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The Conscious Electromagnetic Information (Cemi) Field Theory

The Hard Problem Made Easy?

Abstract: *In the April 2002 edition of JCS I outlined the conscious electromagnetic information field (cemi field) theory, claiming that consciousness is that component of the brain's electromagnetic field that is downloaded to motor neurons and is thereby capable of communicating its informational content to the outside world. In this paper I demonstrate that the theory is robust to criticisms. I further explore implications of the theory particularly as regards the relationship between electromagnetic fields, information, the phenomenology of consciousness and the meaning of free will. Using cemi field theory I propose a working hypothesis that shows, among other things, that awareness and information represent the same phenomenon viewed from different reference frames.*

Key words: consciousness, electromagnetic field, synchronous firing, coherence, hard problem.

Introduction

Field theories of consciousness are inherently attractive due to their natural solution to the binding problem. Using theoretical arguments and examining experimental evidence I previously demonstrated (McFadden, 2002) that the brain generates an electromagnetic (em) field that influences brain function through em field-sensitive voltage-gated ion channels in neuronal membranes. Information in neurons is therefore pooled, integrated and reflected back into neurons through the brain's em field and its influence on neuron firing patterns. I pointed out that this self-referral loop has physical and dynamic properties that precisely map with consciousness and are most parsimoniously accounted for if the brain's em field is in fact the physical substrate of consciousness and conscious volition results from the influence of the brain's em field on neurons that initiate motor actions. I therefore proposed the conscious electromagnetic information (cemi) field theory:

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> *Digital information within neurons is pooled and integrated to form an electromagnetic information field. Consciousness is that component of the brain's electromagnetic information field that is downloaded to motor neurons and is thereby capable of communicating its state to the outside world.*

The cemi field theory provides a simple and elegant solution to the binding problem (without recourse to any new physics or metaphysics), and also provides new insights into the nature and significance of consciousness. It suggests that processing information through the wave-mechanical dynamics of the cemi field provided a significant advantage to our ancestors that was captured by natural selection to endow our minds with the capability to process information through fields. We experience this field-level processing (through the cemi field) as consciousness. Its defining feature is its ability to handle irreducibly complex concepts such as a face, self, identity, words, meaning, shape, tool, or number, as holistic units. All conscious thinking involves the manipulation of such irreducibly complex concepts and must involve a physical system that can process complex information holistically. The only physical system that can perform this function in the brain is the cemi field. It is through this mechanism that — I propose — humans acquired the capacity to become conscious *agents* (Malik, 2000) able to influence the world.

A distinctive feature of the cemi field theory is the proposal that consciousness corresponds to only that component of the brain's em field that impacts on motor activity. This does not imply that the brain's em field acts directly on motor neurons (which may of course be located outside the brain) but only that em field information is communicated to the outside world via motor neurons. The site of action of the brain's em field is most likely to be neurons in the cerebral cortex involved in initiating motor actions, such as the areas that control speech, or the areas involved in laying down memories that may later be reported via motor actions (such as speech). Indeed, there is good deal of evidence (see e.g. Aarons, 1971; Paulesu *et al.*, 1993) that all verbal thought is accompanied by subvocalisations (i.e. motor cortex activity accompanied by appropriate but normally undetectable vocal tract activity). This informational download via the brain's em field avoids the pitfalls of most other field theories of consciousness that either suffer the classic 'mind–matter problem' (a non-physical consciousness whose interaction with the matter of the brain is left unresolved) or leave consciousness as a *ghost in the machine* (somehow generated by the brain but with no impact on its workings). The theory also sheds light on related thorny issues, such as the meaning of free will or the possibilities of creating consciousness in an artificial environment.

The cemi field theory was an extension of the cem field theory outlined in my book *Quantum Evolution* (McFadden, 2000). The theory has much in common with the em field theory of consciousness proposed by Dr Susan Pockett in her book *The Nature of Consciousness: A Hypothesis* (Pockett, 2000). Also in the April edition of *JCS* was a commentary by Susan Pockett (2002) in which she explored 'difficulties' with any electromagnetic field theory of consciousness. The neurophysiologist E. Roy John has also recently published a theory of consciousness involving em fields (John, 2002). Since publication, I have received many comments and criticisms of the theory. I here demonstrate that the cemi field theory is robust to these difficulties and criticisms. I further explore the theory and its implications for our understanding of mind and free will, and I propose a solution to the 'hard problem' of consciousness.

What is the electromagnetic field theory of conscious experience?

