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What are Conscious Sensations?

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Abstract

Existing theories about the nature of conscious sensations are discussed. The oldest classification system contrasts dualist theories (which say consciousness is an abstract entity) with monist theories (which say consciousness is a concrete entity). A more recent system contrasts process theories ("consciousness is a process, not a thing") with vehicle theories (consciousness is a property of one or more of the things associated with brain processes). The present paper first points out that processes are abstracta, which makes process theories dualist. It then argues that (a) dualist theories are untestable and therefore unscientific and (b) process theories which invoke information are at odds with the normal definition of information. Then two separate kinds of vehicle theory are discussed: first the neural identity theory and then a theory that pulls together the enormous volume of data generated by Crick's suggestion to forget about theories and simply measure the neural correlates of consciousness into a proposal equating sensory consciousness with certain patterns in the electromagnetic fields generated by brain function. The paper concludes with an injunction to stop researching this topic altogether, on the grounds that the results are likely to be used in unacceptably dystopian developments.

Key Words: monism, dualism, process theories, vehicle theories, neural identity theory, NCCs, CEMF theory

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Introduction

Thirty years ago, the nature of consciousness was seriously discussed only in university departments of philosophy. Physicists were not averse in principle to studying mind, but in practice were too busy finishing their picture of matter. Neuroscientists regarded any attempt at empirical study of consciousness as pseudoscientific nonsense – in the early 1990s even a Nobel laureate (Francis Crick) could not speak on the topic at a Society for Neuroscience meeting without having half his audience walk out while he was talking. Psychologists, who in the pioneering time of William James had seen consciousness as their main legitimate area of study, had since been derailed by the behaviorist paradigm into believing that in order for psychology to be

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regarded as a proper science, they had to avert their eyes from the elephant of consciousness altogether – as Searle (quoted in Crick 1994) put it "if one raised the subject of consciousness in cognitive science discussions, it was generally regarded as a form of bad taste, and graduate students, who are always attuned to the social mores of their disciplines, would roll their eyes at the ceiling and assume expressions of mild disgust".

To a certain extent, such attitudes persist today. But over the past few decades, an increasing number of researchers in all of the traditional disciplines have started to realize that the nature of consciousness is one of the last major frontiers in science. As an aid to those who might be contemplating a move to this frontier, the present paper provides a critical review of some modern theories of consciousness.

What do we mean by 'consciousness'?

When you don't know what something is, it is a mistake to define it. Nevertheless, it is important to say as clearly as possible what we're talking about. The word 'consciousness' is used in many senses. We use it here to mean what Block (1995) calls phenomenal consciousness – bodily sensations and perceptual experiences – the redness of red, the enticing smell of baking bread. We do not discuss theories that deal primarily with what Block calls monitoring consciousness. We do not deal with theories about self consciousness. We assume for the moment that all phenomenal experiences can be reported (or at least that whether or not a particular experience has occurred can be reported – the intrinsic essence of any sensory experience remains peculiarly private). Thus, we make no distinction between phenomenal consciousness and what Block calls access consciousness. We ignore theories that primarily concern the difference between the state of consciousness and the state of unconsciousness. In this presentation we are primarily interested in theories about what the phenomenal contents of consciousness ARE – not what they have to do with, or are associated with, or correspond to, or correlate with, but what they ARE. Our concept of identity in this regard is that which enables us to say 'lightning IS an electric discharge'.

Classification of theories

Classification is not only a tedious philosophical exercise – biologists have long accepted that taxonomy is a necessary component of any full understanding of the plethora of different entities that populate the natural world. Several classification systems have been applied to theories of consciousness.

The oldest and arguably still the best sorts theories into two major categories, dualist and monist. Dualist theories equate consciousness with abstracta. Monist (aka physicalist) theories equate it with concreta. The Stanford Encyclopedia of Philosophy approaches the difficult task of defining abstracta and concreta by the ancient method of providing examples and letting the reader work it out for themselves: it says “Some clear cases of abstracta are classes, propositions, concepts, the letter ‘A’, and Dante's Inferno. Some clear cases of concreta are stars, protons, electromagnetic fields, the chalk tokens of the letter ‘A’ written on a certain blackboard, and James Joyce's copy of Dante's Inferno."

A more recent system of classifying theories of consciousness divides them into process theories and vehicle theories. Atkinson et al (2000) describe this distinction as follows: “Process theories assume that consciousness depends on certain functional or relational properties of representational vehicles, namely, the computations in which those vehicles engage. On this view, representational contents are conscious when their vehicles have some privileged computational status, independently of any particular intrinsic property of those vehicles. What counts is ‘what representational vehicles do, rather than what they are’ ... For vehicle theories, on the other hand, consciousness is determined by intrinsic properties of representational vehicles, independently of any computations in which those vehicles engage.”

