makes understanding consciousness from the neurological perspective very challenging.

Substantial progress has been made in quantifying some aspects of human consciousness. This field of study is sometimes called "psychophysics." The capacity limits of consciousness have

been studied extensively [6]. Cognitive studies have established that conscious short term memory has a capacity limit of only about 4 simultaneous "chunks," where chunks can be defined [6, pg. 89] as "collections of concepts that have that have strong association to one another" and much weaker associations to the other (up to 3) similar collections that one can hold simultaneously in consciousness. This conscious awareness of 4 simultaneous collections appears to be a very modest achievement when one considers the vast processing power of the human brain. For example when the data for conscious capacity limit is analyzed using information theory a data rate (that seems absurdly low) is obtained of only about 40 bits/s [7]. This is astonishingly small when compared with the processing power of the brain (100 billion neurons each with the potential to fire a few times a second, and each with about 1000 interconnections). Thus, at any given moment consciousness comprises only a microcosm of our total nervous awareness. Analysis of the of the sum of the total conscious nervous data rates for the sensory system (eyes, ears, skin, taste, smell) yields a sum of only 70 bits/s. This compares to the unconscious sensory system input and output to the brain, each of about 11 million bits/s, more than 5 orders of magnitude greater than our conscious perception. Thus, the brain, due to its limits or due to its design, allows consciousness to consider only a very small glimpse of the information that it is receiving from and sending to the world outside the cranium. These experimental measurements of the limits of conscious perception seem counter to our preconceptions about the significance of conscious thought. To paraphrase Descartes, our conscious thought appears to be a very small part of what we are.

Also, counter to our preconceptions are results from experiments measuring the timing of conscious perception relative to brain activity and motor response. These experiments show that consciousness lags an initiating stimulus by about 500 ms [8]. These results are sometimes referred to in the literature as the "half-second delay." Since unconscious reflex actions are usually measured in 10s of milliseconds, the conscious mind requires a "subjective referral" backwards in time so that our conscious mental image synchronizes with our motor actions.

When the above experiments are extended to include the time of the subject's conscious perception of the will to act, the results appear to belie our preconceptions of conscious free will. Before a voluntary act, such as moving a finger, brain electrodes measure a signature rise in electrical potential ("readiness potential") that precedes the motor act by 550 ms. Experiments [9] timing human voluntary conscious intention (for example to move a finger) relative to the measured readiness potential have determined, that although the conscious intention preceded the motor act by 200 ms, the conscious intention itself was always preceded by a 350-400 ms of unconscious readiness potential signal. Thus, it was concluded, all our motor functions begin unconsciously, which challenges our preconception of the free conscious exercise of will.

There are attempts in the literature to rationalize these uncomfortable properties of consciousness. The conscious capacity limit was explained by Crick and Koch (4, pp. 272) (in the context of their original proposal that conscious short term memory is activated by 40-70 cycle oscillations) as: "The likelihood that only a few simultaneous distinct oscillations can exist happily together might explain, in a very natural way, the well-known limited capacity of the attentional system." An attempt to maintain some free will is given by Libet [9] who evokes the possibility of a conscious veto in the last 200 ms before a motor action but then admits that the veto may also be initiated unconsciously. These and other explanations in short are not very satisfying.

In this paper a heuristic model is outlined to explain these features of consciousness. It follows from reflection on the question of why conscious capacity should be so limited. The hypothesis should be experimentally testable. The resulting model of consciousness appears to be consistent with the psychophysical data and provides answers (in the context of the theory) to the questions listed above. If the hypothesis, model and postulates presented stand, then further analysis points to profound implications for our current conscious society. In essence consciousness is viewed as a forcing function assuring diversity of thought and accelerating knowledge. It confers a preeminent survival benefit but can eventually lead to self extinction.

QUESTION AND HYPOTHESIS

Why is the capacity of human conscious perception so limited in comparison to vast capacity of the human brain? Either the capacity limits to conscious perception result from the brain's inherent limits in ability to produce consciousness or consciousness may be constrained by design. The point of view explored here is that the very fact that the brain's processing power is so vast and the requirement for consciousness so limited suggests that coconsciousness is limited by design.