Susan Pockett's published commentary outlined several 'difficulties' with any em field theory of consciousness. Yet despite these difficulties, Dr Pockett remains supportive of the concept that consciousness is identical with the brain's em field, as outlined in her book (Pockett, 2000) and points out that she attempted to publish an account of her own theory as early as 1995.

In her commentary, Pockett claims that consciousness (or qualia) is 'identical with certain yet-undefined spatio-temporal patterns in the electromagnetic field' (Pockett, 2002, p. 52). Since the nature of conscious em fields is left 'undefined', an explanatory gap is left in her theory. This contrasts with the cemi field theory that clearly defines the conscious component of the brain's em field as that information that is downloaded to motor neurons (either directly to drive actions such as speech or indirectly to lay down memories that may later be reported through motor actions such as speech). All other information in the brain's em field is unavailable to any reportable introspection and therefore cannot be equated with any kind of (third person) reportable consciousness. In a departure from the theory outlined in her book, Pockett now casts doubt on whether the putative conscious em field influences neuron firing patterns.

The neurophysiologist E. Roy John has recently proposed another em theory of consciousness. In his detailed proposals, brain em fields are involved in recruiting neurons into reverberant thalamo-cortical oscillations that establish resonating fields in the brain that correspond to conscious percepts. The theory has much in common with both the cemi field theory and Pockett's theory but, as with Pockett's current model (and contrasting with the cemi field theory) John's theory does not include a mechanism for transferring information from the conscious em field to neurons (other than recruiting neurons into a resonating field) and may therefore be subject to a similar *ghost in the machine* limitation that (I believe) afflicts Pockett's current theory.

I: Three 'Difficulties', As Outlined By Susan Pockett

Pockett's difficulty 1

Pockett here argues that the scientific validity of the em field theory is limited by the inability to measure the properties of the brain's em field in order to 'test the electromagnetic field theory of consciousness, by seeing if the artificially produced patterns can be reintegrated into the conscious field of the brain which originally produced them, to allow a re-experience of the original sensation' (Pockett, 2002, p. 53). I agree that the theory is currently limited by the lack of a direct test but would argue that the test Pockett proposes suffers from the *ghost in the machine* problem in relation to her current theory, but nicely illustrates the differences between our theories. Consider a *gedanken* experiment in which the inverse problem had been solved and it was possible to describe fully an electromagnetic field that — in a human brain — was associated with the quale of seeing a red apple. Consider also that an electrical device — a transmitter — has been developed that is capable of generating that precise em field inside a — receiver — human head. Pockett's presumption seems to be that if the em field theory were true then, the receiver should experience the quale of a red apple. But if, as she suggests, qualia are associated with certain em field configurations that are generated by brains (but do not necessarily download that information) then the quale corresponding to the experience of a red apple may be experienced by the generator of the red apple em field — the transmitter — not necessarily the receiver (the brain). For the receiver to report a sensation corresponding to the information in the artificially-generated field (the red apple), there would have to be an informational transfer (download) from the transmitter to the receiver. Pockett's current theory lacks a physical mechanism for that transfer. In contrast, in the cemi field theory, information in the em field is communicated to neurons via the influence of electromagnetic induction on voltage-gated ion channels. In the final section of this paper I discuss an experimental approach involving artificial intelligence that is similar to Pockett's proposed experiment but would both test and distinguish between our theories.

Pockett's difficulty 2

Pockett's second difficulty points out that 'there actually is no one-to-one correspondence between electromagnetic patterns measurable at the scalp or the surface of the brain and the conscious sensations experienced by the "owner" of the brain' (p. 53). However, I would argue that this is only a problem for em field theories that propose an identity between the brain's total em field and conscious experience. Indeed, the issue highlights a difficulty with any identity theory between the brain's em field and consciousness. Since every action potential generates a perturbation in the surrounding em field, the information flow through the brain's em field must be of a similar order of magnitude as the spike rate of cortical neurons, about 10^{12} bits per second. But this is far greater than the approximately 40 bits per second that are estimated to be involved in conscious thinking (Norretranders, 1998). Clearly only a tiny component of the information held in the brain's em field can correspond to consciousness so any identity theory must find some means of discarding the excess information. In the cemi field theory this is explained by the requirement for field information to be downloaded to motor neurons. In my paper, I showed that induced transmembrane voltages are in the range of several microvolts up to about one millivolt. Neurons will thereby only be sensitive to em field effects when they are within a millivolt or less of the firing threshold. Since transmembrane voltages vary across approximately 130 mV, very crudely, we would expect less than one hundredth of neurons to be receptive to information held in the surrounding extracellular field. The corollary of this is that most of the information in the brain's em field will not be downloaded into neurons. Therefore, in the cemi field theory, only a tiny portion of the informational content in EEG or MEG signals would be expected to correlate with consciousness. A one-to-one correspondence between perturbations of the brain's em field and consciousness is not therefore expected in the cemi field theory. Although the failure to make a clearly verifiable prediction of a correlation between the gross structure of the brain's em field and consciousness may be considered to be a weakness of the cemi field theory, the theory does make many alternative predictions, as described in my earlier paper, and I describe a direct test in the final section of this paper.

