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Article

Carving Nature at Its Joints: A Comparison of CEMI Field Theory with Integrated Information Theory and Global Workspace Theory

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“And once I had recognized the taste of the crumb of madeleine soaked in her decoction of lime-flowers which my aunt used to give me (although I did not yet know and must long postpone the discovery of why this memory made me so happy) immediately the old grey house upon the street, where her room was, rose up like the scenery of a theatre to attach itself to the little pavilion, opening on to the garden, which had been built out behind it for my parents (the isolated panel which until that moment had been all that I could see); and with the house the town, from morning to night and in all weathers, the Square where I was sent before luncheon, the streets along which I used to run errands, the country roads we took when it was fine. And just as the Japanese amuse themselves by filling a porcelain bowl with water and steeping in it little crumbs of paper which until then are without character or form, but, the moment they become wet, stretch themselves and bend, take on colour and distinctive shape, become flowers or houses or people, permanent and recognisable, so in that moment all the flowers in our garden and in M. Swann's park, and the water-lilies on the Vivonne and the good folk of the village and their little dwellings and the parish church and the whole of Combray and of its surroundings, taking their proper shapes and growing solid, sprang into being, town and gardens alike, all from my cup of tea.”

Marcel Proust, *Memories of Things Past*, 1913

Abstract: The quest to comprehend the nature of consciousness has spurred the development of many theories that seek to explain its underlying mechanisms and account for its neural correlates. In this paper, I compare my own conscious electromagnetic information field (ceMI field) theory with integrated information theory and global workspace theory for their ability to ‘carve nature at its joints’ in the sense of predicting the entities, structures, states and dynamics that are conventionally recognized as being conscious or nonconscious. I demonstrate the ceMI field theory shares features with both integrated information theory and global workspace theory but consistently outperforms both by correctly predicting the entities, structures, states and dynamics that support consciousness. I argue that the simplest solution to the question of why ceMI field theory consistently outperforms rival theories of consciousness is that the brain's EM field is consciousness.

Keywords: integrated information theory

Introduction

In the above famous lines, Proust's contemplates the nature of memory but his beautiful prose also illustrates the most profound and characteristic feature of consciousness that, in an instant of perceptual time, the conscious mind can grasp the complexity of the imaginary town of Combray with its walks, flowers, gardens, people and even “the old grey house upon the street, where her room was, [which] rose up like the scenery of a theatre”. Since Descartes, philosophers, scientists and writers have pondered where this ‘theatre’, as it is often described, is within the three pounds or so of grey flesh that inhabits our skull. In recent decades, the observer has been expelled from the Cartesian theatre (1) but there remains the puzzle of locating the theatre itself, the conscious mind, amongst the tangle of 86 billion or so neurons in the brain.

There are many theories of consciousness (ToCs) that attempt to solve this problem, many of which have recently been reviewed and compared (2–4) but with no generally agreed solution. In his pioneering book, *The Astonishing Hypothesis* (5), the Nobel Prize laureate, Francis Crick, proposed a revolutionary approach to locating the ‘seat of consciousness’ meaning a place or process in the

brain where consciousness is generated, by identifying measurable neural correlates of consciousness, or NCCs. This approach has been very fruitful in identifying many neural underpinnings of consciousness and anatomical sites in the brain that appear necessary for consciousness but has not yielded any obvious *seat of consciousness* (6). Brain injury, stimulation and surgical resection studies have similarly identified regions of the brain, such as the thalamus, that appear to be required for conscious experience and other, such as the cerebellum, whose activities do not appear to be associated with conscious experience but, once again, without identifying an anatomical site or process that is a plausible seat of consciousness (7,8).

