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Artificial Consciousness: Misconception(s) of a Self-Fulfilling Prophecy Nobody Wants

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Abstract

The rise of Artificial Intelligence (AI) has produced prophets and prophecies announcing that the age of artificial consciousness is near. Not only does the mere idea that any machine could ever possess the full potential of human consciousness suggest that AI could replace the role of God in the future, it also puts into question the fundamental human right to freedom and dignity. This position paper takes the stand that, in the light of all we currently know about brain evolution and the never-stopping formation of adaptive neural circuitry for learning, memory, decision making and, ultimately, fully conscious reasoning and creativity in the human species, the idea of an artificial consciousness appears misconceived. The paper highlights some of the major reasons why. While awareness to external stimuli for processes such as perception, recognition, and operational problem solving is under the direct control of functionally specific brain networks associated with sensory and cognitive functions across animal species, consciousness is a unique property of the human mind. Potentiated by brain evolution, consciousness has come to be when humans became able to represent, and reflect on, the Self in relation to past, present and future, and to project these representations into possible worlds by drawing and other forms of conceptual and creative expression. Epigenetically determined, shaped by experience, capable of representing real and non-real world states, consciousness is enabled by context-dependent adaptive brain circuits that have evolved on the grounds of self-organizing functional interactions

at different levels of integration in a from-local-to global functional brain design. The evolution of the latter being continuous, the limits of consciousness are unpredictable. If cracking the computational code to human consciousness were possible, the resulting algorithms would have to be able to generate temporal activity patterns simulating long-distance signal reverberation across the brain and the de-correlation of spatial signal contents from their temporal signatures. In the light of scientific evidence for complex interactions between implicit (non-conscious) and explicit (conscious) representations in learning, memory, and the construction of conscious representation, the code would have to be capable of making all implicit processing explicit. Algorithms would have to be capable of a progressive, less and less arbitrary selection of temporal activity patterns in a continuously developing neural network structure akin to that of the human brain, from synapses to higher cognitive functional integration. The code would have to possess the self-organizing capacities that generate the brain signatures of phenomenal consciousness. In the biological brain, consolidation or extinction of these temporal brain signatures is driven by external event probabilities according to the principles of Hebbian learning. Consciousness is constantly fed by such learning, capable of generating stable representations despite an incommensurable amount of variability in input data, across time and across individuals, for life-long integration of experience data. Artificial consciousness would require probabilistic adaptive computations capable of emulating all the dynamics of human learning and memory that enable human intelligence and creativity. No AI is likely to ever have such potential.

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Introduction

With the rise of Artificial Intelligence (AI), the idea of “artificial consciousness” has acquired the qualities of a magic spell, an incantation, a prediction that, as some would like to hope, will have the power to shape future reality like a self-fulfilling prophecy. Since AI uncritically absorbs any information it encounters, true or false, including our very own wildest conjectures and beliefs, it has already acquired fundamental systemic flaws by assimilating all the biases ingrained in its training data. In the current context where efforts aimed at creating artificial intelligence capable of emulating what seem to be properties of human learning and consciousness are proliferating, a deeper reflection on the essentially unpredictable dynamics of human consciousness has become a timely and necessary endeavour. The proselytes of a ‘global brain’ doctrine defend the idea of an emerging “super-intelligence defined by properties that are homologous to the neuronal activity in biological brains”. Therein, the concept of “singularity” is used to describe two distinct but linked

beliefs: a) there will be an acceleration of technological progress so radical that it appears like a discontinuity in the development of humankind; b) there will be the creation of an artificially intelligent (AI) system “so intelligent (“superhumanly” intelligent) that it can reprogram itself in order to become even more intelligent”, thus “radically surpassing any human abilities” (Heylighen, 2015). In other work, this kind of “beyond human” AI is announced as “already taking form in algorithmic steps toward machines with a core consciousness”, opening the possibility “to form human-like extended consciousness” (e.g. Krauss and Maier, 2020).

The astonishing plasticity of the (still evolving) human brain enables life-long learning at all functional levels, from the synapse to higher cognitive processes. Such learning is pre-wired in terms of synaptic function, shaped and determined by time and context, and driven beyond predictable capacity in terms of experience dependent and environmental factors, with multiple interactions no science has hitherto been able to model in their full complexity. Previous attempts to “crack the code” to human consciousness have largely failed for reasons that may be illustrated under the light of the neuroscience of awareness-guided behaviour (often called “conscious behaviour” by various authors) and information processing in humans, neural theories of biological event coding, learning and memory, and model accounts for resonant brain processes driving context-dependent awareness to one's immediate environment for decision making and action. The conclusions from this analysis highlight why it is not likely that any machine will ever be able to successfully emulate most of these neurobiological functions and their interdependency in the first place. These functions are the grounds on which consciousness has evolved, yet, they neither explain consciousness in its full complexity, nor do they deliver the keys to any code that would allow implementing human intelligence and consciousness in a machine. Essentially, the idea that such could be possible is based on a variety of wrong assumptions about the nature of consciousness. One such wrong assumption is reflected in the belief that what we see, do, decide, and communicate explicitly by words provides us with a key to the workings of consciousness.

1. Conscious behaviour is not consciousness

Approaches where a specific conscious behaviour is considered as an indicator of consciousness (Lashley, 1956) traditionally consisted of having human observers perform specific tasks that required focussed attention or selective memory retrieval. Experimental efforts in that direction would be, for example, the experiments by Dehaene et al. (Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006), where consciousness was approached in terms of what the authors called “conscious report”. Suggesting that a human subject is phenomenally conscious when some critical event is reliably reported, it was argued that consciousness can be defined in terms of “access of information to conscious report”. Such a restriction of phenomenal consciousness to processes that enable information to access a certain level of conscious representation is grounded in Block's concept of access consciousness (e.g. Block, 1995). Examining the conscious reports of a human observer to unravel the mechanisms of consciousness, or access of information to consciousness, leads to several critical questions that remained then, and still remain to be answered (Buszaki, 2007; Dennett, 1991, 2001). Does information that is made accessible to conscious report have to correspond to ongoing or past, to real or imagined events? Does the conscious experience that is subject to conscious report occur well before,

immediately before, or during the report? How long would it be expected to last thereafter? In their search for the neural correlates of consciousness, Crick & Koch (1995), whose work at the time had received a lot of attention and praise, employed a working model in terms of “subliminal”, “preconscious”, and “conscious perception” which adopts a taxonomy that had been proposed by Kihlstrom (1987) twenty years earlier. Crick and Koch (1995) then claimed that top-down attentive selection is the key to conscious perception. Subsequently, phenomena such as change blindness (e.g. Silverman & Mack, 2006), where human observers are unable to detect important changes in briefly presented visual scenes disrupted by blinks, flashes or other visual masks just before the changes occur, were interpreted in terms of “preconscious perception” on the basis of the argument that observers would fail to report what they actually see because they believe that what is there is what they have seen just before (Dehaene, Sergent, & Changeux, 2003). Such belief would then block the attentive selection process that would otherwise enable the new information contained in a new visual scene (e.g. Delorme et al., 2004) to access the level of conscious perception. But is studying the neural correlates of conscious perception and selective visual attention sufficient for understanding the mechanisms that produce consciousness in the first place? While some seem to agree that it would be important to work out an experimental paradigm in which consciousness is not confounded with the changes in overt or covert behaviours it may engender in stimulus-response designs (e.g. Feinstein, Stein, Castillo, & Paulus, 2004), most have hitherto failed avoiding this trap. Thus, the difficulty of linking conscious behaviour to the mechanisms that generate and fuel consciousness is a critical limiting factor. At that same time, technological progress in the imaging sciences had enabled scientists to visualize which parts of the brain are or are not activated when a human subject is or is not guided by awareness, attentively (“consciously”) performing a behavioural task (see Rees et al., 2002, for a review). These new technologies raised high hopes that functional brain imaging correlated with behavioural designs would help link the mental to the physical (Feigl, 1958). Pictures of a conscious brain were believed to unravel the origins of consciousness. Like in the fourteenth century, when physicians attempted to identify the locus of the human soul in the body, the advent of modern functional imaging techniques had led to the pursuit of the idea of localizing consciousness in the brain, which quickly became the pet subject of a small industry in science. While rapid technological progress, promoting the development of imaging and electrophysiological techniques, had indeed made it possible to correlate cognitive function with increasingly precisely located neural activities and interactions in specific brain areas, such correlations did, however, not lead us any further towards an understanding of the nature of consciousness, or the mechanisms that fuel it, or how the brain finally came to produce it. Some observations suggested that conscious mental activity correlates with occipital neural activity, while others seemed to point toward a correlation between conscious mental events and late parieto-frontal activity (e.g. Driver & Vuilleumier, 2001, Dehaene et al., 2006). Even though some kind of sense may be read into the largely disparate data, fact still is that the much expected break-through that would have allowed to determine a functional *locus* of consciousness in the human brain has not happened. As pointed out already more than a century ago by William James (1890), consciousness encompasses far more than being able to effectively be aware of, attend to, perceive, and describe stimuli. Baars (1993, 1997) referred to phenomenal consciousness as the “theatre of the mind”, which is reminiscent of writings from the first book (part 4, section 6) of the *Treatise of Human Nature* (1740) in which the Scottish Philosopher David Hume compared phenomenal consciousness to a theatre with a scene of complex events where various different sensations and perceptions make their successive appearance in the course of time:

“The mind is a kind of theatre, where several perceptions successively make their appearance; pass, repass, glide away, and mingle in an infinite variety of postures and sensations. There is properly neither simplicity in it at one time, nor identity in different, whatever natural propension we may have to imagine that simplicity and identity. The comparison of the theatre must not mislead us. They are the successive perceptions only, that constitute the mind; nor have we the most distant notion of the places where these scenes are represented, or of the materials of which it is composed.”

Hume’s phenomenal description of successive feelings or sensations appearing as sequences in time is embedded in some contemporary views of consciousness. Decades ago, some neurobiologists discussed the concept of Self in relation with the concept of consciousness (e.g. Di Francesco, 2008), emphasizing that phenomenal consciousness encompasses hardly more than sequences of many distinct perceptions and sensations. Moreover, these are not necessarily related to ongoing external events or stimuli (Natsoulas, 1983; Ramachandran, 1998; Bieberich, 2002). Understanding creative imagination and future-oriented thinking or the striking similarities between object descriptions resulting from direct (aware) perception and from pure imagination (e.g. Kosslyn, 1994, 1999; Kosslyn et al., 2001) requires going beyond studying actively and consciously (awarely) behaving observers. When we dream intensely, we are neither aware of nor attentive to external stimuli in our immediate physical environment, but we are definitely phenomenally conscious (e.g. Schwartz, 2003). Often we may be able to access and report these phenomenal data several hours later, when we recount our dreams over breakfast. LaBerge (1990) believed that amidst the neuronal functions that fuel consciousness dreaming of perceiving and doing is equivalent to actively perceiving and doing. Thus, in line with Hume’s or Baars’ theatre metaphors, our dreams would be like dressed rehearsals in the theatre of our conscious mind. Such a view is supported by neurophysiological correlates of phenomenal consciousness in active wakeful observers and in observers recorded from during lucid dreaming in REM sleep. Lucid dreaming and equivalent wakeful activities are measured in terms of relatively short EEG signal epochs, indicating a specific activation level of the central nervous system (e.g. LaBerge, 1990). Other work on anesthetized patients (e.g. Drover et al., 2002) suggests that different levels of brain activation during anaesthesia are reliably predicted by an invariant set of changes in quantitative EEG analysis. However, despite the valuable insights produced by such lines of research, they have not permitted to unravel the workings of consciousness. This leads us to another erroneous hypothesis about consciousness, which is anchored in the belief that the latter would be the product of some kind of “neural field” within the brain.