I should emphasize that the cemi field theory does not propose that consciousness is necessarily associated with amplitude, phase or frequency of the brain's em field. The defining feature is rather the informational content and its ability to be communicated (downloaded) to motor neurons. This may, but may not always correlate with amplitude or phase of em field perturbations. As I discussed in my paper, regular EEG rhythms may have high amplitudes but contain very little information; they have *nothing to say*.

Although a one-to-one correspondence between EEG activity and conscious sensations is not a prediction of the cemi field theory, some correlation might be expected. As discussed in my earlier paper, there is abundant evidence of this in EEG studies of attention and perception. Indeed, electrical 'microstates' can actually be identified by EEG that persist for about 80 ms (John, 2002), which is a similar duration to the 75–100 ms estimated for 'perceptual frames' that define a 'traveling moment' of perception (sequential stimuli that occur within this interval are generally perceived as occurring simultaneously). E. Roy John has proposed that these electrical microstates are indeed the physical correlates of perceptual frames (John, 2002).

Pockett's difficulty 3

The third problem raised by Pockett is a question of whether we should 'expect consciousness (i.e. conscious electromagnetic fields) to be a direct cause of behaviour?' (p. 54). This of course refers to the thorny problem of free will. In my earlier paper I proposed that free will is our subjective experience of the influence of the brain's field on our actions. Pockett highlights two problems. Firstly, Pockett questions whether 'spatial electromagnetic patterns, which by their very nature quickly become spread and smeared by volume conduction as they move through the brain, could maintain enough structure to affect neural activity patterns in far-flung regions of the central nervous system' (p. 54). I would first point out that distortion of a signal is not necessarily a problem in transmission. So long as the firing of any transmitter neuron(s) induces a reproducible change in the extracellular field surrounding the receiver neuron(s) then information can be efficiently exchanged between them. The only requirement for information exchange is that a correlation be maintained (through the em field) between the firing activity of the transmitter(s) and the probability of firing of the receiver neurons. Nevertheless, it is likely that, as Pockett argues, some information will be lost from the field as the signal attenuates during its transit. However, the cemi field theory accounts for this (as I believe Pockett's theory also can) by emphasizing the importance of synchronous firing of neurons as a means of amplifying and relaying information in the brain's em field.

Secondly, Pockett considers Libet's classic experiments (Libet, 1993; Libet *et al.*, 1983) and later work (Trevena and Miller, 2002), that demonstrate electromagnetic 'readiness potentials' which precede voluntary movement by about a second. Pockett claims that these findings 'seem to indicate the lack of a direct influence of consciousness on the brain' (p. 54). I would argue instead that these experiments demonstrate only that em field fluctuations in the brain are a necessary but are not a sufficient condition for consciousness, a finding that is entirely compatible with the cemi field theory.

Consider Libet's experiments in which 'readiness potentials' were detected up to about 500 ms before the onset of awareness of the intention to perform a voluntary act (Libet *et al.*, 1983). Since — in the cemi field theory — conscious volition is proposed to correspond to our experience of the action of the brain's em field on neurons, then the theory predicts that the field should be playing its role in initiating the action in this period, about 500 ms after the readiness potentials can be detected. Pockett argues that this is incompatible with a causal role for the brain's em field. I would argue instead that the action of the brain's field is a necessary step in the chain of events that lead to a voluntary action, and it is this input from the field that makes those actions voluntary (unconsconsious actions lack this input from the field). However, the field's intensity and dynamics will be a product of preceding neural activity, involving perhaps the reverberant thalamocortical oscillations that E. Roy John has proposed to be involved in recruiting neurons into synchronously-firing networks (John, 2002). The events leading to the voluntary action may initially involve only a small numbers of neurons that generate a relatively weak field. This can be detected by EEG as readiness potentials, but is unlikely to impact on neuron firing patterns. Although — in the cemi field theory — this weak field may be associated with *awareness* (see argument below considering the *hard problem*), the awareness cannot be communicable to neurons and therefore will not be associated with any conscious state. However, as the neural activity progresses and more and more neurons are recruited into a synchronously firing network that eventually initiates the action, the in-phase field fluctuations will generate a stronger field that will eventually impact on nerve firing (if, and only if, the action is voluntary). The impact may be positive, to reinforce the action, or negative, to veto the action, depending on the influence of the field on the target neurons. It is at this point — when our brain's em field is impacting on neurons — that *awareness* of the action is downloaded into consciousness (in Libet's experiment, to report awareness of intention to act). It is interesting to note that the proposed activity of the field is entirely compatible with the role that Libet has proposed for consciousness in providing a 'veto' for actions that are initiated by preconscious neural activity (Libet, 1996). This is perhaps not surprising, since Libet himself proposed that consciousness is some kind of field (though not an electromagnetic field) that acts to reinforce or veto actions that are initiated unconsciously (Libet, 1994).