The inability of NCC approaches to associate consciousness with a particular neurological process or anatomical site in the brain has led other researchers to tackle the problem from a phenomenological direction to identify properties common to the conscious experience and then uncover what kind of processes or activities that are needed to account for these properties. Chief amongst these core consciousness properties is, as Proust's text illustrates, the ability of the conscious mind to grasp complex perceptions or ideas, such as the imaginary town of Combray, as a singular conscious state. The problem, often known as the binding problem, is that of understanding how information that is distributed across many millions, if not billions, of neurons throughout the brain, is bound into a singular conscious state. Possible solutions to this problem are provided by the two of the most popular ToCs, integrated information theory (IIT) and global workspace theory (GWT). The aim of this review is to examine an alternative solution, the cemi field theory, that, quite simply, places the seat of consciousness in the in the physical but immaterial electromagnetic field (EMF) generated by brain neural activity..

The idea that consciousness requires some kind of substrate capable of integrating information goes back at least as far as the Gestalt school of psychology that emerged in the early 20th century (9). Gestalt psychologists insisted that perception and consciousness involve the integration of sensory information, such as the details of the imaginary town of Combray, into complex but integrated wholes which they called "gestalts." One of the movement's founders, Wolfgang Köhler, proposed that these gestalt properties of object perception are encoded in electrochemical "brain-field[s]" that are isomorphic with "the field of a percept" (10). This idea fell out of favour with the emergence of modern neurobiology that did not accept any a role for electric fields in the brain, despite the fact that the brain generates an EM field had been known since Hans Berger's invention of the EEG in the 1920's. In the 1990's philosopher Karl Popper and colleagues (11) (12) and, though a little later, the pioneering experimental neurophysiologist, Benjamin Libet (13,14), took up the gestalt field idea to propose that consciousness is provided by some kind of unifying field in the brain. However, none of these researchers identified consciousness with any known physical field so its nature remained mysterious.

In 2000, both McFadden (15) and Pocket (16) published books that proposed a possible solution. They pointed out that neuron firing and synaptic transmission in the brain generates an endogenous electromagnetic field. This has, of course, been extensively studied by EEG (electroencephalography) and MEG (magnetoencephalography) and is utilized in medical diagnostics, particularly for assessing states of consciousness, yet was mostly considered to play no role in information processing in the brain.

Being a field-mechanical entity, brain EM fields are subject to both constructive and destructive interference. Asynchronously-firing neurons will generate non-overlapping EM field waves that will tend to cancel each other out by destructive interference. However, if neurons are firing synchronously so that the peaks and troughs of their wave oscillations overlap, then the EM field perturbations generated by their firing, and thereby the information encoded by the synchronously-firing neurons, will reinforce each other through constructive interference. So the brain's EM field will be dominated by signals generated by synchronously-firing neurons. Numerous studies have demonstrated that consciousness in both man and animals is strongly correlated with synchronously-firing neurons (5,17–24). Moreover, and crucially, whereas information encoded in neurons is discrete and localized, information encoded in brain EM fields is physically integrated and delocalized across the entire brain. In papers published in 2002, McFadden and Pockett (separately) proposed that

consciousness correlates with synchronously-firing neurons because the substrate of consciousness is not brain matter but the equally physical but immaterial brain EM field (25–27). So, according to the EM field theories of consciousness (EMF-ToCs), the town of Combray in Proust's story would not only be encoded in neurons scattered across the narrator's brain but also in the EM fields generated by those same neurons firing synchronously so that their encoded information is integrated and broadcast to any potential (receiver) neuron localized anywhere in the brain. EMF-ToCs propose that neuronal information becomes conscious only when it is integrated into brain EM fields.

A key difference between McFadden and Pocket's theories is that, in cemi field theory, the brain's EM field is proposed to be causally active by influencing neural firing sufficient to be the cause of motor actions that we experience as willed (rather than automatic) actions: the outputs of our conscious mind (28). In Pocket's theory the brain's EM field, although the seat of consciousness, is proposed to be causally inactive.

Similar theories EMF theories of consciousness (EMF-ToCs) were proposed around the same time by the neurophysiologist E. Roy John (29,30) and the neurophysiologists Fingelkurts and Fingelkurts(31–33). In the following decades, several other EMF-ToCs have been published (34–42) and abundant evidence has emerged for EMF-mediated information transfer in the brain, sometimes known as ephaptic transmission (24,43–48), consistent with McFadden's proposal that the brain's EM field, the substrate of consciousness, is indeed causally active.