2. Consciousness is not a neural field within the brain

In the so-called field theories (e.g. Köhler, 1940; Cacha and Poznanski, 2014, and others), consciousness is conceived in terms of a field in the sense in which it is used in quantum or particle physics, where the notion of ‘field’ applies to all fundamental forces and relationships between elementary particles within a unifying theoretical framework where the forces lead to energy fields that occupy space-time and mediate interactions between elementary particles. In field theories of consciousness the latter is, similarly, seen as having duration and extension in space. In field theories in physics, however, each point of a particular region of the presumed space-time continuum, as well as all interactions

between elementary objects, are objectively measurable and accounted for mathematically. This cannot be claimed by any current theory of consciousness, including the field theories (e.g. Köhler, 1940; Lashley, Chow, and Semmes, 1951; John, 2002; McFadden, 2002; Fingelkurts and Fingelkurts, 2002; Cacha and Poznanski, 2014). These will not be reviewed in detail again here, as an excellent review has been provided earlier by Pockett (2013) earlier. Libet's Mind Field Theory of consciousness, carved out in his book *Mind Time* (2004), may be discussed outside rather than within the realm of the field theories referred to here. Such field theories of consciousness, where the latter is seen as having duration and extension in space, are all limited by the fact that particular regions of the presumed space-time continuum and interactions between elementary objects herein cannot be objectively measured or accounted for mathematically. Libet (1993) was well aware of this fundamental problem by recognizing that "the mind field of consciousness" does not correspond to any category of known physical fields and, therefore, cannot be observed directly by any of the currently known physical means. Pockett (2013) amusingly wrote that "a field that is not observable directly by known physical means is in some danger of remaining confined to the realms of philosophy". Neural field theories of consciousness, whether they relate to representational fields, where *Gestalten* or *qualia* are believed to reflect the very nature of consciousness, occupying a presumed spatio-temporal brain field generating electrical brain states (Köhler, 1940), or to the functionally specific spatio-temporal structure of an electromagnetic field in the brain (Lashley et al., 1951, McFadden, 2002; John, 2002; Fingelkurts and Fingelkurts, 2002) account for specific aspects of brain-behavior function while humans are in an aware or a non-aware state, referred to as "conscious" or "non-conscious" states by many of these authors, which adds a layer of confusion to the initial misconception of the neural field notion, and calls for making a clear distinction at the conceptual level between awareness and consciousness. In summary, if a representational or neural field of consciousness occupying a presumed space-time continuum inside the brain, or outside the brain, as suggested by Shel Drake (2013) and others, existed, it would have to be independent of the neural activities underlying any particular perceptual or cognitive process operating at the same time. While a specific conscious perception, or a conscious memory recall, can be measurably correlated with specific brain activities (Nani et al., 2019), these are not the neural correlates of consciousness as such.

3. Awareness is not consciousness

Consciousness is a complex product of a long process of brain evolution (e.g. Cabanac, Cabanac, and Parent, 2009; Feinberg and Mallatt, 2013). Since the theory of evolution was carved out by Darwin (1871), the problem of a scientific account for the origin of mind or more specifically the origin of consciousness, had arisen. Where and how in evolution it has begun to emerge, and how it could be measured scientifically, is not known with precision. How can we derive mindfulness out of mere biophysical matter? If we wanted to define consciousness adequately, it would need to be in terms of the capability of the Self to know and analyze its own condition and existence in space and time, to ponder this condition under the light of possible worlds beyond the physical world known, and to project these representations and analyses into a future that has not yet happened. Since only humans are endowed with such abstract capability, consciousness is to be considered a unique property of the human mind, or a mental ability no other species known possesses. Awareness of the immediate physical environment, on the other hand, may be present in some mammals,

and certainly in the non-human primate as Köhler's groundbreaking experiments (1940) on awareness, insight, and concrete operational problem-solving in chimpanzees have shown. A biological organism such as *aplysia* is sentient of light in the environment. Several authors (Metzinger, 2009; Ehret and Romand, 2022) argued that animal species possess the inherited possibility to couple different stimuli of one or several modalities, as broad input of perceptual systems, with memory in their global neural workspace in adaptive response behavior. Through this attentional agency, they become aware of stimuli in their immediate environment. Consciousness in the human species, on the other hand, would be linked to higher levels of neural connectivity, possibly involving thalamocortical feed-back loops (Loeb, 2023), linked to the higher level motivated agential involvement of humans (Metzinger, 2009; Froese, 2023). The interaction between awareness-based choice selection and human intentionality driven by free will, allowing for a discretionary selection of information rather than a survival-driven one as in animal species, would then qualitatively differentiate animal awareness from awareness-guided consciousness in humans (Farhani, 2021, 2023). The self-awareness of the human species (which other animal species do not possess) therein acquires a collaborative function with the conscious mind whereas in animals, awareness is outward directed and directly associated with a concrete, immediate, and most often survival relevant goal. Therewith arises the question at which moment in the evolution of the human brain consciousness came to be. The higher level motivated agential involvement of humans coincided with the ability to introspect according to Jaynes (1990), who was among the first to point out that consciousness must therefore be distinguished from sensory awareness and other processes of cognition. Jaynes conceives consciousness as a learned property of the human mind, pointing to the origin of consciousness in ancient human history with the breakdown of what he called "the bicameral mind" – a mentality based on verbal hallucinations about magical forces and spirits. Art is a powerful key to comprehending the evolution in consciousness humankind has been through. During the Renaissance, art helped humans evolve consciousness with the discovery of the perspective. Before this critical point, humans could only picture things in two dimensions. This reference to art helps us realize why it may not be possible to render the whole complexity of the phenomenon of consciousness scientifically operational (e.g. Dresch-Langley, 2022). Ontological links between mind, time, and the Self as a window to understanding specific aspects of human consciousness, and the ability to project one's own existence into the future, are properties none of the theories of consciousness has succeeded to explain. What others have referred to as the "hard problem of consciousness" (e.g. Chalmers, 1996; Searle, 1998) relates to the difficulty of finding brain measures of the conscious *Self* experienced in terms of *I do, I think, I feel, I was, am, and will be*, independently of any particular conscious perception, memory, decision, or action (behavior) remains essentially unresolved.

4. Consciousness is not conscious information processing

The notion of a conscious state and how it may lead to an operational approach to the problem in terms of information processing had been discussed twenty years ago by Tononi & Edelman (1998). Their conscious state concept was based on the idea that consciousness would be reflected by conscious information processing capacity. It encompasses an earlier one proposed by von der Malsburg (1997) in terms of a continuous process with a limited duration. The idea here, again, is reductionist. While it admits that conscious brain states are neither identical nor reducible to states of

awareness or vigilance (Nagel, 1974; Humphrey, 2000; Nielsen & Stentstrom, 2005), it does not account for the workings of consciousness. Cognitive processes such as memory (e.g. Cowan, Elliott, Saults, Morey, Mattox, Hismjatullina, & Conway, 2005; Lin, Osan, & Tsien, 2006), attention (Posner, 1994; Raz & Buhle, 2006), conscious perception (e.g. Crick & Koch, 2000; Dehaene et al., 2006), or volition (Grossberg, 1999; Dehaene et al., 2006) are correctly conceived as possible expressions of a conscious state but not to be confounded such. Rather, a conscious state would correspond to a specific functional state of the brain (e.g. Klausberger et al., 2003) that enables the experience of phenomenal consciousness. John (2002) argued that the most probable invariant level of neural activity or coherent interaction among brain regions that can be measured when a person is in a conscious state would be the best possible approximation of what he called the “conscious ground state of the brain”. Earlier studies concerned with the functional characteristics of conscious and non-conscious information processing, decision making, and action (for detailed early reviews see Kihlstrom, 1987, Dehaene & Naccache, 2001, or Buzsaki, 2007) had suggested approaching consciousness in terms of a brain state or conscious state. The latter appears to have two major functional characteristics in terms of a limited information processing capacity (e.g. Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977; Shiffrin, 2003; Ramsey et al., 2004) and a unique representational content for a limited and relatively short duration (e.g. Duncan, 1980; Mangan, 2003; LeDoux, 2002; Dietrich, 2003). The content of a conscious state would be steadily updated through non-conscious processes, which constitute by far the largest part of all brain activity (e.g. Velmans, 1991; Gray, 2002; Pockett, 2004; Marchetti, 2014). Conscious information processing relies mainly on serial processing, which allows for only a very limited amount of information to be dealt with in a given time span. Most people cannot consciously follow two ideas at the same time, or consciously execute two even simple, simultaneous tasks (e.g. Cherry, 1953; Baars, 1998). Conscious “seriality” undeniably constrains any possible theory of consciousness (Pockett, 1999; Seth & Baars, 2005; Edelman, 2003). Non-conscious activity, on the other hand, is largely based on massively parallel processing and can therefore handle a lot more information (e.g. Mesulam, 1990; Hochstein & Ahissar, 2002; Mangan, 2003; Dietrich, 2003). The function of serialization in terms of an ordered list of conscious events (e.g. Page & Norris, 1998; Seth et al., 2006), discussed already half a century ago by Lashley (1951), is linked to the hypothesis that an event or piece of information, once made conscious, would become selectively available to other processes related to thought and speech production. This function of making non-conscious information accessible to the active mind is an important achievement of brain evolution. The limited capacity of conscious processes, on the other hand, represents a major functional constraint, revealed by psychophysical data, which include data on change blindness mentioned earlier, and more recent observations on change detection (Triesch, Ballard, Hayhoe, & Sullivan, 2003). These have shown that observers detect sudden specific changes in visual scenes only and only just in time when they need the specific information to solve a given problem. The limited capacity of a conscious state entails that it must entirely rely on working memory, which can handle the “magic” number of about 7 representations (e.g. Oberly, 1928; Miller, 1956, and more recently Parkin, 1999, or Vogel, Woodman, & Luck, 2001). Such a limitation severely constrains the top-down processes that can effectively operate within the temporal window of a conscious state. As proposed earlier by Mangan (2003), the pre-conscious processes at the fringe of consciousness may provide some kind of buffer, which both compensates for and regulates the limited conscious capacity. The processing capacity of the non-conscious, in contrast, may be estimated within a range of at least 10^7 bits, knowing that the optical nerve transfers 10^8 bits per second as stated by Koch (1997), which is infinitely more than

working memory can deal with. The limitations of conscious information processing are defined in terms of the representational content that is authorized to invade a conscious state at a given time. Such content would be retrieved selectively from non-conscious long-term memory, where it is stored as an integrated representation. Such have been defined (Churchland (2002) in terms of patterns of activity across groups of neurons which carry information. A fully integrated representation would consist of a unique activity pattern defined by a unique temporal sequence. Certain theoretical approaches to neural signal exchanges in the brain, such as the Lisman-Idiart-Jensen models (Lisman & Idiart, 1995; Jensen et al., 1996; Jensen & Lisman, 1996a, 1996b, 1996c; Lisman, 1998; Jensen & Lisman, 1998; Jensen, 2005), point towards a selective retrieval of temporal activity patterns as the most parsimonious explanation for conscious brain states. These approaches, based on the idea that consciousness would be based on the mechanisms and functional properties of working memory, attempted to explain how a temporal pattern code may activate and maintain a conscious brain state. However, this otherwise powerful model approach to biological memory fails to account for the capacity of human consciousness of projecting representations into the future and to conceive possible world states, which is the basis of all imagination and creativity at the centre of the development of cultures and societies.