So although readiness potentials precede conscious awareness, consciousness (the action of the brain's em field on neurons) still plays a causal role in initiating voluntary actions. The situation may be compared with any causal chain. For instance, it is generally agreed that the assassination of the Archduke Ferdinand played a causal role in initiating the First World War. This is not to say that no other causal events preceded the assassination (e.g. the collapse of the Ottoman empire) but only that, if the assassin had missed, the subsequent war may have been averted. The distinction here is the difference between causality and what Kanan Malik terms 'agency' (Malik, 2000), in the sense of 'conscious beings with purpose and agency, . . . we have the ability to transform our selves, our natures, our world, an ability denied to any other physical being'. In a deterministic world, all actions have a cause (that can theoretically be traced right back to the Big Bang) but I propose that consciousness — as the cemi field — plays the role of *agency* in initiating voluntary actions. Whether this agency is viewed as causal depends on one's philosophical viewpoint, but unless free will is an action without a cause, then we must expect it to be always preceded by earlier neural events. Anything else is incompatible with causality. The only exception here would be the possibility that voluntary actions may sometimes be initiated by acausal quantum dynamics, which will be discussed below. Barring quantum effects, in principle, electromagnetic activity may be detected minutes or even hours preceding our perception of a self-timed voluntary action but will still be linked in a causal chain of events with that self-timed action.

It is interesting to note that an analogous difficulty arises with any neuronal identity theory of consciousness. If conscious awareness (of the initiation of a self-timed voluntary action) is proposed to be identical with certain patterns of neural activity then those patterns of neuronal activity must have been preceded by (caused by) earlier neural activity that was not conscious. In the neural identity theory it is not clear how the unconscious neural activity differs from succeeding conscious neural activity. In neural identity theory and in Pockett's em theory, the problem arises because conscious and unconscious neural processes are proposed to involve the same physical processes that differ in some undefined dynamic property. In the cemi field theory, that difference is defined.

II: Additional Criticisms and Comments

I now turn to various points, criticisms and comments on the cemi field theory that have been made via emails and bulletin board messages.

Why don't external em fields enter our thoughts?

I demonstrated in my earlier paper that static and low frequency electric fields do not significantly penetrate the head and are thereby incapable of influencing the cemi field. High frequency electric fields generated by cellular (mobile) phones would be expected to penetrate the head more effectively (limited by the *electromagnetic skin depth* — the distance in which the field is attenuated by a factor of e^{-1} — which for the head is about one centimeter) but their high frequencies (in the MHz or GHz range) make them unlikely to interact with low brain frequency waves. As discussed in my earlier paper, low frequency magnetic fields, such as those used in transcranial magnetic stimulation, would be expected to interact with brain em fields and there is indeed abundant evidence for cognitive effects of these fields (see for instance, Lyskov *et al*., 1993).

If external fields are unable to penetrate brain tissue then endogenous fields will be similarly attenuated

The fact that EEG signals can be detected on the scalp indicates that endogenous em fields do indeed penetrate brain tissue. The reason for this is that the major source of EEG signals (and more generally, the brain's em field) is not the firing of single neurons but assemblies of neurons firing synchronously (as discussed in my earlier paper). By firing in synchrony, neurons distribute and amplify field effects.

Why aren't artificially-generated em fields conscious?

The only place in the known universe where em fields occur that are capable of communicating self-generated irreducibly complex concepts like 'self' (and thereby persuading an observer that they are indeed conscious) is in the human brain. Artificially generated em fields, such as the em fields that communicate radio and TV signals, are only capable of communicating the information encoded and transmitted within their fields. They have *nothing else to say*. To question whether they are either aware or conscious is meaningless.