An alternative approach to integrating conscious information in the brain was pioneered by the neurobiologist, Giulio Tononi, who, in 2004, proposed that any system with highly integrated information generates consciousness (49,50). In contrast to the EMF-ToC's that propose that conscious information is integrated within a physical field, Integrated Information Theory, or IIT, instead envisages that neuronally-encoded brain information becomes conscious only when it is maximally integrated, in the sense of its cause-effect structure being maximally irreducible to cause-effects relationships of the parts of that system. This irreducibility can be evaluated by calculation of the value of a mathematical parameter called Φ (phi), which reflects the irreducibility of a neuronal network's cause-effect structure. The network that possesses the highest value of Φ will be conscious. So the theory would posit that, if it were possible to calculate the value of Φ for all the neural networks in Proust's narrator's brain then, under the influence of the madeleine cake, that value would be maximal for those that encoded features of the town of Combray. The theory has gathered a lot of support but has recently also been subject to several strong criticisms (51,52).

Global workspace theory (GWT) provides a different phenomenological starting point, which is that of understanding how information encoded in disparate regions of the brain is accessed by the conscious mind in the process that we call thinking, such as when Proust's narrator thinks about the town of Combray. GWT proposes that consciousness arises from a 'global workspace' wherein disparately-encoded brain information can be pooled to be used as working memory, the cognitive system responsible for temporarily holding and manipulating information that is involved in numerous cognitive tasks, such as problem-solving, language comprehension, reasoning, decision-making and writing (53,54). In GWT, all neuron-encoded information in the brain competes for access to the global workspace but only that fraction of brain information that succeeds in gaining access to that workspace becomes conscious so that it can be manipulated in the conscious mind to deliver actions. The workspace is hypothetical in standard GWT so the theory does not identify the physical nature of the global workspace nor provide insight into the nature of the competition that determines access to the workspace, so the theory does not lend itself to experimental verification. However, its subsequent development as global neuronal workspace theory (GNWT) by Dehaene and Changeux (53,55–59) introduced an experimentally-detectable 'ignition' component associated with a temporary increase in synchronized firing leading to a coherent interconnected network of neuronal activity proposed to act as a kind of dynamic global workspace that distributes its neuronally-encoded information to the entire brain. So, according to GNWT, if we could examine the brain of Proust's narrator whilst he was eating his madeleine cake then you would find a network of synchronously-firing neurons encoding features of the town of Combray. A recent study of magnetoencephalography (MEG) patterns in human subjects examined information flow between

brain regions involved in performance of seven different tasks and identified brain regions including the precuneus, posterior and isthmus cingulate, nucleus accumbens, putamen, hippocampus and amygdala that were active across all seven tasks and thereby consistent with being a global neuronal workspace that orchestrates information from perceptual, long-term memory, evaluative and attentional systems(60) to deliver actions, such as completing the test tasks.

In this article, I assess the CEMI field theory together with IIT and GWT/GNWT against the Platonic ideal of science as carving nature at its joints.

Carving nature at the joints

Plato is said to have described the job of philosophy, and by modern extension, science, as that of *carving nature at the joints*, essentially finding those features that distinguish objects according to their kind or form (61). For example, a theory that identified dogs as animals that bark and wag their tails and cats as animals that purr would be a good theory as it, at least, carves the animal world between dogs and cats. An alternative theory that identified dogs as animals with claws would be a bad theory since it would also identify cats or bears as dogs. From the perspective of this article, a ToC should be able to distinguish between objects or systems that are conscious and those that are nonconscious. Of course, there is a great deal of controversy on where the division between conscious and nonconscious living organisms lies but the consensus amongst scientists, philosophers and the rest of humanity is that humans are conscious along with many mammals, such as primate, dogs and cats, but plants, microbes and inanimate objects such as toasters, computers, rocks, photodiodes, electrical grid systems, or our very complex and integrated immune system, are not conscious.