Broadly speaking, process theories shelter under the umbrella term functionalism, the defining assertion of which is ‘consciousness is a process, not a thing’. Tononi and Edelman (1998) succinctly describe both the essence and the provenance of this view when they write “Consciousness, as William James pointed out, is not a thing, but a process or stream that is changing on a time scale of fractions of seconds (James 1890).”

More specifically, most process theories identify consciousness with the processing of information. As Velmans (1991) puts it: “For radical behaviourists, all talk of mind could be translated, without scientific loss, into talk about behaviour. For the new "radical cognitivists" all talk of mind (including consciousness) can be translated, without scientific loss, into talk about information processing.” In the quarter century since 1991, process theories have become so deeply embedded in the zeitgeist that the term ‘radical’ no longer applies. Pretty well all cognitive scientists, computationalists, psychologists – and indeed most philosophers – now think of consciousness in terms of information processing. Among these groups the information processing paradigm is so prevalent that it is usually not seen as necessary to state it explicitly. Perhaps as a consequence, it is not widely recognized that the concepts ‘process’, ‘information’ and ‘information processing’ are all abstracta, so (mapping the new process/vehicle dichotomy onto the old dualist/physicalist axis) process theories are dualist. Philosopher David Chalmers is one of the few process theorists to recognize that his theory is an example of what he calls 'naturalistic dualism' (Chalmers, 1996). The word 'naturalistic' may have been inserted in this description in an attempt to make the 'dualism' part more acceptable to cognitive scientists, most of whom prefer to see themselves as stoutly scientific physicalists.

Process theories of consciousness

At present, process theories of consciousness massively dominate the theoretical landscape. But how sensible are they really?

One of the earliest process theories of what could be called the modern era (post-1994, when the Journal of Consciousness Studies was launched) is that of Chalmers (1996). Chalmers takes information theory (Shannon, 1948) as his starting point, but immediately generalizes Shannon's two-state 'bit' of information to the concept of a multi-state 'information space'. This is defined as an abstract space consisting of a number of information states and a structure of 'difference relations' between them. Chalmers then discusses the ways in which information states can be realized physically, mentioning thermostats, books, telephone lines and Bateson's catchy slogan about information's being "a difference that makes a difference", before proposing as a fundamental principle that "information (in the actual world) has two aspects, a physical and a phenomenal aspect" (Chalmers, 1996; p.286). So, on Chalmers' theory, information actually *is* – has the property of being – conscious.

One immediate problem with this is that it involves a radical redefinition of the word information, slipped in by the back door in the sense that Chalmers never acknowledges that everyone else's definitions are specifically at odds with his. There are several technical definitions of information.

In the field of information philosophy, Floridi (2005) says " 'information' is often used to refer to non-mental, user-independent, declarative semantic contents, embedded in physical implementations like databases, encyclopaedias, web sites, television programmes and so on … The *Cambridge Dictionary of Philosophy,* for example, defines information thus: 'an objective (mind independent) entity … Information can be encoded and transmitted, but the information would exist independently of its encoding or transmission." Floridi lists a number of sources that define information as data + meaning, before arguing that truth is also a necessary ingredient (because if information is not truthful, it should more properly be called misinformation or pseudo-information). Other technical definitions of information explicitly exclude even meaning. Classical or Shannon information theory was born out of a need to address the technical problems experienced by Shannon's employer Bell Labs in extracting signals from noise in telephone and telegraph lines, so Shannon (1948) equates information with the observation that a particular one out of a defined set of possible messages has been sent from one entity to another. Cybernetics (Sayre, 1976) generalizes this to equate information simply with increased probability, or reduction in uncertainty.

The point is that all of these definitions explicitly see information as an objective, mind-independent entity. This means that whatever it is for which Chalmers (1996) claims a subjective or phenomenal aspect, it cannot be what everyone else calls information.

A second objection to the Chalmers proposal, which this time he does acknowledge, is that thermostats (for example) clearly carry information, but are not widely regarded as having any degree of consciousness. Chalmers offers a choice of two options to deal with this:

(1) Perhaps only some *kinds* of 'physically realized information spaces' are conscious.
(2) Perhaps thermostats are conscious.

Chalmers himself chooses option (2). He suggests, on no particular grounds, that the level of organization at which consciousness 'winks out' might be lower than a thermostat but higher than a rock.