Quantum mechanics and the cemi field theory

The cemi field theory proposes that consciousness is a wave mechanical system whose dynamics will have much in common with quantum theories of consciousness. This can be understood by considering an electron first as particle. In this state, it's presence or absence can store a single classical bit. However, the same electron considered as a field can store a range of intermediate numbers between 0 and 1 as a matrix of field density values. Both field computation and quantum mechanics are expressed in terms of Hilbert space, allowing field computation to perform simultaneous nonlinear computation in linear superposition, a capability that has been called *quantum-like computing* (MacLennan, 1999) within a classical system.

But although not integral, the cemi field theory does not exclude the possibility of direct quantum effects in the brain. I proposed in my book *Quantum Evolution* (McFadden, 2000), that the most likely source of quantum effects in the brain would not be microtubules (which have no established role in information processing) but interactions between the brain's em field and voltage-gated ion channels (with a clearly established role in information processing in the brain) in the neuronal membrane. Near to the neuronal cell body (where the firing is initiated) the membrane potential is very close to threshold such that the opening or closing of just a few ion channels may be sufficient to trigger or inhibit firing. Opening of just a single ion channel *in vitro* has been shown to be capable of initiating an action potential (Arhem and Johansson, 1996). The precise number of quanta of em energy that must be absorbed from the surrounding field to open a single voltage-gated ion channel is currently unknown. The field has to push 7–12 charges of the channel molecule's sensor towards the open position, but it is likely that when the membrane potential is already close to the firing threshold, very little additional energy need be absorbed from the field. Absorption of a single photon is sufficient to initiate proton pumping by the bacterior- hodopsin proton pump (Edman *et al*., 1999). It is therefore likely that nerve firing may in some circumstances be triggered (or inhibited) by just a few quanta of energy. If neurons poised on the dynamics of individual membrane proteins are critical to the initiation of a particular course of motor action or cognitive process, then the consequent action or cognitive processes will be subject to non- deterministic quantum dynamics. It is interesting to speculate on whether such un-caused events play a role in human spontaneity or creativity. According to David Bohm, Neils Bohr, the founding father of quantum mechanics, considered it likely that 'thought involves such small amounts of energy that quantum- theoretical limitations play an essential role in determining its character' (Bohm, 1951).

The cemi field theory and artificial consciousness

The cemi field theory claims that consciousness is a by-product of an evolutionary advantage (field-level information processing) captured by the human mind. However, there is no reason why similar advantages should not be captured by artificial minds. In my earlier paper I suggested that an artificial consciousness could be built if real electrical neural networks (rather than the simulated neural networks in a serial computer) were constructed to ensure that their information processing was sensitive to their induced em fields (see discussion in McFadden, 2002, p. 44). At the time of writing I did not know of any evidence to support this claim but I have since been made aware of an intriguing experiment performed by the School of Cognitive & Computing Sciences (COGS) group at Sussex University that appears to have (accidentally) evolved a field-sensitive electronic circuit (Davidson, 1997; Thompson, 1996). The group used a silicon chip known as a field-programmable gate array (FPGA), comprised of an array of cells. Electronic switches distributed through the array allow the behaviour and connections of the cells to be reconfigured from software. Starting from a population of random configurations, the hardware was *evolved* to perform a task, in this case, distinguishing between two tones. After about 5,000 generations the network could efficiently perform its task. When the group examined the evolved network they discovered that it utilized only 32 of the 100 FPGA cells. The remaining cells could be disconnected from the network without affecting performance.

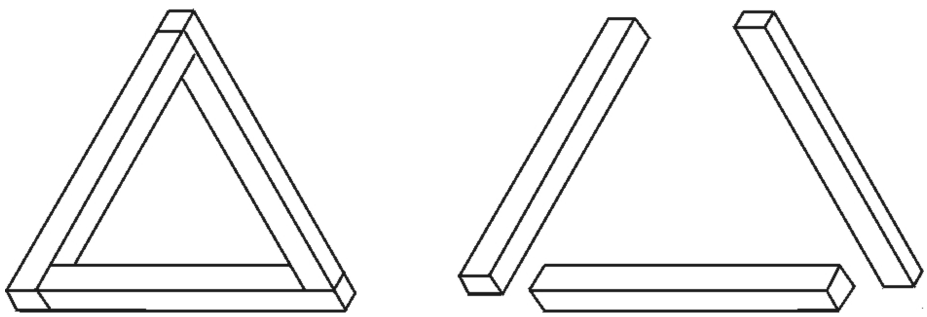
However, when the circuit diagram of the critical network was examined it was found that some of the essential cells, although apparently necessary for network performance (if disconnected, the network failed), were not connected by wires to the rest of the circuit. According to the researchers, the most likely explanation seems to be that these cells were contributing to the network through electromagnetic coupling — field effects — between components in the circuit. It is very intriguing that evolution of an artificial neural network appeared to capture field effects spontaneously as a way of optimizing computational performance. This suggests that natural evolution of neural networks in the brain would similarly capture field effects, precisely as proposed in the cemi field theory. The finding may have considerable implications for the design of artificial intelligence.