The criteria used to distinguish between conscious and non-conscious entities are, of course, anthropomorphized and thereby problematic. We tend to infer that objects that behave somewhat ourselves, such as dogs and cats, are conscious; whereas objects that behave very differently, such as toasters, plants or rocks, are not conscious. Yet the inference is not without foundation. Human consciousness is the driver of what we call “free will” (28) which allows us to choose to swim upstream in a river rather than, like rocks or floating plants, go with the flow, downstream. In this sense, consciousness confers *agency*. Fish, dogs, cats and other animals that are similarly able to resist the predominant thermodynamic flows in their world are also considered to possess a degree of agency. Rocks, toasters, plants and computers that lack agency are considered to also lack consciousness. Any alternative carving of nature’s joints implied by a ToC should, at the very least, be supported by evidence for its alternative carving.

A related criterion is the need to distinguish between nonconscious and conscious information processing within a single human brain. It is well established that most of what the brain does is non-conscious, irrespective of its level of complexity. For example, the processing of sensory information to direct the delicate movements that are involved in keeping us upright when walking, running, playing tennis etc. are highly complex yet are performed automatically without conscious awareness most of the time. Similarly, we don’t need to consciously think about the delicate and complex movements of our larynx, lips and tongue needed to form words when speaking. Even semantic processing, such as formulating spoken sentences in their correct grammatical constructions, is performed without awareness: we are not aware of the fine-grained and complex grammatical rules that our brain automatically applies order and conjugate words into form well-formed sentences. Evidence from brain imaging studies suggest that these non-conscious cognitive feats involve large distributed regions of the brain and thereby highly complex neural processing, but without awareness (62,63). Yet we can be painfully aware of very simple, unintegrated stimuli, such as when someone stands on our toe.

Moreover, several specialist structures in the brain, such as the cerebellum or primary visual cortex operate without consciousness. For us humans at least, we are aware only of the comparatively sparse contents of our conscious mind, more of a trickle rather than a stream of consciousness. Any ToC should thereby be able to carve nature between the brain’s torrents of nonconscious neural processing and their adjacent conscious trickle. Additionally, a successful ToC should also be able to

distinguish between conscious and nonconscious states in the entire brain, such as between waking and deep sleep or anaesthesia.

- a. **Integrated Information Theory.** IIT identifies consciousness with maximally integrated *intrinsic* information, that is information processing that possesses the highest value of Φ . In his 2008 IIT 'Provisional Manifesto' Tononi insisted that '*to generate consciousness, a physical system must be ... unified; that is, it should be doing so as a single system, one that is not decomposable into a collection of causally independent parts*' (64). All sub-maximally integrated information processing is proposed to be nonconscious; so IIT does carve neural processing between conscious and nonconscious streams. However, in the IIT context, "intrinsic" means that the information can be defined independently of a particular observer or reference frame. Here we hit a problem since, as Barret and Mediano have argued "However one might reformulate the theory, any attempt to create a formula for consciousness as intrinsic information needs to define, spatially, where one system ends and another begins." (65). The calculation of Φ is observer-dependant. For example, one can arbitrarily divide the brain up into various potentially overlapping function parts, such as the cerebellum, cerebral cortex, visual cortex, motor cortex, cerebrum, temporal and occipital lobes, etc. Considering the cerebellum, it would certainly be possible to calculate the sub-division of the cerebellum with the highest value of Φ which, according to IIT should then be conscious. Yet, although the cerebellum plays a crucial role in motor coordination, balance, and motor learning, there is no evidence that any of its activities are associated with consciousness. Perhaps it should be considered along with the adjacent temporal and occipital lobes which will, including the cerebellum, have some sub-division with a higher values of Φ , relegating the cerebellum itself to a consistently lower Φ ranking and therefore nonconsciousness. But why just three sub-divisions of the brain? A larger value of Φ would certainly be obtained for some subdivision of the entire brain that includes the cerebellum and adjacent lobes, but an even larger value would be generated if one also included the entire nervous system, larger still if, say, the immune system, which certainly interacts with the nervous system, is included. But why stop at a single person? No man, or woman, is an island. Φ could also, potentially, be calculated for all the possible sub-partitions of an entire city yielding values higher than any individual. Are cities then conscious? But why stop at a city, why not a country or the entire human population or the solar system or the universe? Where do you stop? As Barret and Mediano argues, the observer-dependence IIT does not identify the joints needed to carving nature into conscious and nonconscious entities.