Reflection on consciousness suggests the metaphor of two facing mirrors. When looking into parallel mirrors the regression into infinity is visually obvious. If an analogous experiment is done with facing video cameras with a small time lag, slight changes in initial conditions can cause chaotic patterns [10]. In mathematics, a simple recursive self-referential expression, like the Mendelbrot set, can lead to infinite complexity. Is it reasonable that consciousness, the mind's awareness of its awareness, produces complexity in the manner of these physical and mathematical metaphors? The structure of the human brain is simulated by neural networks. Neural nets with time delayed self-referential feedback typically exhibit high non-linearity and violent instability that prevents stable representations from being learned. Only with very careful control of time dependent transfer functions is stability achieved and learning optimized [11]. When self-reference is added to simple fuzzy logic (human like logic with a range of values for true and false) what results [12] is a full range of dynamic non-linear behavior including strange attractors and repellers, full chaos, fractals and paradoxes. Thus, if consciousness is recursive self-referential thought, then it would be expected to add a high degree of complexity to the thought process with a strong tendency towards chaos. Let us propose that conscious capacity is so restricted by the brain because if it were not then the tendency towards chaos would otherwise be overwhelming.

The view of consciousness discussed in the above paragraph is consistent with the "school of thought" that the brain is a dynamical system. Much of psychology including the notion of "self" can be described [13, 14] in terms of chaos or complexity science [15]. The non-linear nature of dynamical systems has been applied in therapy [16] as a model to explain psychological techniques where small stimuli evoke massive responses. It has been suggested [17] that consciousness is like a dynamical "strange attractor" governing thought. Theoretical models of cellular automata evolved to perform computations find [18] a maximum information peak at the boundary between order and chaos. Many systems in nature appear to operate at a fluid boundary between predictable order and unpredictable chaos [13]. At this boundary the system maintains enough stability for reliable function but has enough instability for flexible adaptation. Consciousness, it has been suggested [19], is at this "edge of chaos" which gives it a creative advantage by enabling it to shift from a steady state to one where novel responses emerge.

In this paper we take these concepts a step further and propose that the survival benefit conferred by consciousness is that it assures variability of response among individuals to similar input. That is it consciousness assures that if the population is large enough all points of view will be taken.

In essence, let us propose the hypothesis, that consciousness (recursive self-referential thought) is highly constrained to avoid chaos, but the amount of the mind that is conscious is also optimized to assure in a deterministic but unpredictable manner that with sufficient concentration (time or numbers of conscious minds) all points of view will be taken.

CONSCIOUSNESS AND THE SCIENTIFIC METHOD

The scientific method, let us propose, is a formalization of the natural way that our consciousness interacts with our brain and environment.

The non-linear nature of consciousness, due to its high sensitivity to initial conditions, leads to unlimited complexity in response to stimuli. This complexity is not random, like a fair game of chance, but is deterministic in the same sense that the weather is. We can sense the deterministic nature of our stream of consciousness when we attempt to back track our thought patterns. One thought leads to another, each connected in some subtle way. Yet if one tries to predict what one will be thinking 10 minutes in the future it is not possible because the pattern has unlimited complexity. The deterministic nature of consciousness, on the other hand, gives it validity, relative to our brain's model of the environment, which random thoughts would not have.

Let us also argue that unpredictability of individual response to the same stimuli is only beneficial from the point of view of fitness for survival when it is combined with a large powerful brain. The myriad of solutions to a given problem that consciousness continually produces would be disastrous for survival were there not a mechanism to eliminate obviously bad approaches. The vast model (that is our brain) of our interactions with the environment serves as a discriminator to eliminate ideas that are inconsistent with nature. For example suppose a problem presents itself of how to get an apple on a high branch. An unconscious animal would try some set of procedures that it was evolved to employ, and if unsuccessful move on. If the problem is dwelled on by a conscious animal then many possibilities will come to mind. These conscious possibilities are then naturally compared with the brains model of the environment (our memory) and many bad ideas are discarded immediately. Some seem to work, in the mind and they are attempted in reality. This process gives a large survival benefit to having a large brain which contains a conscious component that offers creative suggestions to explain what is unknown. This process, let us suggest here, was formalized in the scientific method beginning with Sir Francis Bacon and his contemporaries. The question is followed with hypothesis, model and experiments. The scientific process allows for the elimination of false hypotheses (by experimentation) and our collective model of nature is updated. Similarly, each time we consciously consider memories relative to the present environment our brain's model is updated. The formalization of this process in the scientific method made the process global and the growth rate of human power over nature accelerated.