Conceptual binding is part of the grand illusion, so there is no binding problem

One of my main arguments in support of the cemi field theory is that it solves the binding problem without resort to extra physics or metaphysical *ghosts in the machine*. Yet it has been argued that the binding problem is a *pseudoproblem* since conceptual binding is part of the grand illusion (Blackmore *et al*., 1995; Dennett, 1991; see also special issue of *Journal Consciousness Studies*, Volume 9, No. 5/6). According to the grand illusion hypothesis, visual scenes (or any other bound aspect of consciousness) are actually as fragmented as the neuronal information within our brains but our minds somehow fool us into thinking the information is all stuck together. If binding is not a problem then the *raison d'etre* for the cemi field theory is at least suspect.

I fully accept that our visual experience is not as rich as we naively assume and the stream of consciousness may actually be closer to a dribble. However, despite this, binding remains a problem even within the grand illusion hypothesis. 'Change blindness', 'inattentional blindness' and other cognitive effects indicate that our conscious mind can attend to only five or six objects within a visual scene but each attended object is a complex item whose informational content must be bound within consciousness. This can be illustrated by considering the familiar 'impossible triangle'.

The geometric inconsistencies of the object are a property of the percept corresponding to the whole object, not a collection of its parts. During the information processing performed first by the retina and then by neurons in the visual cortex,



information corresponding to various properties of the object (in this case just lines and angles but normally including colour, texture, shading, etc.) is stripped, separated, handled and processed by thousands of distinct neurons. However, the illusion only makes sense if this disparate information is somehow bound together again within our conscious minds to generate a unified percept of the triangle.

To further emphasize this point, it is illuminating to consider replacing the neurons of the brain involved in processing this task, with people. We can imagine an artificial retina that captures the same information than enters the human eye and processes that information through a functionally equivalent neural network as the brain, but with a network of people rather than neurons. Just as in the brain, the information is dissected and processed by parallel and serial lines of feature detectors and information processors (in this case all people) by some kind of signaling process (perhaps hand shakes) to generate an output — the - terminal person-processor issues some kind of verbal report. This person neural network could perform exactly the same informational processing task as performed by the neurons in your brain and generate the same verbal report, but who would *see* the triangle? Each person in the neural network *sees* only the signal from incoming neuron-persons (a sequence of handshakes) that correspond to a single feature — perhaps the thickness of one of the lines or its orientation. There is no person-neuron that sees the whole triangle. No one is puzzled by the illusion.

The imaginary person neural network acutely illustrates the binding problem. The network is constructed from conscious agents. It inputs information, processes that information and generates an output, just as the neuronal brain. Just as in the brain, the information corresponding to the triangle is scattered and distributed through the network. Every component of the network performs its computation task but there is nothing or no one in the network that even *knows* there is a triangle out there. At this point, neural identity theorists generally claim that the percept is some kind of emergent property of the entire network ('it is the whole network that *knows*') but I would argue that it is preposterous to claim that a neuron or network of neurons could generate a greater level of awareness than a network of persons. In the person network it is clear that there is nothing or nobody that *sees* the whole triangle. The neural brain is similarly ignorant of the reality of the whole triangle. It is only in the cemi field that the information gets bound into conscious percepts.

III: The Hard Problem, Information and Frame of Reference

Several commentators have claimed that the cemi field theory does not really address what Chalmers calls the 'hard problem' of consciousness (Chalmers, 1995); that is, to account for how subjective experience arises from objective neural activity. I will briefly discuss how the cemi field theory provides fresh insight into the problem.

The most basic property of (reportable) consciousness is that it must have informational content. Information needs to be encoded within some kind of physical substrate. A fundamental question regarding consciousness is therefore the nature of that substrate. It is useful first to consider the physical substrate of other kinds of information. Although it is often assumed that the information transmitted in electrical circuits (such as in digital computers) is encoded within the matter of the electrons that carry current down a wire, a moment's consideration will show that this cannot be the case. Signals in an electric circuit travel at nearly the speed of light but electrons flow along a metallic wire much more slowly, at the *drift speed* of about 1 mm/s. These facts are reconciled when it is realized that the signal is carried, not by the electrons themselves, but by an electromagnetic wave that propagates the length of the wire (guided by the charged electrons) at approximately light speed. So even in a digital computer, information is encoded, not by particles, but by electromagnetic waves.