5. Consciousness is not memory

Inspired by some of the experimental data and theories discussed here above, the Lisman-Idiart-Jensen models have been referred to in this context (e.g. Dresch-Langley and Durup, 2009, among others). The models consist of a working memory architecture with a maximum processing capacity of 7 ± 2 items. Each such item is represented by the firing of a cell assembly (the so-called “coding assembly”) during one gamma period (Herrmann, Munk, & Engel, 2004), the whole phenomenon occurring in a theta period composed of about 7 gamma cycles. Specific model accounts, for the slope of the so-called Sternberg curve (38 ms per item) for working memory time spans were developed on the basis of this approach (for the details, see Jensen & Lisman, 1998, 2005). Başar (1998) and Başar et al. (2000) considered the cognitive transfer activities to be based on oscillations at specific temporal frequencies (e.g. Gutman, Gilroy, & Blake, 2007). These would be combined like the letters of an alphabet to deliver a temporal code for conscious brain activity, measurable through wavelet analysis of EEG or event-related potentials (ERP). The functional identity of the neurons delivering the code is deemed irrelevant, only the timing of the signal sequences matters, the nested functional hierarchy of spatiotemporal patterns produced by neuronal assemblies and operational modules and their intrinsic dynamics. Subsequently, Fingelkurts & Fingelkurts (2001, 2008) analyzed and modelled event-specific EEG signal sequences further in that direction. Their models highlight what they called “the nested hierarchy” of unconscious and conscious processes, where higher levels are physically composed of lower levels (Maccaferri & Lacaille, 2003; Fellin & Carmignoto, 2004; Fields, 2004; Machens, Romo, & Brody, 2005) and where there is no central control of the system as a whole. This results in extremely weak constraints for higher processing levels in the brain on the lower (non-conscious) ones, and therefore represents a major limiting condition for artificial intelligence and machine learning algorithms. There are no known criteria for integrating non-explicit (i.e. non-conscious) contents into the procedural command chains of machine learning algorithms, not even when they involve essentially unsupervised adaptive neural network learning. Whenever a unique combination of temporal signal sequences in the human brain attains some critical activity threshold, a unique conscious

state could be generated, and regenerated whenever that signature is retrieved again, either by the same set of neurons or any other set capable of producing it. Such neural timing for conscious state access would rely on simultaneous supra threshold activation of sets of cells within dedicated neural circuits in various, arbitrarily but not necessarily randomly determined loci of the brain. The intrinsic topology that determines which single cell of a given circuit produces which spike pattern of a given temporal signature is, therefore, independent of the topological functional organization of the brain. This idea that a conscious brain state is triggered by temporal signals of cells that are arbitrarily associated with any other functional properties of cells suggested a way of thinking about a neural code for consciousness radically different from what had been offered by most of the earlier approaches. It had the considerable functional advantage that, should some subsets of coding cells be destroyed, other subsets could still deliver the code elsewhere in the brain. Like the temporal signal sequence or activity pattern of any single coding cell is determined by its firing activity across a certain length of time (Van Rullen & Thorpe, 2001), the temporal signature of a conscious state would also be linked to its duration, the so-called “psychological moment” (Pöppel & Logothetis, 1986; von der Malsburg, 1999; Tononi & Edelman, 1998), with variations in the limited dynamic range of a few hundreds of milliseconds. This estimate was established decades ago on the grounds of a considerable body of psychophysical and neurobiological data (e.g. Lehmann et al., 1987; Lestienne & Strehler, 1988; Thorpe & Imbert, 1989; Crick & Koch, 1990; Potter, 1993; Gray, 1995; Pascual-Marqui et al., 1995; Taylor, 2002; Koenig & Lehmann, 1996; Lehmann et al., 1998; von der Malsburg, 1999; Bressler & Kelso, 2001; Chun & Marois, 2002). Work by Libet (1993, 2003, 2004), for example, has shown that a time minimum of about 500 ms is required for a near-threshold stimulus to produce a conscious perceptual experience. In order to analyze neural patterns in terms of the temporal codes they deliver, the duration of a conscious state is to be divided into critical time windows, or “bins”, the length of which would be limited by the accuracy of neuronal timing, or the lower limit of biophysics. Such a time window, or “bin”, is expressed through the parameter t which would represent the sum of standard deviations for the time delay of synaptic transmission including the duration of the refractory period. An average estimate of 6 ms for this parameter appears reasonable in light of the data available (Bair, 1999). Helekar (1999) based his calculations of a temporal code on an average duration of 3 ms for Δt , operating under the hypothesis of an average estimate of only 30 ms for a state duration, expressed in terms of the parameter t . An average estimate of 6 ms for Δt is consistent with bin durations proposed by Shastri & Ajjanagadde (1993), Moore & King (1999), or Rieke et al. (1997). Others (e.g. Singer, 2000) have suggested bin durations of up to 10 ms and no longer than 10 ms. Interspike intervals and integration times of cortical neurons display a similar dynamic range (Eggermont, 1998). Under the simple assumption that within each such “bin” there is either a signal or no signal, derived from McCulloch & Pitts’ (1943) germinal work on information transmission in neural networks, the information content of each bin is 1 bit. On the basis of an average duration of 300 ms for a given conscious state, which seems more realistic than the 30 ms state duration suggested by Helekar, a 6 ms duration for a critical time window or “bin” within that state, and with a deterministic signal being generated during each “bin”, the information content of such a conscious state would be $300/6 = 50$ bits. A similar computation of the maximum quantity of information conveyed by a duration t with a number of temporal windows identified by a given Δt was proposed by MacKay & McCulloch (1952). Considering equal probabilities for activity (signal) and non-activity (no signal) within each “bin”, a conscious state of a duration of 300 ms would then generate 61 bits of content (for $\Delta t = 6$ ms). This theoretical approach is detailed in Rieke et al. (1997), who pointed out that the neuronal systems under study approach the

theoretical limit of information transmission. The figures given above may be compared with estimates of the number of visual prototypes held in memory given by Tsotsos (1990), which correspond to information contents of 17 to 23 bits. Similar time-based estimates were suggested later by Thorpe et al. (2001) and VanRullen et al. (2005). Approaches in terms of dynamic analyses of correlated oscillations in cortical areas at various frequencies (e.g. Bassett et al., 2006) and functional interactions between gamma and theta oscillations in different structures of the brain (e.g. Axmacher et al., 2006) are consistent with the estimates given here. How such purely temporal functional aspects of an immense variety of neural signals produce a temporal code for conscious state access was discussed in greater detail earlier (Dresp-Langley & Durup, 2009). It can be understood as a result of the properties of reverberant neural circuits in the brain, functionally identified previously in neurobiology (Llinás et al., 1998; Steriade, 1997; Pollen, 1999; Llinás & Ribary, 2001; VanRullen & Koch, 2003; Lamme, 2004, 2006). The reverberant circuits or loops thus far identified in the brain appear to have their own intrinsic topology (e.g. Abeles et al., 1993; Edelman, 1993; Crick, 1994; Grossberg, 1999; Constantinidis et al., 2000; Lau & Bi, 2005; Dehaene et al., 2006). Reverberant neural activity was found in thalamo-cortical (Llinás et al., 1998; Llinás & Ribary, 2001; VanRullen & Koch, 2003) as well as in cortico-cortical pathways (Steriade, 1997; Pollen, 1999; Lamme, 2004, 2006). Reverberant neural activity as such is a purely temporal process that generates feed-back loops in the brain, referred to by some in terms of “re-entrant circuits” (Edelman, 1989, 1993; Tononi et al., 1992, 1998; Tononi & Edelman, 1998, 2000; Edelman & Tononi, 2000; Fuster, 2000; Prinz, 2000; Di Lollo et al., 2000; Klimesch et al., 1997; Edelman, 2003; Robertson, 2003; Koch & Crick, 2000; Crick & Koch, 2003). Reverberation is an important functional property of the brain (Lamme & Roelfsma, 2000) because without it, the conscious execution of focussed action would be difficult, if not impossible (e.g. Lamme, 2006). Dehaene et al. (2006) argued that conscious perception and report would rely on the extension of local brain activation to higher association cortices that are interconnected by long-distance connections and form a reverberating neuronal circuit extending across distant perceptual areas. Reverberation would allow holding information on-line for durations that are unrelated to the duration of a given stimulus and long enough to enable the rapid propagation of information through different brain systems. In their view, conscious information processing in the brain is associated with the parieto-frontal pathways of the brain (Frith & Dolan, 1996), which are protected from fast fluctuations in sensory signals and which would allow information sharing across a broad variety of cognitive processes. While it is straightforward to agree with Dehaene et al.’s postulate that conscious information processing would be enabled on the basis of signal reverberation and propagation across long-distance connections in the brain, it is less clear how the complex cross-talk between neural signals necessary to generate information sharing across a broad variety of non-conscious cognitive processes could be implemented into a code for consciousness. If this were possible, the conscious brain would be able to sort out a seemingly infinite number of different signals from multi-channel cross-talk to generate stable, reliable, unifying and reportable conscious state access. In other words, the whole chain of interactive processes could in principle be made explicit. Instead, what is happening is that the brain most likely relies on signal de-correlation, possibly enabled through long-distance reverberation and based on some critical internal threshold that is not known. De-correlation of temporal from spatial messages for capacity-limited representation within consciousness would clarify how a stable and precise brain code for conscious state access can be generated in light of the largely plastic and diffuse spatial functional organization of the brain. De-correlation has become an important concept in neural network theory and in systems theory in general. It describes a mechanism that reduces crosstalk between multi-channel signals in a system like

the brain, while preserving other critical signal properties. The work by Lazar, Pipa, & Triesch (2007) on interactions between spike timing dependent and intrinsic synaptic plasticity in recurrent neural networks for the dynamic genesis of specific sequences, or series, of temporal activity patterns may be compatible with such a mechanism. While memory capacity definitely constrains consciousness, it does not suffice as an explanation or model thereof. Brain evolution fueled by self-organized and highly plastic mechanisms of learning need to be taken into account.