Thus, let us state that the unlimited points of view generated by consciousness combined with a means to discard bad concepts, originally provided by our large mostly unconscious brains leads to the rapid growth of knowledge about our environment and techniques for its control. The scientific method formalizes this approach and makes the evolving world model collective. Techniques for applying the knowledge lead to better technology and the process accelerates.

THE QUESTION OF FREE WILL AND THE PROBLEM OF ATTENTION

As discussed in the introduction experiments find a half-second delay between a stimulus and its conscious perception. This delay requires a "subjective referral" backwards in time so that our conscious mental image synchronizes with our motor actions. This delay in the onset of consciousness is consistent with and lets argue is predicted as a consequence of the above hypotheses. Since conscious thought is always after the fact *because* it is reflection. The attention is turned upon a small part of the real-time nervous function; the recursive self-reference process requires additional time, thus the approach in our model is consistent with the delay.

The delay required for the recursive self-reference process could also preclude consciousness from real-time motor control. However, although the motor action is initiated in the unconscious, the experiments indicate that if the attention is drawn to the action, the conscious mind can observe and reflect on the feelings and motivation that occur 200 ms preceding the motor action, as well as on the action itself. Thus, by the proposed model, if the conscious attention is drawn to a motor action, it will act on the motivation and action adding a non-linear component to its memory. Then, the subsequent times when that motor action is performed it would have a unique and unpredictable character or personality conveyed by the

conscious attention. Thus, although consciousness does not do real-time motor control, attention provides the nuances that conscious beings apply to motor function. *In this way, by the model described in this paper, the unique character conveyed by conscious attention could be the source of human artistry.* So, in the context of our model, all volition ultimately results from consciousness. Thus, consciousness, because of the inherent time delay due to self reference, can not effectively control real-time motor function. It can only reflect on it, and in doing so can profoundly affect future actions.

The more fundamental question is what controls the "spotlight" of attention. As previously discussed the application of consciousness to any action or thought creates our unique personal point of view that then affects all future related actions. Yet at any instant consciousness acts on only a microcosm of our total nervous awareness, thus the direction of its application, attention, is the critical component of free will.

Let us propose that attention is simply controlled by consciousness itself. Attention is directed by reflection on our own reflection. Attention to Primary Conscious (awareness of our awareness) is directed by Secondary Consciousness (our reflective awareness of Primary Consciousness). Let us propose that Secondary Consciousness controls the "spotlight" of Primary Consciousness.

This concept immediately suggests the question of what controls Secondary Consciousness. Are there infinite levels, like the Homunculus paradox [1]? Here we will propose that the answer is no, because human consciousness has been shown, by experiment, to be limited to 4-6 simultaneous "chunks." Thus the limit to the levels of human consciousness is about four. *Thus we predict here that there are two to four additional levels of consciousness then have been previously discussed in the literature. Following convention they could be called Primary, Secondary, Tertiary, and Quaternary Consciousness.* Tertiary Consciousness is then awareness of Secondary Consciousness, and quaternary Consciousness is awareness of Tertiary Consciousness. Consistent with the dynamical model advocated here, let us suggest that beyond this, awareness is damped by the mind's design in order to avoid chaos in the direction of attention.

Also, according to our model, expansion of human consciousness, whether widening the of Primary Conscious bandwidth or increasing the number of "chunks" that can be held in short term conscious memory, would under normal circumstances, only lead to chaotic thought, and not as has been suggested, enlightenment. Thus it is proposed that the failure of the regulation of consciousness bandwidth can contribute to mental illness. For example too much conscious bandwidth could be associated with the erratic thought processes of schizophrenia, and lack of secondary consciousness bandwidth might contribute to the inability to control attention in autism.