Neuronal signals involve the movement of ions rather than electrons, but similarly, neuronal information cannot be encoded within ions since they move perpendicular to the membrane and thereby in the wrong direction with respect to information flow along the neuron. The information carrier along a neuron is the em field fluctuation that propagates along the neuron: the action potential. Therefore, even if we propose that consciousness is a property of neurons, the only conceivable substrate for its information content is the em field of the neuron. But, if it is accepted that the informational content of consciousness resides within the em field of individual neurons then we must also consider that the informational content of each neuron is causally connected, through the brain's em field, to the informational content of all other neurons in the brain. It is a small step from this realization to the cemi field theory of consciousness.

Yet it is still valid to ask: why is the brain's em field associated with subjective experience or awareness? Although it may be accepted that the brain's em field performs an essential function with regard to informational transfer and processing in the brain, that function is logically consistent with a system that lacks awareness. Where then does subjective experience (Chalmers, 1995) or awareness come from? This is of course the 'hard problem' of consciousness.

Chalmers has proposed the 'double-aspect theory of information' (Chalmers, 1995) in which information is proposed to have two aspects, a physical aspect and a phenomenal aspect. In this sense, subjective experience is a non-reductive aspect of information, as fundamental to information as gravity is to mass. The cemi field theory builds on this proposal to argue that awareness — what Chalmers terms *experience* (see, e.g., Chalmers, 1995, p. 201) and Block terms *phenomenal consciousness* (Block, 1995) — is what complex information encoded in em fields feels like *from the inside*. The experience of hearing middle C is therefore *what it is like* (Nagel, 1974) to be on the inside of electromagnetic field-encoded information that corresponds to the statement, 'the acoustic vibration detected has a frequency in the range of around 256 cycles per second'. In this sense, information and awareness are considered to be two aspects of the same phenomenon (we could call it information/awareness) viewed from alternative frames of reference. Frame of reference arguments are familiar in physics where an electromagnetic field may be experienced as an electric field from one frame of reference (e.g. stationary) but a magnetic field from another frame of reference (moving). Many other apparently disparate physical attributes, such as space and time, are complementary aspects of the same phenomenon viewed from different frames of reference. I propose that information/ awareness is experienced as information from the reference frame of an observer external to that information but is experienced as awareness from the reference frame of the particles/fields that encode the information.

In this view, all information possesses an awareness aspect. But the nature of that awareness is a function of the complexity and dynamics of the physical system that encodes the information. It is possible to distinguish at least three levels of awareness, depending on the dynamics of the physical system encoding information/awareness. At the first level is information/awareness located with the particles of matter. A single electron, proton, atom or molecule may (from its reference frame) possess informational awareness but only of the very limited static information encoded within that particle (essentially, its quantum wave function). A collection of particles, as in a single neuron of even a neural network, may encode more complex information, *but only from the frame of reference of an outside observer*. From the reference frame of any particle within the network, it makes no difference whether it is in a brain, or in a bowl of soup; its information content (and the awareness associated with that information content) remains the same. Awareness based in matter, we could call it *discrete awareness*, including the particles of neurons or the electrons of an electronic circuit, is always discrete, limited, static and independent of context. It cannot encode complex concepts such as 'self' and it cannot correspond to the kind of dynamic concept-driven awareness that we experience as consciousness.

The next level of awareness is that associated with fields, which, in contrast to particles, have unlimited capacity to encode complex information within a single unified physical system. Complex informational objects, like faces and shapes, and abstract objects like numbers or words, may be completely encoded (with all their inherent meaning) within a single unified field. And *from the frame of reference of the field encoding that concept*, information will be associated with awareness of the entire informational content of the object or concept. This level of awareness, *field awareness*, may be associated with any system where complex information is encoded in fields. But crucially, without a mechanism to communicate with the outside world, this field awareness will be a mere 'ghost in the machine'. As discussed above, most of the information in the brain's em field is not downloaded to neurons. Without access to the motor system, these non-downloaded em fields will be mute and cannot thereby correspond to any third person reportable consciousness (although it may be interesting to explore how far these fields may correspond to 'the unconscious'). They are 'ghosts in the machine'. Since they have no phenotype, these fields will also be invisible to natural selection so evolution will not have contributed to their structure or dynamics.

The final level of awareness is consciousness, what Block terms *access consciousness* (Block, 1995). This has the same physical structure as field awareness discussed above — it is encoded within fields — but its additional defining characteristic is that it can communicate. This level of awareness is associated with that component of the brain's em field — the cemi field — that is able to communicate via its impact (directly or indirectly) on motor neurons and thereby generate reportable consciousness. In the cemi field theory, consciousness is field-encoded information/awareness that can talk. And, crucially, the ability to affect nerve-firing patterns endows consciousness with a phenotype that is visible to natural selection. In contrast to discrete awareness or field awareness, the structure and dynamics of consciousness will have been honed by evolution to optimize fitness of conscious animals.