6. Brain plasticity and self-organization

The brain is the only system known capable of self-organization, enabled by brain plasticity and a from-local-to-global functional neural network architecture (e.g. Grossberg, 1993, 2020; Dresch-Langley, 2020). Sensory, somatosensory, and proprioceptive signals may instantly be integrated into the immediate data of unified conscious experience (e.g. Keppler, 2018; Dresch-Langley, 2022, 2023), eliciting what psychophysicists call sensations. The integration of such a variety of signals into brain representations (Keppler, 2018; Revonsuo, 2000; Holmgren et al., 2003), however, relies on non-conscious mechanisms, which have to be sufficiently adaptable (Lewis, 1983; Edelman, Baars, & Seth, 2005) and display a certain functional plasticity to enable the continuous updating of representations as a function of changes. Such changes are imposed on our brains day by day by new situations and experiences. To be made available to consciousness, there has to be some permanently reliable, unifying “tag” which ensures stable access across time. Grossberg (1999) referred to this problem as the “plasticity-versus-stability dilemma”. While such learning quite satisfactorily accounts for non-conscious information processing by the brain, it has not helped clarify through which mechanism non-conscious brain representations would be made available to consciousness. The need for a mechanism of neural integration that explains how non-conscious representations are delivered to consciousness is highlighted further by some neurological data, such as ERP and functional imaging data on neurological patients with unilateral neglect or extinction after unilateral brain damage. Such patients are unaware of objects or events that take place on the contralesional side of physical space. Depending on how far their parietal lesion extends to the occipital or temporal cortex, a more or less important amount of non-conscious perceptual processing is found to be preserved (see Driver & Vuilleumier, 2001, for a review). This suggests that localized brain damage of the parietal lobe affects the mechanisms that enable specific perceptual representations to access the conscious state level but does not affect the perceptual representations as such. Other neurological observations severely challenge the idea that function should be fixed in specific loci. The “phantom limb” syndrome (e.g. Ramachandran, Rogers-Ramachandran, & Cobb, 1995 ; Ramachandran, 1998), for example, reveals an extraordinary plasticity of topological functional brain organization. The phantom limb syndrome is a phenomenon that was already mentioned in writings by Paré and Descartes, and described in greater detail by Guéniot (1868). It has been repeatedly observed in hundreds of case studies since. After arm amputation, patients often experience sensations of pain in the limb that is no longer there, and experimental data show that a third of such patients systematically refer stimulations of the face to the phantom limb, with a topographically organized map for the individual fingers of a hand. On the basis of similar evidence for massive changes in somatotopic maps after digit amputation and other experimental data showing that several years after dorsal rhizotomy in adult monkeys, a region corresponding to the hand in the cortical somatotopic map of the primate’s brain is activated by stimuli delivered to the

face (Merzenich et al., 1984), Ramachandran and his colleagues proposed their “remapping hypothesis” (e.g. Ramachandran, Rogers-Ramachandran, & Stewart, 1992). The latter clarifies how spatial and topological representations are referred to other loci in the brain through massive cortical re-organization. The findings reported by Ramachandran and others delivered compelling evidence that, despite dramatic changes in non-conscious topology, representations remain available to conscious state access and can still be experienced in terms of sensations such as pain, cold, digging or rubbing. This is most likely so because the temporal signatures of these representations persist in the brain. In the light of the long-distance propagation hypothesis, it can be assumed that the neural signatures for conscious state access propagate well beyond local sensory and somatosensory areas which receive and process input from a given part of the body such as an arm or a leg. Long-distance propagation and reverberation would then lead to the consolidation of the temporal signatures of conscious sensations, resonating across the whole brain. The signatures can then reach critical threshold activation levels even when stimulus input to specific local sensory areas is no longer delivered. John (2001, 2002) suggested that a conscious state may be identified with a brain state where information is represented by levels of coherence among multiple brain regions, revealed through coherent temporal firing patterns that deviate significantly from random fluctuations. This assumption is consistent with the idea of a stable and perennial temporal code for conscious state access despite spatial remapping or cortical re-organization. Empirical support for John’s theory comes from evidence for a tight link between electroencephalographic activity in the gamma range defined by temporal firing rates between 40 and 80 Hz (i.e. the so-called “40-Hz” or “phase-locked” gamma oscillations) and conscious states (e.g. Engel et al., 1992). This “coherence index”, with its characteristic phase-locking at 40 Hz, was found to change with increasing sedation in anaesthesia, independent of the type of anaesthetic used (Stockmanns et al., 2000). Decreasing temporal frequencies were reported when doses of a given anaesthetic were increased. Moreover, the characteristic phase-locking at 40 Hz displays coherence not only across brain regions during focussed arousal, but also during REM sleep, when the subject is dreaming (Llinás & Ribary, 1993). Coherence disappears during dreamless, deep slow-wave sleep, which is consistent with the findings reported on deeply anesthetized patients. The fact that the temporal coherence index of a conscious state is produced during focussed arousal as well as during dreaming in REM sleep phases is fully consistent with the idea (e.g. LaBerge, 1990) that dreams and conscious imagination represent functionally equivalent conscious states. Phase-locking at the critical temporal frequency would be achieved through intra-cortical reverberation, enabled by a digital event within a hybrid system (John, 2001, 2002). This hybrid system, the brain, establishes arbitrary but non-random departures from different loci or topological maps. These latter may undergo functional re-organization, yet, the temporal code for conscious state access remains intact. This would lead to cortico-thalamic feedback loops, or resonance loops, generating the temporal signatures of conscious states on the basis of a statistical computation of non-conscious memory events coinciding in time. Potential mechanisms explaining how such memory events are read out by non-conscious processes in the brain were discussed by Grossberg in his Adaptive Resonance Theory ART (Grossberg, 1975, 1999; Dresch-Langley, 2023 for a review).

7. Insights from Adaptive Resonance Theory

Adaptive Resonance Theory (ART) was initially conceived as a universal theory of learning to explain how the brain

generates and updates representations of continuously changing physical environments (Grossberg, 1975). Subsequently, the theoretical framework of ART was extended to account for learning-related phenomena such as attention, intention, and volition. According to Grossberg (1999), the link between these three may be described by the fact that intentions would lead to focus attention on potentially relevant internal or external events. These foci of attention would lead to new representations when the system (the brain) is able to validate and integrate them into resonant states, which would include certain conscious states of the brain. According to the theory, all conscious states would be resonant states, triggered either by external or internal events and mediated by either attention or volition. This as such, however, does not explain how non-conscious representations may become available to consciousness. The theory does not functionally separate spatial from temporal coding, which is necessary to account for the integration of non-conscious representations into conscious experience of past, present, and future at a moment in time. However, ART plausibly explains how the brain ensures the continuous updating of non-conscious representations through a mechanism termed top-down matching, which produces resonant brain states. A resonant brain state would be achieved through the repeated matching of external or internal events in short-term or working memory to internal events activating top-down representations. According to the theory, the brain is continuously confronted with ongoing internal or external representations (bottom -up) and therefore has to continuously generate probabilistic hypotheses to determine what all these transitory events are most likely to be and whether they are relevant. This involves matching the ongoing representations to representations stored in long-term memory (top-down). Coincidence of bottom-up representations and top-down representations (top-down-matches) would produce so-called matching signals, or coincidence signals which, when repeatedly generated, lead to resonant states in the brain. The representations generated through top-down matching would be coded topologically in the “What” and “Where” processing streams of the brain (see Grossberg, 1999 for an extensive review of relevant physiological data), and what he calls “the resonant code” is therefore tightly linked to functional topological organization. The question how non-consciously encoded topological information would be made available to consciousness is left unanswered. The brain circuitry that produces resonance requires, essentially arbitrary but not necessarily random, functional topology in terms of “which cell fires first”. This intrinsic topology would be determined by purely temporal resonance principles. While there is no empirically based description of resonators receiving, amplifying and transmitting time-patterned messages in the brain, it is nevertheless certain that a large number of physical and biophysical phenomena can be plausibly and parsimoniously explained on the basis of resonance principles or mechanisms. Also, it makes good sense that evolution would have produced brains capable of resonance. Biological resonators, in contrast to “ordinary” resonance devices designed by humans, would have highly sophisticated operating principles, given that hundreds of functionally different kinds of cells exist in the brain. On the other hand, there is no reason why resonators in the brain would have to function with a high level of precision, provided they operate according to some redundancy principle and the whole ensemble of cells producing a conscious resonance state behaves in a statistically predictable way. This has led to the idea that specific neural signal sequences (signatures) would form a specific biophysical key that activates, maintains, and inactivates a conscious brain state like an electronic lock would open and close the door to a safe (Dresp-Langley & Durup, 2009) However, this being inevitably a simplification of reality, the known temporal properties of conscious information processing are consistent with the idea that brains are capable of generating messages corresponding to variable specific representations with variable durations and context. In the same

way as bar codes provide the key to an almost infinite variety of things, temporal brain signatures could provide the keys that open the doors of consciousness. This does, however, not account for the dynamics of consciousness in terms of mental energy (Peperell, 2018), or how such potential is derived from the brain processes enabling its development (Dresp-Langley, 2022).