Moreover, although Φ is notoriously difficult to calculate, except for the simplest toy systems, it is, as I have previously highlighted (28), essentially a variant of *mutual information* which, in probability and information theory, is a measure of the mutual causal dependence between different variables within a system (66). Unlike Φ , mutual information can be, and has been, calculated for a wide variety of complex systems, ranging from social networks (67,68) to communities(69,70), ecological networks (71), financial (72) and institutional networks (73). Systems biology approaches have calculated mutual information for physiological systems (74), transcriptional regulatory networks (75), immune networks (76) and metabolic networks (77). These systems are also highly complex. For example, the immune system is composed of around 10^{12} interacting immune cells, slightly more than the brain's 10^{11} interacting neurons. All of these systems are characterized by high levels of integrated complex information that are thereby highly likely to be "not decomposable into a collection of causally independent parts" and thereby include subsystems with high values of Φ , if it were to be calculated. Similarly, high values for mutual information have also been described for artificial intelligence systems, such as in robotics (78) deep neural networks (79) as well as random Boolean networks (80). Each of these systems will have some partition with a maximal value of Φ which would, according to IIT, would be conscious. Yet there is no evidence for consciousness in any of these systems.

It should similarly be possible to find a maximal value of Φ for any information processing system, including all living organisms, from bacteria to plants and animals as well as inanimate devices including not only computers but even photodiodes or large-scale electrical power grids (52,81). IIT is thereby hugely panpsychist. Tononi accepts the rampant panpsychism implied by IIT

and goes on to argue that any inanimate system that can process information in a highly interconnected and irreducible manner will, in theory, exhibit some degree of consciousness, irrespective of its cognitive capabilities, what he refers to as being 'noncognitively conscious' (81). But then the distinction between conscious and non-conscious entities, according to common sense, is not accounted for within IIT but instead must be attributed to some, as yet, unspoken theory that differentiates between cognitive and non-cognitive conscious states. IIT alone is clearly unable to carve nature at the joints between conscious and non-conscious entities.

IIT performs better in distinguishing between conscious and non-conscious neural activity within the brain by proposing that they differ in terms of their level of complexity and integration, as measured by Φ . For example, an approximation to calculation of Φ has been used to examine EEG patterns (as a surrogate of detailed knowledge of neural firing patterns) was quite successful in distinguishing conscious and non-conscious patients with disorders of consciousness (DoCs) (50,82) and anaesthesia (83). However, it should also be noted that EEG is the most widely-used tool for clinical assessment levels of consciousness in patients with DoCs or anaesthesia (84), and most applications do not apply IIT but use simpler measures such as information complexity or (negative) entropy (85,86). Moreover, the theory does not predict that consciousness should be associated with synchronously-firing neurons which, as highlighted above, are the strongest correlates of consciousness in the brain.

The proponents of IIT have claimed that IIT successfully predicts that the cerebellum is nonconscious on the grounds that its values of Φ are likely to be relatively low compared to the rest of the brain. However, this conclusion is based entirely on analysis of toy networks used to represent the cerebellum consisting of only 12 elements grouped into three "modules" (49,87). As has been recently pointed out (81), this toy network grossly underestimates the enormous complexity of the cerebellum with its 69 billion neurons together with several internal structures, such as its four pairs of cerebellar nuclei that receive and transmit signals from sites both within and outside of the cerebellum. No actual calculation of Φ has been attempted for the cerebellum so there is no evidence that it is associated with relatively low values of Φ . IIT thereby currently fails to account for why the cerebellum is nonconscious.