Tononi (2004, 2008, 2012) prefers option (1). His integrated information theory (IIT) proposes that only *integrated* information is conscious. Actually, the initial proposal (Tononi, 2004) is not quite this, in that the question of what consciousness *is* is sidestepped altogether: "The theory presented here claims that consciousness has to do with the capacity to integrate information" or "To recapitulate, the theory claims that consciousness corresponds to the capacity to integrate information." However, this unobjectionable formulation later becomes the firm statement "consciousness is integrated information" (Tononi, 2008). Integrated information is defined in terms of various brain processes associated with consciousness –one almost gets the feeling that it may have been tempting simply to equate integrated information with conscious information, but this would not have been terribly informative in the cybernetic sense of the word – and both Tononi and Seth et al. (2011) invest considerable effort in suggesting how integrated information might be quantified. Later Koch (2014) adds Chalmers' option (2) to the IIT mix and invokes panpsychism, admitting that inasmuch as integrated information is everywhere, consciousness must also be everywhere. Despite all the work that has by now been put into mathematical quantification of integrated information, no specific estimate of the quantity necessary for the appearance of consciousness is offered, but Koch speculates that the internet might be conscious.

McFadden (2013) in his CEMI (conscious electromagnetic information) theory, sticks with Chalmers' option (1), proposing that consciousness is associated only with *electromagnetically encoded* information. McFadden draws a distinction between extrinsic information (which is symbolic and arbitrary and exemplified by Shannon information) and intrinsic information, (which "preserves structural aspects of the represented object and thereby maintains some gestalt properties of the represented object"). He then argues that "to avoid the necessity of a decoding homunculus, conscious meaning must be encoded intrinsically – as gestalt information – in the brain." The precise relationship of this encoded gestalt information to consciousness is not spelled out, but it is probably not identity – McFadden does ascribe properties to consciousness and as he rightly says in his discussion of Chalmers' dual aspect theory, "it is not at all clear whether it is legitimate to ascribe properties to abstractions, such as the informational content of matter."

To summarize, there are several problems with all of this. First, since information is explicitly defined by everyone except process theorists as an objective entity, it is not clear how process theorists can reasonably claim that either information in general, or any particular subset or variety of information, is subjective.

Second, since information is explicitly defined by everyone (including Chalmers) as an abstract entity, any particular physical realization of information is not itself information at all. A 'physical realization of an information space' like James Joyce's copy of Dante's Inferno may *carry* information, but it is not itself information – it's just an arrangement of paper and ink. A 'physical realization of an information space' like Joe Bloggs' brain state when he looks at an octopus may *encode* information, but it is not itself information – it's just an arrangement of neurons, glia and ions. Of course, it is certainly possible to claim that a particular arrangement of neurons, glia and ions *is* conscious (and some remarkably eminent people have done so – see later). But this claim is no longer a dualist or process theory. It is a physicalist or vehicle theory. Since at least Chalmers specifically identifies his theory as dualist, it is not clear how he can then claim information status, let alone consciousness, for any particular kind of 'physically realized information space'.

Third, it is a problem for scientists that process theories are intrinsically untestable. The hypothesis that a particular brain process *correlates with* consciousness can certainly be tested (although even then, Pockett (2000) and Aru (2012) both point out that it is harder than often realized to separate correlates of consciousness from correlates of processes that usually covary with consciousness, like attention and working memory). But the one potentially testable prediction of theories that claim *identity* between consciousness and a particular kind of information or information processing is that this kind of information or information processing will be conscious no matter how it is physically instantiated. This prediction makes process theories very attractive to those who would like to build a conscious artifact out of hardware. According to process theories, all one has to do to create consciousness is emulate somehow the computations done by the brain – any physical instantiation will do. But suppose it were possible to build a piece of hardware that adequately reproduced the brain computations underlying a particular sensory experience. How could we know whether or not the resulting artifact was conscious? Consciousness is such a private phenomenon that nobody can be 100% sure even that their human neighbors are conscious at any given moment. We (with the possible exception of Daniel Dennett) know *we* are conscious. The other guy looks and acts more or less like us, so we legitimately give other humans the benefit of the doubt. But what about a bit of hardware? Even a novice software writer could produce a piece of code that typed 'I feel hot' whenever a thermostat registered a high temperature, but not many people would believe that this meant the thermostat was experiencing hotness in the same way we do. Hence, neither the idea that information or information processing is conscious, nor its logical extension panpsychism (the idea that everything is conscious) is in any obvious way testable.