8. The neural doors to consciousness

The considerations and arguments discussed here above under the light of neurophilosophical arguments lead us to consider the following:

- Only non-conscious brain processes dispose of enough capacity to integrate signals originating from various functionally specific sensory areas across both time and space.
- The temporal brain signatures of conscious states are likely to be generated and consolidated in reverberating interconnected neural circuits that extend across long distances and well beyond functionally specific topology.
- The activation of a temporal signature that may trigger a conscious state depends on statistically determined temporal coincidence of activity patterns related to non-conscious memory events that cannot be made explicit.
- The temporal signatures have to be, at some stage, de-correlated from related signals or messages originating from the brain's spatial maps.
- Finally, the brain genesis of conscious state potential does not account for consciousness as a stream of mental energy with the capacity of projecting representations onto possible future world states

Temporal brain signatures are generated spontaneously at any given moment from early brain development on. Subsequently, they may or may not become consolidated during brain learning to become what we may call the “doors to conscious learning and experience”. Consolidation is a result of repeatedly iterated reverberations in cortical memory circuits, leading to resonance states which correspond to more or less specific conscious states in the flux of a holistic conscious experience. Once a resonance circuit is formed, it may be able to generate conscious state access at any given moment in time provided there is a statistically significant temporal coincidence between activity patterns in long-term memory. As long as this threshold of statistically significant coincidence is not attained, representations processed in the resonant circuitry would remain non-conscious or pre-conscious. A brain or system operating on the basis of such purely temporal resonance principles would have to work in a specific way. All principal resonant neurons would have been primed during brain development to preferentially process statistically significant signals. Thus activated, principal resonant neurons would send signals along all delay paths originating from them, and all those receiving a signal coinciding with the next input signal would remain activated. The connections between principal resonant neurons of the circuit would thereby be potentiated, as in the classical Hebbian model (e.g. Dresp-Langley, 2022). Simultaneously, signals travelling from initially activated neurons to connected cells with too long delay paths would be cancelled. Thus, once a given substructure of a resonant network is potentiated along all of its edges, it would reverberate temporally coinciding signals while amplifying more and more the potentiation of the resonant connections. Considering the example of a simple sensorimotor task, which can be performed either consciously or non-consciously, the message sent by the

sensory system has to be decoded by the motor system. This would happen via non-conscious signal exchanges generating cross-talk between multiple channels across different functional levels (Nelson, 2002; Ransom, Behar, & Nedergaard, 2003; Nedergaard, Ransom, & Goldmann, 2003; Volterra & Meldolesi, 2005; Yamazaki et al., 2005). A conscious state, where the content of the representations activated by such crosstalk in the brain becomes subjectively experienced data of consciousness, would only be triggered if the temporal coincidence between signals reverberating within resonant circuitry generates levels of potentiation beyond a given statistical threshold. How neuronal circuits would be able to learn statistical temporal information embedded in distributed patterns of activity was recently discussed by Gutig & Sompolinski (2006). Such resonant circuits would be inter-connected across large distances in the brain and develop all over the cortex during lifespan brain learning. Their intrinsic topology would, as explained above, not be related to cortical maps reflecting spatial functional organization of the brain. Like time-dependent resonance itself, the selection of the critical temporal firing patterns that constitute the access code for conscious states uses purely statistical criteria, leading to fewer and fewer consolidated patterns for increasingly complex and integrated signal coincidences as our brain learns and develops. When we are born, all brain activity is more or less arbitrary, not necessarily random. During brain development, temporal activity patterns elicited by events in biophysical time (t) ranging from 30 to approximately 500 ms (as explained above) will be linked to particular conscious experiences in a decreasingly arbitrary manner as frequently occurring codes are progressively consolidated through a process of developmental selection. Helekar (1999) daringly proposed a genetically determined linkage, which flies into the face of a large body of work suggesting that brain processes are highly plastic and experience dependent, and which may explain why his work did not receive much consideration from the neuroscience communities. A linkage of subjective experience and specific temporal brain activities that would be innate and genetically determined leaves, however, the question of a mechanism for consciousness unanswered. Yet again, we find ourselves confronted with theoretical reasoning in terms of some kind of obscure superstructure. Helekar's "elementary experience-coding temporal activity patterns" are conceived in terms of pre-programmed, designated subsets of neural firing patterns, belonging to a set of all possible temporal patterns that can be generated by the brain. His original hypothesis claimed that only patterns that are members of a designated subset would give rise to conscious states upon their repeated generation or activation. The repeated occurrence of ordinary patterns, which he called non-coding patterns, would not produce conscious states. The problem with this reasoning is that the contents we may consciously experience are also represented non-consciously in the brain. Helekar's assumption that the subjective nature of phenomenal consciousness *per se* may be genetically determined leads us right back to the nature *versus* nurture problem raised by brain scientists in the 1950ies and, ultimately, to the question raised since the dawn of the science of consciousness: "what exactly is phenomenal consciousness" (Gray, 1971; Dennett, 1991; Rosenthal, 1986; Roth, 2000; Zeman, 2001; Rosenthal, 2002)? There is the possibility of an experience-dependent, increasingly non-arbitrary linkage of individual conscious states to their temporal signatures on the basis of developmental processes and brain learning. Once a given temporal signature has been arbitrarily linked to a conscious state, it remains potentially available as a "brain hypothesis", which is then either progressively consolidated or not following the principles of Hebbian learning. Only once consolidated, the linkage of brain signatures to experience would become non-arbitrary, or deterministic. This progressive consolidation as a function of context clearly happens without awareness, through brain processes that operate through the repeated matching of currently ongoing representations to stored representations in

long-term memory, as suggested in ART.

9. Artificial consciousness, what for?

Multiple sensory, somatosensory, and proprioceptive signals are instantly integrated into an individual conscious experience. The integration as such relies on non-conscious mechanisms. These have to be sufficiently adaptable and must display a considerable functional plasticity to enable the continuous updating of representations as a function of changes with context, time, the ageing of the underlying circuitry, and so on. To achieve this, the human brain must rely on a great deal of redundancy in what Fingelkurts & Fingelkurts (2014) called a “nested functional hierarchy”, most of which is not, and will never be, made available to our consciousness. New information is imposed on our brains day by day, by new situations and world states; for making all this novelty available to consciousness, there would have to be permanently reliable, unifying “tags” which ensure stable access across time. Such have never been found, although some have suggested that they may refer to processes involving the parieto-frontal pathways of the brain, which are protected from fast fluctuations in sensory signals, and which would allow information sharing across a broad variety of cognitive processes on the basis of signal reverberation and propagation across long-distance connections in the brain. However, it is impossible to conceive how such complex cross-talk between neural signals and the information sharing across a broad variety of non-conscious processes could be implemented into a code for consciousness. If this were possible, the conscious brain would be able to sort out a seemingly infinite number of different signals from multi-channel cross-talk and, more importantly, it would be able to access the whole command chain of non-conscious processes this involves. Only then, the chain of commands could be made explicit and implemented in an AI system. Implementing a code into a machine that would emulate human consciousness in all its complexity has become the final limit of our scientific endeavours and, in the light of what is discussed here above, a limit we are unlikely to ever be able to cross. It is an individual’s daily phenomenal experience that consciousness represents in terms of what was (past), what is right now (present) and what will be (future), as discussed earlier in by others (Dresp-Langley and Durup, 2009; 2012; Fingelkurts & Fingelkurts, 2014). The limits of this consciousness are pushed further by continuous brain evolution pushing the limits in functional plasticity of resonant brain mechanisms. The conscious Self of the individual is an expression of this evolution. Developing a computational code that could be implemented in Artificial Intelligence generating such potential in full remains the final limit of science. In the light of the complex interactions between implicit (non-conscious) and explicit (conscious) contents of representation, emulating human consciousness through artificial intelligence would imply that it is possible to make implicit (non-conscious) brain processes explicit by algorithm. These latter would have to be capable of a progressively less and less arbitrary selection of temporal signatures in a continuously developing neural network structure identical to that of the human brain, from the synaptic level to that of higher cognitive functions. This would then involve dynamically adaptive computations capable of emulating the properties of individual human experience in all their complexity including sensations such as pleasure and pain, and including feelings and moods such as sad or happy. Moreover, the computations would have to be able to represent past, present and future of complex event chains stored in the system’s long term memory. No AI system known at present has such potential.

Conclusions

From the neurophilosophical perspective it seems extremely unlikely that an artificial consciousness that emulates the properties of consciousness in their full potential will ever see the day. At best, the prophecy may self-fulfil by bringing about technologies capable of self-organization and mimicking specific aspects of what appears to the naive observer as a form of “conscious” behaviour or reasoning. This reminds us of toys able to say “I feel sleepy”, “I am hungry” or “you are naughty” when certain sensors trigger certain signals. Psychology undergraduates learn that there is no learning without consolidation in a stable memory system, and generalization of what has been learnt to other use cases and domains. AI is currently not capable of delivering such quality (see also Bishop, 2021). Capacity for consolidation and generalization is enabled in the human brain by complex neurobiological processes that are still not fully understood. Such processes have enabled the emergence of consciousness, however, they do not account for consciousness as such. Apart from the moral issues arising with the idea of an artificial consciousness, discussed with considerable effort and in great detail elsewhere (e.g. Hildt, 2023), we should ask the question what consciousness is for (Kotchoubey, 2018), and why we would want artificial consciousness in the first place. We must either accept a vicious form of panpsychism wherein every open physical system is phenomenally conscious, or reject the claim for artificial consciousness or computational accounts of phenomenal consciousness (Bishop, 2002). Our motivation to assert the qualitative superiority of human intelligence and the unique existence of human consciousness is to justify continuing human control over machines rather than foolishly wanting to hand over the keys to the machines that our minds have created (see Gerald Loeb's review of this paper). This last stand of human specieism must hold against the proselytes of a global brain prophecy and their ugly singularity gospel. Rather, given the role of consciousness as a vital energy source (<https://www.scientia.global/dr-birgitta-dresplangley-an-exciting-new-perspective-on-the-how-and-why-of-consciousness/>), we should focus on methods and techniques that expand our own human consciousness (Paulson et al., 2017 a, b), such as meditation and mindfulness practice. In Buddhism, pure consciousness is often described in terms of moments of inner and outer silence during meditation, for example (see also Paoletti & Ben-Soussan, 2020). While technocracy has no use for mindfulness, these powerful approaches to developing our full human potential may allow us to adjust individual and collective expectations, find greater purpose and fulfilment in our lives despite any adversity we may encounter. In this way, consciousness as a form of vital energy could be harnessed to become a fundamental driving force in developing our humanity.

References

- Abeles, M., Bergman, H., Margalit, E., & Vaadia, E. (1993). Spatiotemporal Firing Patterns in the Frontal Cortex of Behaving Monkeys. *Journal of Neurophysiology*, 70, 1629-1638. <https://doi.org/10.1152/jn.1993.70.4.1629>
- Axmacher, N., Mormann, F., Fernandez, G., Elger, C. E., & Fell, J. (2006). Memory Formation by Neuronal Synchronization. *Brain Research Reviews*, 52, 170-182. <https://doi.org/10.1016/j.brainresrev.2006.01.007>
- Baars, B. J. (1993). How Does a Serial, Integrated and Very Limited Stream of Consciousness Emerge from a Nervous System That Is Mostly Unconscious, Distributed, Parallel and of Enormous Capacity? In *Experimental and Theoretical Studies of Consciousness* (Ciba Foundation Symposium 174, pp. 282-303). Chichester, NY: Wiley.