EFFECT OF ATTENTION SPAN WITH AND WITHOUT SECONDARY CONSCIOUSNESS

Let us postulate that attention span or "concentration" means holding a problem in the conscious mind to allow the recursive self-referential process to continuously alter the minds point of view, thus providing many possible solutions. Or for a manual task, attention to its repetition or practice yields creativity or personal style. If one has an effective discriminator (such as the brain's model of the environment for a physical problem or an ideal for a manual task) solutions to the problem found or the action can become refined. The longer the attention is held on a problem or object the more the mind's associations to it are modified.

Now let us, in the context of our model, consider an animal, for example a dog, which we will assume has only Primary Consciousness. If its environment brings its attention to a ball, then its consciousness will act upon the "ball" and its mind's association to the ball. Suppose that in the next moment the dog's environment brings a bone to the dog's attention. Now the dog's conscious is applied to "bone" and its mind's associations to bone. If such a being, with only Primary Consciousness, is continually confronted with some object like the ball or bone then it will develop a unique approach to that object class due to the action on it by its Primary Consciousness. However, a being with only Primary Consciousness is dependent on the environment to direct attention. Now let's consider a man with Primary Consciousness and the ability to direct attention using Secondary and higher levels of consciousness. The man is presented with a ball by his environment and his Primary Consciousness acts on his concept of a ball. The being with Secondary and higher levels of consciousness can leave the ball but continue to think about "ball." He sits on a chair and thinks of a ball as a chair. He eats dinner and looks at peas on his plate and thinks of many balls and perhaps conceives of a game like "pool." In this way the time that consciousness is applied is limited to the environment for Primary Consciousness but becomes unlimited with Secondary Consciousness.

The effect of consciousness on response to a stimuli or on the brain's model of the stimuli would be expected be the nonlinear self-reference term proportional to the time (or number of recursive cycles) which is a function of attention time on that stimuli. This prediction can be tested and quantified by experiment by experiments with lab animals and compared to data from experiments with humans. The response characteristics of primary and secondary conscious can be determined. The results can be applied to answer the question of which entities are conscious and what their level of consciousness is. *Thus, the model outlined in this paper could yield the first method to assess whether a living or artificially intelligent entity is conscious and to what degree.*

MANY INTERACTIVE CONSCIOUS BEINGS AND THE ASSURANCE OF ALL POINTS OF VIEW

Let us assume that a large number of intelligent but unconscious beings are presented a problem or situation. These unconscious beings would converge on a solution or set of solutions that are only a function of the stimuli (problem or situation) and the structure of their brains that have been formed by their

environment and genetics. For unconscious creatures evolution and the resulting genetics play the role of the discriminator that eliminates untenable solutions. The exact form that the response curve takes versus number of population would have to be determined by experiment, but for simplicity let us assume that the solution set is a normal distribution or Gaussian Curve. Once a certain minimum capacity was reached, increased intelligence would not be expected to broaden the response curve appreciably. An analogy would be the personal computer running a modern operating system and some application and presented with some input. Once the processor is capable enough to run the program, increasing the processor power and memory affect the efficiency of operation but not the solution. If you have many computers, no matter what their power, they all yield the same results.

Next let us add a small amount of consciousness to unconscious intelligent entities discussed above. When the "spotlight" conscious attention for each individual is focused on the problem the individual's point of view begins to diverge from the population's mean. This is because the recursive self-referential nature of consciousness changes the memories of the problem in a nonlinear deterministic but unpredictable way. Each individual has a small difference in the initial conditions of its observation of the problem that can cause a large difference in its point of view about the solution. The more conscious attention that the group or individual gives to the problem, the more divergence that occurs in the group's point of view. Thus, with enough conscious beings, and/or enough time, consciousness assures that all possible points of view will be taken.

Experience presents physical limits on allowed points of view. It is well known that our Primary Consciousness can be limited by experience (or the content of the brains model of the environment). For example, it seems impossible to visualize a new color. This limitation is mitigated by the ability of Secondary and higher levels of consciousness which allow us to relate the image of the "remembered present" to a series of memories and thus allow levels of abstraction. So although one cannot visualize colors beyond red and violet, one can visualize a chart in one's mind which includes ultra-violet, x-rays, gamma rays and such. Also, it is reasonable to assume that the path of the control of attention by Secondary and higher levels or consciousness has limits.