Of course, that doesn't necessarily mean these ideas are untrue – it just means they are unscientific. It may be fine for philosophers to play with the idea that thermostats and computer networks are conscious, but scientists are usually constrained to testable hypotheses.

Vehicle theories of consciousness

Vehicle theories propose that consciousness is a property of some special arrangement or configuration of a physical vehicle. Since there are two kinds of physical entity – matter and fields – there are two kinds of vehicle theory. The first to appear on the scene equated consciousness with particular arrangements of matter.

Neural identity theory

Neural aka psychoneural aka mind/brain identity theory (Place, 1956; Feigl, 1958; Smart, 1959; 2012) postulates that mental states (including conscious states) are identical with brain states. Since the brain is composed of matter – organic molecules delicately arranged into various sorts of neurons and glia, together with a selection of mobile ions in a watery medium – neural identity theory can be categorized as monist i.e., physicalist, and materialist.

Among philosophers, neural identity theory was popular for about ten years after it was first proposed, but then came under sustained attack. A few of the more sensible philosophical arguments are summarized and discussed below.

The *multiple realization argument* (Putnam, 1967) attacked type identity (the idea that types of mental experience are identical with types of brain state) by saying that mental states have different physical realizations in different species – the neural realization of pain is different for snails and men – therefore no mental state can be identified with any single biological state, therefore “pain” cannot be identical with a brain state. From a biologist’s point of view, there are a couple of problems with this. First, there is no reason to suppose that snails do experience pain in the same way humans do (indeed no good reason to suppose that snails experience anything at all). Secondly, even if one considers only the sensations experienced by a single, definitely sentient entity (oneself), it becomes clear that the label “pain” describes a grab bag of sensations that are only vaguely similar, which makes it entirely reasonable that different pains should have different brain correlates. In a sense it is trivially true that type identity is implausible, because types are not biological realities – they are just mutable categories or concepts abstracted by humans from biological reality. Thus the only version of neural identity theory that is even vaguely credible to a biologist is token identity, which says that any particular conscious experience is identical with a particular brain state.

Another philosophical argument widely taken as being anti-identity is *anomalist monism* (Davidson, 1980; 1990). The first strand of this asserts that the mental domain is ‘anomalous’ vis a vis the physical (which means it is impossible to discover laws connecting mental kinds and physical kinds). For reasons given above, this assertion seems not unreasonable. But like multiple realization, anomalous monism then goes over the top and argues that therefore it is impossible to reduce the mental to the physical and *therefore* the mental domain cannot be the object of serious scientific investigation at all. Apparently, the general feeling among cognitive scientists that dualism is an unacceptable stance for a scientist is shared by this particular philosopher. But moving on, the second strand of the anomalist monism argument then claims that all individual mental events are physical events, subject to the laws of physics. Perhaps a calmer way of putting the whole thing might be ‘Type identity is nonsense. Some version of token identity must be right’.

A different approach to the general philosophical attack on neural identity theory was then taken by the *conceivability argument aka the explanatory gap* (Levine, 1983) and the *knowledge argument* (Jackson, 1986). Both of these essentially re-express in modern terms the then century old sentiment (Huxley, 1866): “how it is that anything so remarkable as a state of consciousness comes about as a result of irritating nervous tissue is just as unaccountable as the appearance of Djin when Aladdin rubbed his lamp”. This was edited after Huxley’s death to “how it is that anything so remarkable as a state of consciousness comes about as a result of irritating nervous tissue is just as unaccountable as any other ultimate fact of nature” – a more 'scientific' but infinitely less memorable statement of the problem ("Lessons in Elementary Physiology" 1905 edition p.341). Basically, both the explanatory gap and the knowledge arguments appeal, in variously colorful ways, to the deep human intuition that consciousness just seems to be a different class of entity from matter (on which more later).

Among scientists, such philosophical issues were recognized, then ignored. The essential idea of neural identity was introduced to neurophysiologists by Barlow (1972), whose paper on 'a neuron doctrine for perceptual psychology' presaged the explanatory gap with the words "There does not seem to be anything that could be said about the activity of nerve cells accompanying [the personal, subjective, aspect of my experience] that would in any way 'explain' the aspect of it that is mysterious, personal, and subjective. I think this ... is something that one must be content to leave on one side for the moment." Twenty years later Crick (1994) rebranded Barlow's neuron doctrine as "the astonishing hypothesis that 'You' ... are in fact no more than the behavior of a vast assembly of nerve cells and their associated molecules', again admitting at the end of the book that he had "said almost nothing about qualia – the redness of red – except to brush it to one side and hope for the best." But Crick then very sensibly suggested that neuroscientists should forget about theories of what phenomenal consciousness *is* and concentrate on the relatively theory-neutral activity of discovering its neural correlates. The neural correlate of consciousness (NCC) was duly defined as some variant of 'the minimal set of neuronal events sufficient to produce a particular conscious experience', and a number of neuroscientists energetically set about discovering NCCs.