- Baars, B. J. (1997). *In the Theater of Consciousness*. New York and Oxford: Oxford University Press.
<https://doi.org/10.1093/acprof:oso/9780195102659.001.1>
- Baars, B. J. (1998). Metaphors of Consciousness and Attention in the Brain. *Trends in Neurosciences*, 21, 58-62.
[https://doi.org/10.1016/S0166-2236\(97\)01171-5](https://doi.org/10.1016/S0166-2236(97)01171-5)
- Bair, W. (1999). Spike Timing in the Mammalian Visual System. *Current Opinion in Neurobiology*, 9, 447-453.
[https://doi.org/10.1016/S0959-4388\(99\)80067-1](https://doi.org/10.1016/S0959-4388(99)80067-1)
- Basar, E. (1998). *Brain Functions and Oscillations, I. Brain Oscillations: Principles and Approaches*. Berlin: Springer.
<https://doi.org/10.1007/978-3-642-72192-2>
- Basar, E., Basar-Eroglu, C., Karaka, S., & Schürmann, M. (2000). Brain Oscillations in Perception and Memory. *International Journal of Psychophysiology*, 35, 95-124. [https://doi.org/10.1016/S0167-8760\(99\)00047-1](https://doi.org/10.1016/S0167-8760(99)00047-1)
- Bassett, D. S., Meyer-Underberg, A., Achard, S., Duke, T., & Bullmore, E. (2006). Adaptive Reconfiguration of Fractal Small-World Human Brain Functional Networks. *Proceedings of the National Academy of Sciences of the USA*, 103, 19518-19523. <https://doi.org/10.1073/pnas.0606005103>
- Bieberich, E. (2002). Recurrent Fractal Neural Networks: A Strategy for the Exchange of Local and Global Information Processing in the Brain. *BioSystems*, 66, 145-164. [https://doi.org/10.1016/S0303-2647\(02\)00040-0](https://doi.org/10.1016/S0303-2647(02)00040-0)
- Bishop J. M. (2002). Dancing with pixies: strong artificial intelligence and panpsychism, in *Views into the Chinese Room: New Essays on Searle and Artificial Intelligence*, eds Preston J., Bishop J. M. (Oxford, UK: Oxford University Press;), 360–378.
- Bishop JM. (2021). Artificial Intelligence Is Stupid and Causal Reasoning Will Not Fix It. *Front Psychol*.11:513474. doi: 10.3389/fpsyg.2020.513474.
- Block, N. (1995). On a Confusion about a Function of Consciousness. *Behavioral and Brain Sciences*, 18, 227-287.
<https://doi.org/10.1017/S0140525X00038188>
- Bressler, S. L., & Kelso, J. A. S. (2001). Cortical Coordination Dynamics and Cognition. *Trends in Cognitive Sciences*, 5, 26-36. [https://doi.org/10.1016/S1364-6613\(00\)01564-3](https://doi.org/10.1016/S1364-6613(00)01564-3)
- Bullock, T. H., Bennett, M. V. L., Johnston, D., Josephson, R., Marder, E., & Fields, R. D. (2005). The Neuron Doctrine, Redux. *Science*, 310, 791-793. <https://doi.org/10.1126/science.1114394>
- Buzsaki, G. (2007). The Structure of Consciousness. *Nature*, 446, 267. <https://doi.org/10.1038/446267a>
- Cabanac M., Cabanac A. J., Parent A. (2009). The emergence of consciousness in phylogeny. *Behav. Brain Res.* 198 267–272. <https://doi.org/10.1016/j.bbr.2008.11.028>
- Cacha L. A., Poznanski R. R. (2014). Genomic instantiation of consciousness in neurons through a biophoton field theory. *J. Integr. Neurosci.* 13 253–292. <https://doi.org/10.1142/S0219635214400081>
- Chalmers, D. J. (1996). *The Conscious Mind*. Oxford: Oxford University Press.
- Cherry, E. C. (1953). Some Experiments on the Recognition of Speech, with One and Two Ears. *Journal of the Acoustical Society of America*, 25, 975-979. <https://doi.org/10.1121/1.1907229>
- Chun, M. M., & Marois, R. (2002). The Dark Side of Visual Attention. *Current Opinion in Neurobiology*, 12, 184-189.
[https://doi.org/10.1016/S0959-4388\(02\)00309-4](https://doi.org/10.1016/S0959-4388(02)00309-4)
- Churchland, P. S. (2002). *Brain-Wise. Studies in Neurophilosophy*. Cambridge, MA: MIT Press.

- Churchland P. S. (2005). A neurophilosophical slant on consciousness research. *Prog. Brain Res.* 149 285–293. [https://doi.org/10.1016/S0079-6123\(05\)49020-2](https://doi.org/10.1016/S0079-6123(05)49020-2)
- Constantinidis, C., Williams, G. V., & Goldman-Rakic, P. S. (2002). A Role for Inhibition in Shaping the Temporal Flow of Information in Prefrontal Cortex. *Nature Neuroscience*, 5, 175-180. <https://doi.org/10.1038/nn799>
- Cowan, N., Elliott, E. M., Saults, J. S., Morey, C. C., Mattox, S., Hismjatullina, A., & Conway, A. R. A. (2005). On the Capacity of Attention: Its Estimation and Its Role in Working Memory and Cognitive Aptitudes. *Cognitive Psychology*, 51, 42-100. <https://doi.org/10.1016/j.cogpsych.2004.12.001>
- Crick, F. (1994). *The Astonishing Hypothesis: The Scientific Search for the Soul*. New York: Simon and Schuster.
- Crick, F., & Koch, C. (1990). Towards a Neurobiological Theory of Consciousness. *Seminars in Neuroscience*, 2, 263-275.
- Crick, F., & Koch, C. (1995). Are We Aware of Neural Activity in Primary Visual Cortex? *Nature*, 375, 121-123. <https://doi.org/10.1038/375121a0>
- Crick, F., & Koch, C. (2000). The Unconscious Homunculus. *Neuro-Psychoanalysis*, 2, 3-11. <https://doi.org/10.1080/15294145.2000.10773273>
- Crick, F., & Koch, C. (2003). A Framework for Consciousness. *Nature Neuroscience*, 6, 119-126. <https://doi.org/10.1038/nn0203-119>
- Darwin, C. (1871). *The descent of man*. London: Murray.
- DeCharms, R. C., & Zador, A. (2000). Neural Representations and the Cortical Code. *Annual Review of Neuroscience*, 23, 613-647. <https://doi.org/10.1146/annurev.neuro.23.1.613>
- Dehaene, S., & Naccache, L. (2001). Towards a Cognitive Neuroscience of Consciousness: Basic Evidence and a Workspace Framework. *Cognition*, 79, 1-37. [https://doi.org/10.1016/S0010-0277\(00\)00123-2](https://doi.org/10.1016/S0010-0277(00)00123-2)
- Dehaene, S., Changeux, J. P., Naccache, L., Sackur, J., & Sergent C. (2006). Conscious, Preconscious and Subliminal Processing: A Testable Taxonomy. *Trends in Cognitive Science*, 10, 204-211. <https://doi.org/10.1016/j.tics.2006.03.007>
- Dehaene, S., Sergent, C., & Changeux, J. P. (2003). A Neuronal Network Model Linking Subjective Reports and Objective Physiological Data during Conscious Perception. *Proceedings of the National Academy of Sciences of the USA*, 100, 8520-8525. <https://doi.org/10.1073/pnas.1332574100>
- Delorme, A., Rousselet, G. A., Mace, M. J., & Fabre-Thorpe, M. (2004) Interaction of Top-Down and Bottom-Up Processing in the Fast Visual Analysis of Natural Scenes. *Cognitive Brain Research*, 19, 103-113. <https://doi.org/10.1016/j.cogbrainres.2003.11.010>
- Dennett, D. (2001). Are We Explaining Consciousness Yet? *Cognition*, 79, 221-237. [https://doi.org/10.1016/S0010-0277\(00\)00130-X](https://doi.org/10.1016/S0010-0277(00)00130-X)
- Dennett, D. C. (1991). *Consciousness Explained*. Brown: Little.
- Di Francesco M. (2008). Consciousness and the self. *Funct Neurol.*, 23(4):179-87.
- Di Lollo, V., Enns, J. T., & Rensink, R. A. (2000). Competition for Consciousness among Visual Events: The Psychophysics of Re-Entrant Visual Processes. *Journal of Experimental Psychology: General*, 129, 481-507. <https://doi.org/10.1037/0096-3445.129.4.481>
- Dietrich, A. (2003). *Functional Neuroanatomy of Altered States of Consciousness: The Transient Hypofrontality*

- Hypothesis. *Consciousness and Cognition*, 12, 231-256. [https://doi.org/10.1016/S1053-8100\(02\)00046-6](https://doi.org/10.1016/S1053-8100(02)00046-6)
- Dresch-Langley, B., & Durup, J. (2009). A Plastic Temporal Code for Conscious State Generation in the Brain. *Neural Plasticity*, 2009, Article ID 482696. <https://doi.org/10.1155/2009/482696>
 - Dresch-Langley, B., & Durup, J. (2012). Does Consciousness Exist Independently of Present Time and Present Time Independently of Consciousness? *Open Journal of Philosophy*, 2, 45-49. <https://doi.org/10.4236/ojpp.2012.21007>
 - Dresch-Langley, B. (2012). Why the Brain Knows More than We Do: Non-Conscious Representations and Their Role in the Construction of Conscious Experience. *Brain Sciences*, 2, 1-21. <https://doi.org/10.3390/brainsci2010001>
 - Dresch-Langley, B. (2020). Seven Properties of Self-Organization in the Human Brain. *Big Data Cogn Comput*, 4, 10. <https://doi.org/10.3390/bdcc4020010>
 - Dresch-Langley, B. (2022). Grip force as a functional window to somatosensory cognition. *Frontiers in Psychology*, 13, 1026439. <https://doi.org/10.3389/fpsyg.2022.1026439>
 - Dresch-Langley, B. (2022). From Biological Synapses to Intelligent Robots. *Electronics*, 11, 707. <https://doi.org/10.3390/electronics11050707>
 - Dresch-Langley B. (2022). Consciousness Beyond Neural Fields: Expanding the Possibilities of What Has Not Yet Happened. *Frontiers in Psychology*, 12, 762349. <https://doi.org/10.3389/fpsyg.2021.762349>
 - Dresch-Langley B. (2023) The Grossberg Code: Universal Neural Network Signatures of Perceptual Experience. *Information*, 14(2), 82. <https://doi.org/10.3390/info14020082>
 - Driver, J., & Vuilleumier, P. (2001). Perceptual Awareness and Its Loss in Unilateral Neglect and Extinction. *Cognition*, 79, 39-88. [https://doi.org/10.1016/S0010-0277\(00\)00124-4](https://doi.org/10.1016/S0010-0277(00)00124-4)
 - Drover, D. R., Lemmens, H. J., Pierce, E. T., Plourde, G., Ornstein, E., Prichep, L. S., Chabot, R. J., & Gugino, L. (2002). Patient State Index (PSI): Titration of Delivery and Recovery from Propofol, Alfentanil, and Nitrous Oxide Anesthesia. *Anesthesiology*, 97, 82-89. <https://doi.org/10.1097/00000542-200207000-00012>
 - Duncan, J. (1980). The Locus of Interference in the Perception of Simultaneous Stimuli. *Psychological Review*, 87, 272-300. <https://doi.org/10.1037/0033-295X.87.3.272>
 - Edelman, D. B., Baars, B. J., & Seth, A. K. (2005). Identifying Hallmarks of Consciousness in Non-Mammalian Species. *Consciousness and Cognition*, 14, 169-187. <https://doi.org/10.1016/j.concog.2004.09.001>
 - Edelman, G. M. (1989). *The Remembered Present*. New York: Basic Books.
 - Edelman, G. M. (1993). Neural Darwinism: Selection of Re-Entrant Signalling in Higher Brain Function. *Neuron*, 10, 115-125. [https://doi.org/10.1016/0896-6273\(93\)90304-A](https://doi.org/10.1016/0896-6273(93)90304-A)
 - Edelman, G. M. (2003). Naturalizing Consciousness: A Theoretical Framework. *Proceedings of the National Academy of Sciences of the USA*, 100, 5520-5524. <https://doi.org/10.1073/pnas.0931349100>
 - Edelman, G. M., & Tononi, G. (2000). Re-Entry and the Dynamic Core: Neural Correlates of Conscious Experience. In T. Metzinger (Ed.), *Neural Correlates of Consciousness: Empirical and Conceptual Questions* (pp. 139-151). Cambridge, MA: MIT Press.
 - Eggermont, J. J. (1998). Is There a Neural Code? *Neuroscience and Biobehavioral Reviews*, 22, 355-370. [https://doi.org/10.1016/S0149-7634\(97\)00021-3](https://doi.org/10.1016/S0149-7634(97)00021-3)
 - Ehret G, Romand R. (2022). Awareness and consciousness in humans and animals - neural and behavioral correlates