IIT does have another problem in accounting for nonconscious states of the entire brain, such as in anaesthesia, deep sleep or during epileptic seizures. The problem arises because IIT is built on the premise that those neural networks with the highest values of Φ will be conscious, irrespective of the actual value of Φ . Living brains are never completely idle so it will always be possible to calculate values of Φ for the trillions of partitions of active and inactive neurons, remembering that, in IIT, inactive neurons also contribute to the conscious state. So brains will always have neural networks with a range of values of Φ so there should always be a most-highly-ranked winner that is expected to be conscious. Just as newspapers never have blank front pages, in IIT, brains will always be conscious. Once again, this does not correspond to our experience or common-sense notion of consciousness.

b Global Workspace Theory. GWT defines the global workspace as the contents of working memory that, in the familiar theatre metaphor, are highlighted by a kind of attentional spotlight on the neural ensembles that act upon the consciousness stage, making their informational content available to be broadcast to various output neurons such as those involved in speech or other motor outputs that deliver conscious reports. Rather like IIT, there is also a competition amongst a much larger nonconscious *audience* of neural ensembles that compete to gain access to the attentional stage. Since GWT defines the global workspace functionally, rather biologically, it is not clear whether the presumed restriction of consciousness in GWT to biological brains is valid. Many animate or inanimate system could also be defined as accessing a functional global workspace. For example, the bloodstream pools and transmits a wide variety of information sources, such as hormones, cytokines, chemokines and nutrients to the cells of the body and could thereby be considered as a circulatory global workspace. Similarly, the air around us pools and transmits lots of information encoded in acoustic vibrations generated by spoken language that it makes available to anyone in within earshot. Computer memory systems, such as Random Access Memories, also act as global workspaces, just as the internet

acts as a global workspace accessible to anyone with a computer or smartphone. ChatGPT could be even be considered to the mouthpiece of the internet's global workspace. But none of these electronic systems is considered to be conscious.

If possession of a global workspace is sufficient for consciousness then GWT is, like IIT, rampantly panpsychist. GWT theorists generally sidestep this problem by framing GWT within cognitive neuroscience and specifically within the brain or even regions of the brain such as the prefrontal cortex and other regions involved in higher-order cognitive functions. But then what is special about brain global workspaces that makes them, rather than non-brain global workspaces, conscious? This is not addressed within GWT so, like IIT, GWT does not carve nature at the common-sense joints between conscious and non-conscious systems, except by adding criteria which distinguish between conscious and nonconscious systems thereby moving the differentiation between conscious and non-conscious systems away from GWT towards some, as yet unformulated, theory of why only brain global workspaces are conscious. GWT is then not really a theory of the nature of consciousness but one of its function.

GWT does better than IIT in dealing with nonconscious states, such as anaesthesia. It proposes that neural information may be restricted from entering, or leaving, the global workspace during non-conscious states. This allows information or cognitive processes to be active in the brain but are not part of the conscious experience. Like IIT, GWT does not predict the correlation between consciousness and synchronously-firing neurons. However, Global Neuronal Workspace Theory (GNWT) does propose that global ignition events, which are proposed to be responsible distributing information encoded in the global workspace around the brain, are generated by synchronously-firing neurons. So GNWT does correctly predict that consciousness will be correlated with synchronously-firing neurons. However, GNWT does not, in itself, provide a mechanism by which the brain can distinguish between synchronously-firing neurons from those that are not synchronously firing. Even in ignition events, most neurons in the brain are not firing synchronously so how does the brain *know* which neurons are firing synchronously and thereby constitute the global workspace to be used in conscious thinking? This is not specified in GNWT.