Neural correlates of consciousness

One of the first NCC candidates was the presence of what was then generally but inaccurately known as '40 Hz' (gamma and high-gamma) oscillations (Singer and Gray, 1995). However, it soon became clear that gamma also appeared – in some circumstances even more strongly – in unconscious brains (Steriade *et al.,* 1996; Vanderwolf, 2000; Pockett and Holmes, 2009).

The next major NCC candidate was synchrony. Multiunit recording in cat visual cortex (Engel *et al.,* 1991a) demonstrated the existence of interhemispheric synchronization, which suggested the hypothesis that synchrony of firing between widely separated areas of cortex may solve the binding problem by producing 'dynamic representation of objects by assemblies of synchronously oscillating cells' (Engel *et al.,* 1991b; Singer and Gray, 1995). Further single cell animal data (Engel *et al.,* 2001) were taken as supporting this idea, although evidence (Lamme and Spekreijse, 1998) and arguments (Shadlen and Movshen, 1999) against it had already been advanced.

But irrespective of whether binding was the link, synchrony did seem to be important in some way for consciousness. In cats trained to perform a visually triggered motor task, cells in the visual, association and motor cortices synchronized their activity when the animals began to prepare themselves for the task and gamma synchronization over the visual areas increased as soon as the visual stimulus appeared (Roelfsema *et al.,* 1997). In cases of uncorrected strabismus (squint) one eye often becomes amblyopic (unable to generate a visual percept) – visual cortex neurons driven by the amblyopic eye were unable to synchronize their responses in the normal way (Roelfsema *et al.,* 1994). In binocular rivalry (a phenomenon that happens when an experimenter presents very different visual images to the right and left eyes of a subject – the two images do not fuse into one coherent percept but are seen alternately, flipping uncontrollably back and forth at intervals of a second or two) the discharge rates of visual cortex neurons responding to the suppressed eye were the same as those for neurons responding to the perceiving eye, but the synchronization of neuronal firing was very much greater for the perceiving eye (Fries *et al.,* 1997). In human subjects, the sudden perception of a face in ambiguous visual stimuli was accompanied by equally sudden onset of long-distance neural synchronization (Rodriguez *et al.,* 1999).

Later both gamma and beta synchrony of ECoG oscillations were again shown to be sometimes higher during unconsciousness than consciousness (Pockett and Holmes, 2009) and some of the evidence cited above was found to be flawed – one attempt to replicate the results of Rogriguez et al (1999) reported that phase synchrony differences between face perception and non-face perception could be reproduced only if data were recorded against a common nose reference that was contaminated by microsaccades (Trujillo *et al.,* 2005). But the problem involved in measuring synchrony between multiple EEG traces all of which are recorded against the same reference (Fein *et al.,* 1988; Pockett *et al.,* 2009) does not apply to measurements of synchrony between single units, so it remains a reasonable conclusion that neuronal synchrony has something important to do with the production of phenomenal consciousness (Melloni *et al.,* 2007).

Another, apparently unrelated, NCC-ish observation was that *recurrent* neural activity is necessary for phenomenal consciousness (Lamme *et al.,* 1998; Lee *et al.,* 1998; Pollen, 1999; Lamme and Roelfsema, 2000; Pascual-Leone and Walsh, 2001; Supèr *et al.,* 2001; Juan and Walsh, 2003; Pollen, 2003; Ro *et al.,* 2003; Juan *et al.,* 2004; Lamme, 2004; Silvanto *et al.,* 2005; Fahrenfort *et al.,* 2007; Pollen, 2008; Koivisto *et al.,* 2010). Much of the abundant evidence for this was obtained by interfering with neural activity using TMS (transcranial magnetic stimulation) applied at various intervals after a peripheral stimulus. For example, Boyer *et al.* (2005) showed that blindsight (a condition in which the subject can accurately guess the nature of a visual stimulus but reports that they cannot consciously see it at all) could be induced by brief inactivation of V1 at 100 ms poststimulus, and Silvanto *et al.* (2005) reported that consciousness of motion could be ablated by TMS delivered to any of V1 at 40–60 ms, V5/MT at 60–80 ms, or V1 again at 80–100 ms post-stimulus.