- in an evolutionary perspective. *Front Syst Neurosci.* 2022;16:941534. doi: 10.3389/fnsys.2022.941534:
- Engel, A., Konig, P., Kreiter, A., Schillen, T., & Singer, W. (1992). Temporal Coding in the Visual Cortex: New Vistas on Integration in the Nervous System. *Trends in Neurosciences*, 15, 218-226. [https://doi.org/10.1016/0166-2236\(92\)90039-B](https://doi.org/10.1016/0166-2236(92)90039-B)
 - Feigl, H. (1958) The "Mental" and the "Physical". In H. Feigl, M. Scriven, & G. Maxwell (Eds.), *Concepts, Theories and the Mind-Body Problem*, Minneapolis, Minnesota Studies in the Philosophy of Science (Vol. 2). Minneapolis: University of Minnesota Press.
 - Feinberg T. E., Mallatt J. (2013). The evolutionary and genetic origins of consciousness in the Cambrian Period over 500 million years ago. *Front. Psychol.* 4:667. <https://doi.org/10.3389/fpsyg.2013.00667>
 - Feinstein, J. S., Stein, M. B., Castillo, G. N., & Paulus, M. P. (2004). From Sensory Processes to Conscious Perception. *Consciousness and Cognition*, 13, 323-335. <https://doi.org/10.1016/j.concog.2003.10.004>
 - Fellin, T., & Carmignoto, G. (2004). Neurone-to-Astrocyte Signalling in the Brain Represents a Distinct Multifunctional Unit. *Journal of Physiology*, 559, 3-15. <https://doi.org/10.1113/jphysiol.2004.063214>
 - Fields, R. D. (2004). The Other Half of the Brain. *Scientific American*, 290, 54-61. <https://doi.org/10.1038/scientificamerican0404-54>
 - Fingelkurts, A. A., & Fingelkurts, A. A. (2002). Operational Architectonics of the Human Brain Biopotential Field: Towards Solving the Mind-Brain Problem. *Brain and Mind*, 2, 261-296. <https://doi.org/10.1023/A:1014427822738>
 - Fingelkurts, A. A., & Fingelkurts, A. A. (2008). Brain-Mind Operational Architectonics Imaging: Technical and Methodological Aspects. *The Open Neuroimaging Journal*, 2, 73-93.
 - Fingelkurts, A. A., & Fingelkurts, A. A. (2014). Present Moment, Past, and Future: Mental Kaleidoscope. *Frontiers in Psychology*, 5, 395. <https://doi.org/10.3389/fpsyg.2014.00395>
 - Frith, C., & Dolan, R. (1996). The Role of the Prefrontal Cortex in Higher Cognitive Functions. *Cognitive Brain Research*, 5, 175-181. [https://doi.org/10.1016/S0926-6410\(96\)00054-7](https://doi.org/10.1016/S0926-6410(96)00054-7)
 - Froese T. (2023). Irruption Theory: A Novel Conceptualization of the Enactive Account of Motivated Activity. *Entropy (Basel)*; 25(5):748.
 - Fuster, J. M. (2000). Cortical Dynamics of Memory. *International Journal of Psychophysiology*, 35, 155-164. [https://doi.org/10.1016/S0167-8760\(99\)00050-1](https://doi.org/10.1016/S0167-8760(99)00050-1)
 - Gamez, D. (2008). Progress in machine consciousness. *Conscious Cogn*,17(3), 887-910. <https://doi.org/10.1016/j.concog.2007.04.005>
 - Gray, J. A. (1971). The Mind-Brain Identity Theory as a Scientific Hypothesis. *Philosophical Quarterly*, 21, 247-252. <https://doi.org/10.2307/2218130>
 - Gray, J. A. (1995). Consciousness and Its (Dis) Contents. *Behavioral and Brain Sciences*, 18, 703-722. <https://doi.org/10.1017/S0140525X00040693>
 - Gray, J. A. (2002). To Thine Own Synapses Be True? *Nature Neuroscience*, 5, 1115. <https://doi.org/10.1038/nn1102-1115>
 - Grossberg, S. (1975) A Neural Model of Attention, Reinforcement and Discrimination Learning. *International Review of Neurobiology*, 18, 263-327. [https://doi.org/10.1016/S0074-7742\(08\)60037-9](https://doi.org/10.1016/S0074-7742(08)60037-9)

- Grossberg, S. (1999). The Link between Brain Learning, Attention, and Consciousness. *Consciousness & Cognition*, 8, 1-44. <https://doi.org/10.1006/ccog.1998.0372>
- Grossberg, S. (1993). Self-organizing neural networks for stable control of autonomous behavior in a changing world. In *Mathematical Approaches to Neural Networks*; Taylor, J.G., Ed.; Elsevier Science Publishers: Amsterdam, The Netherlands, pp.139–197.
- Grossberg S. (2020). A path toward explainable AI and autonomous adaptive intelligence: Deep Learning, adaptive resonance, and models of perception, emotion, and action. *Front Neurobot*, 14:36.
- Gutig, R., & Sompolinski, H. (2006). The Tempotron: A Neuron That Learns Spike Timing-Based Decisions. *Nature Neuroscience*, 9, 420-428. <https://doi.org/10.1038/nn1643>
- Guttman, S. E., Gilroy, L. A., & Blake, R. (2007). Spatial Grouping in Human Vision: Temporal Structure Trumps Temporal Synchrony. *Vision Research*, 47, 219-230. <https://doi.org/10.1016/j.visres.2006.09.012>
- Helekar, S. A. (1999). On the Possibility of Universal Neural Coding of Subjective Experience. *Consciousness and Cognition*, 8, 423-446. <https://doi.org/10.1006/ccog.1998.0377>
- Hempel, P., & Oppenheim, C. G. (1948). Studies in the Logic of Explanation. *Philosophy of Science*, 15, 135-175. <https://doi.org/10.1086/286983>
- Herrmann, C. S., Munk, M. H., & Engel, A. K. (2004). Cognitive Functions of Gamma-Band Activity: Memory Match and Utilisation. *Trends in Cognitive Sciences*, 8, 347-355. <https://doi.org/10.1016/j.tics.2004.06.006>
- Heylighen F. 2015. Return to Eden? Promises and perils on the road to a global super-intelligence. In: Goertzel, B., Goertzel, T. (Eds.) *The End of the Beginning: Life, Society and Economy on the Brink of the Singularity* Humanity Press. <https://researchportal.vub.be/en/publications/return-to-eden-promises-and-perils-on-the-road-to-a-global-superi>
- Hildt, E. (2023). The Prospects of Artificial Consciousness: Ethical Dimensions and Concerns. *AJOB Neurosci*, 14(2), 58-71. <https://doi.org/10.1080/21507740.2022.2148773>
- Hochstein, S., & Ahissar, M. (2002). View from the Top: Hierarchies and Reverse Hierarchies in the Visual System. *Neuron*, 36, 791-804. [https://doi.org/10.1016/S0896-6273\(02\)01091-7](https://doi.org/10.1016/S0896-6273(02)01091-7)
- Holmgren, C., Harkang, T., Svennenfors, B., & Zilberter, Y. (2003). Pyramidal Cell Communication within Local Networks in Layer 2/3 of Rat Neocortex. *Journal of Physiology*, 551, 139-153. <https://doi.org/10.1113/jphysiol.2003.044784>
- Hume, D. (1740). *A Treatise of Human Nature*. Oxford: Oxford University Press.
- Humphrey, N. (2000). How to Solve the Mind-Body Problem. *Journal of Consciousness Studies*, 7, 5-112.
- Guéniot, T. (1868). D'une hallucination du toucher (hétérotopie subjective des extrémités) particulière à certains amputés. *Journal de Physiologie de l'Homme et des Animaux*, 4, 416-418.
- James, W. (1890). *Principles of Psychology*. New York: Holt. <https://doi.org/10.1037/11059-000>
- Jaynes J. (1990). *The Origin of Consciousness in the Breakdown of the Bicameral Mind*. Boston, MA: Houghton-Mifflin.
- Jensen, O. (2005). Reading the Hippocampal Code by Theta Phase-Locking. *Trends in Cognitive Sciences*, 9, 551-553. <https://doi.org/10.1016/j.tics.2005.10.003>
- Jensen, O., & Lisman, J. E. (1996a). Novel Tests of 7 ± 2 Known Items Can Be Reliably Stored in an Oscillatory Short-Term Memory Network: Interaction with Long-Term Memory. *Learning and Memory*, 3, 257-263.