Regarding the nonconsciousness of the cerebellum, in some papers, Baars and colleagues identify the likely site for the global workspace as the 'cortico-thalamic core [which] is a great mosaic of multi-layered two-dimensional neuronal arrays. Each array of cell bodies and neurites projects to others in topographically systematic ways'(88) and GNWT proponents argue that "this connectivity is different from other structures that do not directly enable conscious contents, like the cerebellum. The cerebellum is organized in modular clusters that can run independently of each other, in true parallel fashion. But in the C-T [cortico-thalamic] core any layered array of cortical or thalamic tissue can interact with any other, more like the world-wide web than a server farm." But they do not explain why the "world-wide web-like" global workspaces support consciousness whereas 'great mosaic[s] of multi-layered two-dimensional neuronal arrays' as in the cortico-thalamus, do not support consciousness. Also, why the world-wide web isn't conscious isn't explained. Once again and like IIT, the division between conscious and non-conscious systems in the brain is not provided by GWT itself but by additions to the theory. The theory itself, does not carve nature at its joints.

c CEMI Field theory. The proposal that consciousness *is* the experience of the brain's EM field has features of both IIT and GWT. Firstly, physical fields automatically (without need for any calculation) physically integrate information. For example, our weight represents an integration of our mass with that of the entire planet performed instantly by the Earth's gravitational field. EM fields similarly integrate information, for example, the direction of compass needle represents an integration of the magnetic moment of the entire planet with that of the needle. We are also familiar with the distributed nature of EM field-encoded information whenever, for example, we download a movie from any position within the range of a wifi router. The CEMI field theory simply proposes that consciousness is the experience of the integrated EM-field encoded information generated by 80 billion or neurons in the brain.

Proposing that EM fields are sometimes conscious may seem strange but is it any stranger than proposing that matter is sometimes conscious? As Einstein's famous equation highlights, matter and

energy are equivalent; both are entirely physical. However, whereas information encoded in matter is always discrete and localized, information encoded in EM fields is always integrated and delocalized, exactly what we would expect for the substrate of consciousness.

EM fields are everywhere so CEMI field theory has the same potential for panpsychism as IIT and GWT. However, just as all matter has the potential to be alive but only a very small subset of that matter possesses the property of life so, the CEMI field theory insists that, although all EM fields have the potential for consciousness, only a small subset of EM fields are conscious. In CEMI field theory, consciousness is proposed to have evolved when, during the process of evolution, neurons became more and more tightly packed within space-limited skulls such that EM field interference began to influence neural firing so was captured by natural selection to deliver novel capabilities, such as *EM field computing*. This is a form of analogue computing in which the computation is performed by the interaction of EM fields, rather than the binary digits that are used to compute both in conventional computers and, as far as we know, in the neuronal mind. Sometimes called 'quantum-like' computing (89,90) EM field computing confers, according on the CEMI field theory, on conscious minds the capability of computing with gestalt objects, such as the idea of the town of Combray, transmitted into the brain's EM field by neuron firing. Note that this EM field-based computational capability is entirely lacking in conventional computers that are designed to avoid EM field interference between electrical components. So the CEMI field theory predicts that conventional computers or electrical devices, such as power lines, are not conscious. Indeed, the theory makes the strong prediction that conventional computers built to exclude EM field interactions will never be conscious. Moreover, since EM field computational devices are unknown in nature outside of brains, the CEMI field theory, correctly carves nature at the common-sense joint being a property of the living but not inanimate world.