These observations fitted to a certain extent with the concurrent finding that phenomenal experiences were not reported in the absence of 'ignition' of an extensive frontal network (Dehaene and Naccache, 2001; Del Cul *et al.,* 2009; Dehaene and Changeux, 2011), but failed to support the conclusion that prefrontal activity itself is essential for conscious experience. First, the TMS experiments showed that late re-entrant V1 activity (which occurs *after* the activation of prefrontal and other brain networks) is necessary for phenomenal visual experience. Second, when subjects did not have to report their experiences, there was no difference in prefrontal activity between conscious and non-conscious stimuli (Tse *et al.,* 2005), suggesting that prefrontal activity is essential for report but not for conscious experience *per se*. Then TMS over prefrontal cortex was shown to affect voluntary control of bistable stimuli, but not passively experienced bistable stimuli (de Graaf *et al.,* 2011), which similarly suggests that prefrontal activity is needed for voluntary control but not for phenomenal experience.

Many other apparently unrelated experimental observations also appeared. A significant time lag was demonstrated between delivery of a peripheral stimulus and appearance of sensory awareness (Libet *et al.,* 1964; Pockett, 2002). Reportable perceptions in several sensory modalities were found to correlate with mesoscopic spatial EM patterns – despite the fact that these patterns were recorded over sensory rather than prefrontal or temporal cortex, they correlated not with specific peripheral stimuli *per se*, but with the meaning the stimulus had for the animal (Barrie *et al.,* 1996; Freeman., 1978; Freeman and Baird., 1987; Freeman and Grajski., 1987; Freeman and van Dijk., 1987). Single cell recordings showed that 90% of neurons in the temporal cortex predicted perception during binocular rivalry, while only 18% of units in V1 modulated their firing in line with perception (Logothetis and Schall., 1989; Leopold and Logothetis, 1996; Sheinberg and Logothetis, 1997). Consciousness was found to correlate with more intense EM patterns during binocular rivalry (Tononi *et al.,* 1998). The ancient spectre of the grandmother cell (Gross, 2002; Connor, 2005) was raised by a report of individual neurons in the human temporal lobe that fired only in response to pictures of specific people (Quiroga *et al.,* 2005). Low frequency local field potentials (LFPs) and fMRI signals in V1 were found to correlate with consciousness, while higher frequency LFPs and single cell firing rate did not (Wilke *et al.,* 2006; Maier *et al.,* 2008). The duration of psychologically measured frames of consciousness was shown to correlate with the duration of frames in the broadband analytic power of ECoG data taken from conscious, but not unconscious subjects (Pockett *et al.,* 2011).

While none of these observations apparently identifies the minimal set of neural events *sufficient* for any particular conscious experience, all of them reveal neural events that are related somehow to consciousness. But what does all this tell us about what consciousness *is*?

Feigl (1958) points out that "the advance of scientific theories consists essentially in the reduction of a variety of originally heterogeneous observable facts and regularities to a unitary set of explanatory concepts and postulates." The NCC paradigm was accepted by neuroscientists exactly because it allowed them to forget about theory and concentrate on collecting data. As a result, we have plenty of data. What is needed now is a theoretical framework that reduces the variety of originally heterogeneous observable facts and regularities produced by the NCC paradigm to a unitary set of explanatory concepts and postulates about the nature of consciousness. Neural identity doesn't really do that. But surprisingly, such a theoretical framework does already exist ....

CEMF (Conscious Electromagnetic Field theory)

Conscious electromagnetic field theory (CEMF) a.k.a. the electromagnetic field theory of consciousness (Pockett, 2000; 2012) proposes that phenomenal experiences are brain-generated, 4-D (spatiotemporal) electromagnetic (EM) patterns. CEMF thus represents the second major kind of vehicle theory. Neural identity says consciousness is identical with certain arrangements of matter in waking brains – CEMF says it is identical with certain arrangements of the EM fields generated by waking brains. In terms of the dualist/monist axis, neural identity is physicalist (monist) and materialist. CEMF is physicalist (monist) but not materialist.

Philosophically, both neural identity and CEMF are identity theories, so both are subject to the philosophical objections mentioned earlier. The hardest of these to rebut is that represented by the explanatory gap and knowledge arguments, both of which basically appeal to the deep and stubborn intuition that consciousness just seems to be a different class of phenomenon from matter. This intuition poses no problem for CEMF – EM fields *are* a different class of phenomenon from matter.