I should emphasize that the three levels of awareness (information/awareness experienced from an internal reference frame) discussed above are in reality the same phenomenon — awareness — but with differing dynamics. The distinct properties of discrete awareness, field awareness and consciousness are merely a logical consequence of the dynamics of the underlying physical structures that encode the information/awareness. No new principles are involved. In fact, it could be argued that additional forms of awareness may be associated with information/awareness encoded by further distinct physical systems. For instance, although the particles of neurons are proposed to possess discrete awareness, if those particles are able to enter quantum states (as proposed in quantum consciousness theories) to generate a quantum field that can encode complex informational objects, then those particles may possess something analogous to field awareness. Or, if electronic devices are constructed to generate light fields that can represent complex information (as in optoelectronics) then the awareness associated with this light-based information/awareness is likely to have its own distinct dynamics.

The cemi field theory proposes that consciousness is the inner experience of information/awareness encoded in the brain's em field. From the reference frame of the cemi field, conscious actions are *its* actions — its influence on the world. In this sense, *agency* (Malik, 2000) is the experience of influence on the world from the frame of reference of information/awareness capable of encoding meaning. Only human brains generate fields with this capacity and are able to communicating these objects and concepts (although artificially generated fields may encode complex information and transmit it to TVs or radios, they lack the dynamics to communicate anything other than the information encoded within their signal — they have *nothing else to say*). That capacity — human consciousness — may be the key evolutionary advantage captured by the human mind.

Discussion

As I emphasized in my earlier paper, the cemi field theory is based on the very simple premise that em fields impact on neuron firing and may thereby contribute both positively and negatively to information processing in the brain. If this is accepted (and, along with the arguments outlined in my earlier paper, the COGS experiment described above indicates that field effects may at least contribute to information processing in artificial systems) then natural selection will inevitably act to optimize field-level effects when they provide an advantage and minimize them when they are detrimental. Over millions of years, two parallel systems will evolve: an em field-sensitive information processing system and an em field-insensitive system. The cemi field theory proposes that these systems correspond to our conscious and unconscious mind, respectively. I show here that the cemi field theory is robust to criticism and is rich with insights and implications for our understanding of mind, free will and artificial intelligence. The theory accounts for why consciousness is serial, why synchronous firing of neurons correlate with attention and awareness, and why readiness potentials are detected prior to conscious actions. Unlike many 'theories of consciousness' that deal primarily with abstractions with no or little reference to the underlying neurophysiological processes, the cemi field theory is firmly grounded in the neurophysiology of the brain without recourse to any new physics or new biology. As well as making many clear predictions, the theory may even be directly tested in the not too distant future, as I will now briefly discuss.

Consider constructing a supercomputer with conventional electronic architecture but with the complexity of the human brain (perhaps achievable within a few decades) and capable of communicating. Most AI researchers claim that consciousness would spontaneously emerge in such a system. I would argue instead that any AI based on digital circuitry will lack consciousness since it will lack the influence of a field capable of encoding whole concepts. This in itself will be testable (leaving to one side the thorny issue of how to detect consciousness) and any emergence of consciousness within a digital AI will clearly disprove the cemi field theory. However despite its predicted lack of consciousness, the electrical circuitry of the supercomputer will generate em fields with informational complexity and dynamics similar to the fields generated by the human brain. Such fields would — in the cemi field theory — be associated with awareness of that information. Yet without an informational downloading mechanism, those fields will be mute, and possess only *field awareness*. But it should be possible to engineer the system to allow the information/awareness in the fields to influence the computational process. If this were achieved then it should be possible to evolve (as in the COGS experiment described above) a field-sensitive computer that is capable of downloading its information/awareness. Such an AI will, I predict, possess a conscious mind. However, in the proposed experiment, it would not yet be clear whether consciousness had somehow emerged entirely within the digital circuitry of the AI or whether it truly resided within the em field. Fortunately, within an artificial system, it should be possible to separate these systems. Computer X could generate a field whose informational content could be downloaded into computer Y. In this case, the cemi field theory predicts that computer Y, but not computer X, would be conscious.

The cemi field theory places consciousness within a secure scientific framework that is amenable to experimental verification. The theory suggests ways to engineering consciousness within an artificial system, potentially allowing future researchers to investigate the origin and dynamics of awareness and consciousness.

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