As outlined above, the CEMI field theory was originally proposed to account for experimental findings that consciousness is correlated with synchronously-firing neurons (25) so it correctly associates consciousness with synchronously-firing neurons. The CEMI field theory also account for why neural activity in cerebellum appears to be non-conscious. This is due to the cerebellum's intricate folding, compared to cerebral cortex, which ensures that currents arising in neighbouring patches of cerebellum activation tend to be running in opposite directions resulting in cancellation of their EM fields through destructive interference. The same reason is responsible for the invisibility of the cerebellum in EEG or MEG measurements(91). The theory also account for the lack of consciousness in absence epileptic seizures in which patients lose consciousness. These are associated with strong regular and usually bilaterally synchronous and symmetric EEG signals particularly in the 2–4 Hz range(92). Naively, one might expect that that the CEMI field theory might predict that strong EEG signals would be associated a heightened, rather than reduced state of consciousness. However, in contrast to the information-rich EM-encoded information detectable in a normal EEG, which correlates with sensory information, perception, memory and the contents of consciousness, the highly rhythmic EMF fluctuations characteristic of EEG seizures are devoid of information so they cannot encode thoughts. According to EMF-ToCs, they represent a kind of consciousness brain-wipe that is entirely consistent with the loss of consciousness in absence seizures.

Also consistent with CEMI field is the fact that EEG and MEG, both measures of brain EM fields, are routinely used to detect signs of consciousness in anaesthesia (93–97) and in disorders of consciousness, such as locked-in syndrome(84,98). Novel prosthetic devices, including brain-computer interfaces(99,100) that detect EEG signals have recently been developed to restore communication and control to people paralyzed by chronic neuromuscular disorders and allow locked-in patients to communicate via their (conscious) EEG signals. These advances demonstrate that the information needed to consciously direct the motion of limbs is encoded in brain EM fields. CEMI field theory adds to this necessary conclusion the proposal that brain EM fields also direct the conscious motion of the body in healthy people. Of course, other ToCs sometimes accommodate these developments but the CEMI field theory is the only ToC that predicts them. Once again, CEMI field correctly carves nature at the commonly recognized joints between conscious and nonconscious neural activity.

According to the CEMI field theory, neurons located anywhere in the brain have access to information encoded in the brain's EM field that has been put there by synchronously-firing neurons. The brain's CEMI field thereby acts as the brain's global workspace and is consistent with GWT. Since brain EM field information is mostly a product of synchronously-firing neurons, the theory is also consistent with GNWT, identifying neuronal ignition events, or neuronal avalanches as they are sometimes called, as the gateway into the brain's EM field global workspace.

The CEMI field theory as the physical instantiation of global workspace and thereby the substrate for working memory is also consistent with recent remarkable findings by Pinotsis and Miller(101,102). In a paper entitled 'Beyond dimension reduction: Stable electric fields emerge from and allow representational drift' the team examine what is known as *representational drift*. Although standard neurological theories of memory generally propose that memories are encoded in *hardwired* neural ensembles, recent studies have demonstrated instead that the exact neurons maintaining a given memory in working memory actually varies from trial to trial: *representational drift*(103). It is clearly difficult to account for representational drift in any neuronal-based theory of working memory but Pinotsis and Miller's studies reveal that, although the neurons encoding a memory change from trial to trial, stability of working memory emerges at the level of the brain's electric fields, as detected by EEG(101). In their 2023 paper(102), the author's go on to propose that 'electric fields sculpt neural activity and "tune" the brain's infrastructure'. The higher level of correlation between the contents of working memory and the brain's EM fields, rather than the state of the brain's matter-based neurons, in these studies represents a considerable challenge to all neural-ToCs but is entirely consistent with the CEMI field theory.

Conclusions

The CEMI field theory shares features of both IIT and GWT. Like IIT, it proposes that consciousness represents integrated information, a proposal that goes at least as far back as the Gestalt psychologists of the early 20th century(9). Unlike the hypothetical mathematical substrate for integrated information described by IIT, the CEMI theory proposes that conscious information is physically integrated in the brain's EM field. The CEMI field theory also accepts the central tenets of GWT but, unlike GWT, proposes a specific site for the global workspace in the brain: its EM field. CEMI field theory consistently outperforms both IIT and GWT in carving nature at the conventional and common-sense joints between conscious and nonconscious entities, systems or states. Applying Occam's razor(104) to the question of where to locate conscious experiences, such as the imaginary town of Combray, the simplest solution is that it was encoded in the electromagnetic field of Proust's brain and is similarly encoded in those EM fields that fill the brains of his readers.

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