But this is a scientific theory, not a philosophical one. How does CEMF reduce all the hard-won NCC data cited above to a unitary set of explanatory concepts? We should investigate the NCC data one piece at a time.

First, synchrony. A basic statement of CEMF (Pockett 2012) is that any given conscious sensory experience is a spatial pattern of LFPs in primary and/or secondary sensory cortex. What are LFPs (local field potentials), and what do they have to do with synchrony?

The term LFP has been used by a subset of neurophysiologists for over half a century to describe population EPSPs (excitatory post-synaptic potentials). These are extracellular manifestations of the more or less simultaneous activation of many glutamate synapses on the apical dendrites of many neighboring cortical pyramidal cells. Other neuronal processes may sculpt LFP waveforms a little (Buzsaki *et al.,* 2012; Einevolle *et al.,* 2013), but population EPSPs evoked by the activity of excitatory synapses on pyramidal cell apical dendrites are the main contributor. There are two reasons for this. The first is the strict anatomical alignment of pyramidal cell apical dendrites, which permits spatial summation of the extracellular EPSP sinks of synapses on hundreds or even thousands of neighboring apical dendrites. The second is that single units (the extracellular manifestations of action potentials) contribute little or nothing to LFPs, because they are (a) very fast events (which means they do not summate temporally) and (b) recordable only very close to the firing cell (which means they do not summate spatially). The fact that single units can only be recorded within about 10µm of their source, while extracellular EPSPs spread over much larger distances, has been noted since the earliest studies (Bremer, 1949; Eccles, 1951), but is still not explained entirely satisfactorily. One possible explanation is that spatial variations in the conductivity of the extracellular matrix impose a low-pass filter (Bédard *et al.,* 2004; 2006). Both radial (interlaminar) and tangential (intercolumnar) discontinuities in extracellular conductivity have indeed been found (Pettersen *et al.,* 2006; Goto *et al.,* 2010), but whether this is sufficient to explain the issue is debated (Einevoll *et al.,* 2013). In any case, getting back to synchrony, it is now clear that three different sorts of synchrony are necessary to produce LFPs.

First, more or less synchronous action potential firing of multiple presynaptic axon terminals is necessary to allow the spatial summation of individual extracellular EPSPs that generates a population EPSP. Secondly, action potentials – or at least 'normal' sodium action potentials – start at the neuron's initial segment (where the axon leaves the cell body) so firing at an axon terminal implies more or less synchronous firing at that axon's cell body. So, the second sort of synchrony is synchronous firing between the area where the synapses are and the area where the presynaptic axons' cell bodies are. For the synapses in question this would mainly be some other area of cortex, although Layer 1 synapses are also involved in cortico-thalamic loops (Jones, 2007; Rubio-Garrido *et al.,* 2009). Finally, if there is more or less synchrous firing at multiple presynaptic terminals, logically there must also be more or less synchronous firing of multiple cell bodies in whatever area of brain sends those presynaptic axons TO the synapses. In other words, you can't have the first of these three kinds of synchrony (which is absolutely necessary for the production of population EPSPs) without also having the other two kinds of synchrony.

Now CEMF says a conscious sensory experience is a pattern of population EPSPs (aka LFPs) in sensory cortex. Therefore, it is a necessary prediction of CEMF that all of the aforementioned three types of synchrony will be necessary for sensory consciousness. And lo and behold, the NCC experiments cited above show that yes, all of these three types of synchrony do appear to be necessary for the production of sensory consciousness.

The next NCC –derived dataset to be explained is the requirement for recurrent or reentrant processing. To reiterate, it is an experimentally observed fact that consciousness does not arise during the first, feed-forward pass of activity through the primary sensory cortex. It arises only when incoming activity from peripheral receptors has passed through primary sensory cortex, fanned out to other areas of brain and then come back to sensory cortex, presumably laden in some way with information about the meaning of the stimulus for the subject. But why should this be the case? Again, CEMF delivers a clear mechanistic explanation. The first pass of activity through sensory cortex goes by way of cytoarchitectonic Layer 4. Layer 4 was dubbed by early anatomists the 'granular' layer, because it is populated mainly by stellate cells, which look like grains of sand in stained sections. The dendrites of stellate cells project at all angles from the cell body, which means that the positive and negative poles of individual extracellular EPSP dipoles cancel each other out. Thus, LFPs do not appear in Layer 4. It is only when activity re-enters sensory cortex at cortico-cortical or thalamo-cortical synapses on the Layer 1 apical dendritic tufts of pyramidal cells that the LFP patterns CEMF proposes as being conscious are produced.