The addition of consciousness is a powerful but dangerous strategy for survival. First, if too much conscious component is added to the individual intelligence, thought processes can becomes chaotic and the points of view of the community start to look random. Thus, it is reasonable to infer that our brains were evolved to very strictly constrain the amount of consciousness we possess. Second, the many points of view are only valuable if the individual and the society possess the means to dampen the untenable concepts. As we discussed above, the individuals use the environmental model in their large brains and interaction with reality as the discriminators, and the society uses collective remembered and recorded records, and ultimately the scientific method to dampen untenable approaches. Third, as evidenced by human power over nature, and the steady growth of human presence on the globe, the human implementation of consciousness has unprecedented power. *Thus we propose here that this technological power is the direct result of the application of our higher levels of consciousness.* The diversity of point of view is a direct consequence of consciousness and can not be eliminated without eliminating consciousness itself. As a consequence, as will be discussed next, human consciousness threatens our self-extinction.

CONSCIOUSNESS, EXPONENTIAL GROWTH OF TECHNOLOGICAL POWER AND SELF-EXTINCTION

Human knowledge and the technological power have been growing at an accelerating (exponential) rate at least since the scientific revolution. Beginning in the mid-twentieth century, for the first time in our history, some humans have had the technological capability to initiate human self-extinction (for example by exchange of thermonuclear weapons). We have survived because the human propensity for self annihilation (murder-suicide) is small (about one in five hundred thousand people). However, the number of people who have the ability to initiate human self-extinction increases exponentially in time in proportion to the growth of knowledge and technology.

As a thought experiment we can ask the following question. How long would we survive if we all had a button that would initiate human self-extinction? From the arguments in this paper it would be about 20 milliseconds or the response time of a human finger. This is obvious because consciousness assures that we have all points of view (including what we call "good" and "evil") so we know that in 6 billion people someone would start pushing the button immediately. In a separate paper [20], considering the exponential growth of the means of self-extinction and using the human murder-suicide rate the probability of human extinction with time is estimated to approach one in about 90 years if all humanity remains confined to Earth. This is because our technological power has grown large compared to our planet.

Concurrently in time with the power to destroy our planet we gained the technological power for people to leave the planet, as was illustrated by landing men on the moon. It was quickly realized by O'Neill [21] that by utilizing extraterrestrial materials and energy that we also had the ability to colonize space. NASA studies confirmed that it was technically possible to build large vista space habitats in free space, essentially anywhere in the solar system (out to the asteroid belt if only solar power were used) with up to about 4 million people in each. In O'Neill's habitat model the space citizens would live on the inside surfaces of radiation shielded spheres, cylinders, or torus's which would be rotated to provide Earth normal gravity. The prohibitive Earth launch costs for these massive structures could be off set by using lunar and asteroid materials. Construction of space solar power satellites by the space colonists would make the project economically viable. Economic break even for the O'Neill model was calculated to be about 35 years after which very large profits would be incurred. More recent calculations [22,23] show that if smaller (300 person) habitats were utilized for the first 10 years of the program, that economic break even would occur in 25 years about with peak expenditures reduced by about 80%.

The space habitat is considered independent if it is separated spatially such that for a given technological power that the habitat would not be directly effected by the self-destruction of its neighboring habitats. A statistical analysis can then be done [20] estimating the probability of human self-extinction considering the number of impendent habitats and the number of extinction events (people with the capability and the will to initiate habitat destruction).

An everyday analogy of this probability calculation is given as follows. Consider that a deck of cards represents an independent habitat and the Aces are extinction events. The probability that we have an Ace in the deck (extinction) is 100%. If we cut the cards into two piles the probability of extinction is less than 100 % since all the Aces could be in one pile. If we make 5 piles then the probability that each pile has one of the 4 Aces is zero.

The result [20] of this analysis is that the probability of self-extinction decreases at a higher rate than the increase in number of habitats. For example for the case where the number of habitats and number of extinction events are equal, for one habitat the probability of extinction by definition is one. For 3 habitats it is one in ten per year. For five habitats it is one in 100 per year and for 10 habitats it is one in ten thousand per year. If technology increases to where all people have the capability to destroy their habitat then 1 billion people in 75 habitats would still have a one in ten chance per year of self-extinction. However for 150 habitats the probability would drop to one in ten thousand per year.

Thus, consciousness constrains the development of society.

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