Hence, the observable time lag of between 80 and several hundred ms between delivery of a sensory stimulus and its entry to consciousness is also easily explained – it takes time for activity to spread out to multiple brain areas and then return to sensory cortex.

The multiple findings that single cells in temporal cortex modulate their firing in concert with sensory percepts simply reflect the cell body origins of recurrent activity. Since no distinction was made in the experiments cited between early and late V1 firing, many of the V1 single units may have been recorded during the early feedforward activity (which as we have just seen does not reflect consciousness) or local circuit activity, some of which involves inhibitory cells (which produce single units indistinguishable from those produced by excitatory cells).

In this context the previously inexplicable finding that slow LFPs in V1 do correlate with consciousness while single units and fast LFPs do not also becomes understandable. Slow LFPs are population EPSPs generated by recurrent activity. Single spikes and/or fast LFP components reflect either early feedforward activity in Layers 4 and 3b, or later activity in the local inhibitory circuits of layers 2/3a and 5/6, which carry on working independently of incoming recurrent activity (and thus, according to CEMF, independently of consciousness).

The finding that slow but not fast LFPs correlate with consciousness also ties in with the independent observation that consciousness correlates with more intense EM patterns during binocular rivalry. Because of the universally observed 1/f power spectrum of EEG and ECoG oscillations, slow LFPs are an order of magnitude larger than fast LFPs. Again, these two independent observations that consciousness correlates with larger EM patterns are transparently explained by CEMF – if consciousness is an EM pattern, a certain minimum level of EM power must be necessary for this pattern to emerge from background EM noise.

An interesting extension of this argument involves the 'cinematographic' hypothesis of consciousness (Freeman, 2006). A number of psychological experiments (summarized by Pockett *et al.,* 2011) have suggested that consciousness occurs discontinuously, in frames. ECoG measurements (Pockett *et al.,* 2011) show that local minima in the broadband analytic power of conscious but not unconscious brains plateau at inter-minima intervals similar to the duration of psychologically measured frames of consciousness. These frames, as measured independently by both psychological and physiological experiments, turn out to last of the order of 100 ms – a duration similar to that of the spatially defined 'microstates' measured much earlier (Lehmann,1971; Lehmann *et al.,* 1987; 1998; Lehmann and Koenig, 1997). The minimum analytic power necessary for the emergence of consciousness is measured by this method at about 50 $\mu V^2/Hz$ (Pockett *et al.,* 2011).

The last NCC-ish experimental finding cited above was reported long before Crick made his suggestion about NCCs and was circumspectly not interpreted by its authors in terms of consciousness. Walter Freeman and colleagues showed in the late 1980s that the meaning a particular sensory stimulus had for an animal (whether or not it predicted delivery of a small electric shock to the cheek) correlated with the spatial EM pattern evoked by the stimulus in sensory cortex. Mathematical simulation later showed that similar patterns could be produced by dipoles spaced 3 mm apart (Pockett *et al.,* 2007), so given that LFPs always come in dipole pairs (Berens *et al.,* 2008, Pockett, 2012, Buzsaki *et al.,* 2012) and that human ocular dominance columns are about 1 mm wide (Horton and Hedley-Whyte, 1984), Freeman's observations nicely fit the CEMF proposal (Pockett, 2012) that different percepts within a given sensory modality are different tangential patterns of the LFPs produced by neighboring cortical columns.

Conclusions

To summarize the story at this stage, CEMF performs surprisingly well at reducing the plethora of originally heterogeneous observable facts and regularities delivered by the NCC paradigm to a unitary set of explanatory concepts and postulates about the nature of sensory experience. Given the lack of any such reduction by other theories of consciousness, it may be time to start taking CEMF seriously.

On the other hand, it may also be time to drop it completely – leave it alone and walk away. If Oppenheimer and colleagues had JUST STOPPED as soon as they realized the consequences of their invention of the atom bomb, the world would not now be living with the ever-present possibility of nuclear annihilation. Once any particular genie is out of its bottle, it can't be stuffed back in.

If the neuroscientists of the present day fail to JUST STOP investigating the electromagnetic basis of consciousness, we could easily wind up living in a world where one can never be sure whether one's thoughts and emotions at any given moment are generated internally, or imposed from that damn radio transmitter on the nearest lamp post. "Active denial" systems are already used as a crude and ugly method of crowd control. Further investigation of CEMF could result in a society so dystopian as to make George Orwell's novels look like love songs.

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