<https://doi.org/10.1101/lm.3.2-3.257>

- Jensen, O., & Lisman, J. E. (1996b). Theta/Gamma Networks with Slow NMDA Channels Learn Sequences and Encode Episodic Memory: Role of NMDA Channels in Recall. *Learning and Memory*, 3, 264-278. <https://doi.org/10.1101/lm.3.2-3.264>
- Jensen, O., & Lisman, J. E. (1996c). Hippocampal Region CA3 Predicts Memory Sequences: Accounting for the Phase Precession of Place Cells. *Learning and Memory*, 3, 279-287. <https://doi.org/10.1101/lm.3.2-3.279>
- Jensen, O., & Lisman, J. E. (1998). An Oscillatory Short-Term Memory Model Can Account for Data on the Sternberg Task. *Journal of Neuroscience*, 18, 10688-10699.
- Jensen, O., & Lisman, J. E. (2005). Hippocampal Sequence-Encoding Driven by a Cortical Multi-Item Working Memory Buffer. *Trends in Neuroscience*, 28, 67-72. <https://doi.org/10.1016/j.tins.2004.12.001>
- Jensen, O., Idiart, M. A. P., & Lisman, J. E. (1996). Physiologically Realistic Formation of Autoassociative Memory in Networks with Theta/Gamma Oscillations-Role of Fast NMDA Channels. *Learning and Memory*, 3, 243-256. <https://doi.org/10.1101/lm.3.2-3.243>
- John, E. R. (2001). A Field Theory of Consciousness. *Consciousness and Cognition*, 10, 184-258. <https://doi.org/10.1006/ccog.2001.0508>
- John, E. R. (2002). The Neurophysics of Consciousness. *Brain Research Reviews*, 39, 1-28. [https://doi.org/10.1016/S0165-0173\(02\)00142-X](https://doi.org/10.1016/S0165-0173(02)00142-X)
- Keppler J. (2018). The role of the brain in conscious processes: a new way of looking at the neural correlates of consciousness. *Front. Psychol.* 9:1346. <https://doi.org/10.3389/fpsyg.2018.01346>
- Kihlstrom, J. F. (1987). The Cognitive Unconscious. *Science*, 237, 1445-1452. <https://doi.org/10.1126/science.3629249>
- Klausberger, T., Magill, P. J., Marton, L. F., Roberts, J. D. B., Cobden, P. M., Buzsaki, G., & Somogyi, P. (2003). Brain-State- and Cell-Type-Specific Firing of Hippocampal Interneurons In Vivo. *Nature*, 421, 844-848. <https://doi.org/10.1038/nature01374>
- Klimesch, W., Doppelmayr, M., Yonelinas, A., Kroll, N. E. A., Lazzara, M., Röhlm, D., & Koch, C. (1997). Computation and the Single Neuron. *Nature*, 385, 207-210. <https://doi.org/10.1038/385207a0>
- Koch, C., & Crick, F. (2000). Some Thoughts on Consciousness and Neuroscience. In M. S. Gazzaniga (Ed.), *The New Cognition Neurosciences* (2nd ed., pp. 1285-1294). Cambridge, MA: MIT Press.
- Köhler W. (1940). *Dynamics in Psychology*. New York, NY: Liveright.
- Koenig, T., & Lehmann, D. (1996). Microstates in Language-Related Brain Potential Maps Show Noun-Verb Differences. *Brain and Language*, 53, 169-182. <https://doi.org/10.1006/brln.1996.0043>
- Kosslyn, S. M. (1994). *Image and Brain: The Resolution of the Imagery Debate*. Cambridge, MA: MIT Press.
- Kosslyn, S. M. (1999). If Neuroimaging Is the Answer, What Is the Question? *Philosophical Transactions of the Royal Society of London B*, 354, 1283-1294. <https://doi.org/10.1098/rstb.1999.0479>
- Kosslyn, S. M., Ganis, G., & Thompson, W. L. (2001). Neural Foundations of Imagery. *Nature Reviews Neuroscience*, 2, 635-642. <https://doi.org/10.1038/35090055>
- Kotchoubey B. (2018). Human consciousness: where is it from and what is it for. *Front. Psychol.* 9:567. <https://doi.org/10.3389/fpsyg.2018.00567>

- Krauss P and Maier A (2020) Will We Ever Have Conscious Machines? *Front. Comput. Neurosci.* 14:556544. doi: 10.3389/fncom.2020.556544
- LaBerge, S. (1990). Lucid Dreaming: Psychophysiological Studies of Consciousness during REM Sleep. In R. R. Bootzen, J. F. Kihlstrom, & D. L. Schacter (Eds.), *Sleep and Cognition*. Washington, DC: APA Press. <https://doi.org/10.1037/10499-008>
- Lamme, V. A. F. (2004). Separate Neural Definitions of Visual Consciousness and Visual Attention: A Case for Phenomenal Awareness. *Neural Networks*, 17, 861-872. <https://doi.org/10.1016/j.neunet.2004.02.005>
- Lamme, V. A. F. (2006). Towards a True Neural Stance in Consciousness. *Trends in Cognitive Sciences*, 10, 494-501. <https://doi.org/10.1016/j.tics.2006.09.001>
- Lamme, V. A., & Roelfsema, P. R. (2000). The Distinct Modes of Vision Offered by Feedforward and Recurrent Processing. *Trends in Neurosciences*, 23, 571-579. [https://doi.org/10.1016/S0166-2236\(00\)01657-X](https://doi.org/10.1016/S0166-2236(00)01657-X)
- Lashley, K. (1951). The Problem of Serial Order in Behavior. In L. A. Jeffress (Ed.), *Cerebral Mechanisms in Behavior* (pp. 112-136). New York: Wiley.
- Lashley, K. S. (1956). Cerebral Organisation and Behavior. In *The Brain and Human Behavior*. Proceedings of the Association for Nervous and Mental Diseases (pp. 1-18). New York: Hafner.
- Lashley K. S., Chow K. L., Semmes J. (1951). An examination of the electric field theory of cerebral integration. *Psychol. Rev.* 58 123–136.
- Lau, P.-M., & Bi, G.-Q. (2005). Synaptic Mechanisms of Persistent Reverberatory Activity in Neuronal Networks. *Proceedings of the National Academy of Sciences of the USA*, 102, 10333-10338. <https://doi.org/10.1073/pnas.0500717102>
- Lazar, A., Pipa, G., & Treisch, J. (2007) Fading Memory and Time Series Prediction in Recurrent Networks with Different Forms of Plasticity. *Neural Networks*, 20, 312-322. <https://doi.org/10.1016/j.neunet.2007.04.020>
- LeDoux, J. (2002). *Synaptic Self. How Our Brains Become Who We Are*. New York: Macmillan.
- Lehmann, D., Ozaki, H., & Pal, I. (1987). EEG Alpha Map Series: Brain Microstates by Space Oriented Adaptive Segmentation. *Electroencephalography and Clinical Neurophysiology*, 67, 271-288. [https://doi.org/10.1016/0013-4694\(87\)90025-3](https://doi.org/10.1016/0013-4694(87)90025-3)
- Lehmann, D., Strik, W. K., Henggeler, B., Koenig, T., & Koukkou, M. (1998). Brain Electric Microstates and Momentary Conscious Mind States as Building Blocks of Spontaneous Thinking. I. Visual Imagery and Abstract Thoughts. *International Journal of Psychophysiology*, 29, 1-11. [https://doi.org/10.1016/S0167-8760\(97\)00098-6](https://doi.org/10.1016/S0167-8760(97)00098-6)
- Lennie, P. (2003). The Cost of Cortical Computation. *Current Biology*, 13, 493-497. [https://doi.org/10.1016/S0960-9822\(03\)00135-0](https://doi.org/10.1016/S0960-9822(03)00135-0)
- Lestienne, R., & Strehler, B. L. (1988). Differences between Monkey Visual Cortex Cells in Triplet and Ghost Doublets Informational Symbol Relationships. *Biological Cybernetics*, 59, 337-352. <https://doi.org/10.1007/BF00332924>
- Lewis, D. (1983). Mad Pain and Martian Pain. In D. Lewis (Ed.), *Philosophical Papers* (Vol. 1). Oxford: Oxford University Press. <https://doi.org/10.1093/0195032047.003.0009>
- Libet, B. (1993). The Neural Time Factor in Conscious and Unconscious Events. In *Experimental and Theoretical Studies of Consciousness* (pp. 282-303). Chichester, NY: Wiley.

- Libet, B. (2003). Timing of Conscious Experience. *Consciousness and Cognition*, 12, 321-331. [https://doi.org/10.1016/S1053-8100\(03\)00048-5](https://doi.org/10.1016/S1053-8100(03)00048-5)
- Libet, B. (2004). *Mind Time*. Cambridge, MA: Harvard University Press.
- Lin, L., Osan, R., & Tsien, J. Z. (2006). Organizing Principles of Real-Time Memory Encoding: Neural Clique Assemblies and Universal Neural Codes. *Trends in Neuroscience*, 29, 48-57. <https://doi.org/10.1016/j.tins.2005.11.004>
- Lisman, J. E. (1998). What Makes the Brain's Tickers Tock? *Nature*, 394, 132-133 <https://doi.org/10.1038/28061>
- Lisman, J. E., & Idiart, M. A. P. (1995). Storage of 7 ± 2 Short-Term Memories in Oscillatory Subcycles. *Science*, 267, 1512-1515. <https://doi.org/10.1126/science.7878473>
- Llinás, R., & Ribary, U. (1993). Coherent 40-Hz Oscillation Characterizes Dream States in Humans. *Proceedings of the National Academy of Science USA*, 90, 2078-2081. <https://doi.org/10.1073/pnas.90.5.2078>
- Llinás, R., & Ribary, U. (2001). Consciousness and the Brain: The Thalamocortical Dialogue in Health and Disease. *Annals of the New York Academy of Sciences*, 929, 166-175. <https://doi.org/10.1111/j.1749-6632.2001.tb05715.x>
- Llinás, R., Ribary, U., Contreras, D., & Pedroarena, C. (1998). The Neuronal Basis for Consciousness. *Philosophical Transactions of the Royal Society of London B*, 353, 1841-1849. <https://doi.org/10.1098/rstb.1998.0336>
- Loeb, G.E. (2023). Remembrance of things perceived: Adding thalamocortical function to artificial neural networks. *Frontiers in Integrative Neuroscience* 17, 1108271, doi.org/10.3389/fnint.2023.1108271.
- Maccaferri, G., & Lacaille, J.-C. (2003). Interneuron Diversity Series: Hippocampal Interaction Classification-Making Things as Simple as Possible, Not Simpler. *Trends in Neurosciences*, 26, 564-571. <https://doi.org/10.1016/j.tins.2003.08.002>
- Machens, C. K., Romo, R., & Brody, C. D. (2005). Flexible Control of Mutual Inhibition: A Neural Model of Two-Interval Discrimination. *Science*, 307, 1121-1124. <https://doi.org/10.1126/science.1104171>
- MacKay, D. M., & McCulloch, W. S. (1952). The Limiting Information Capacity of a Neuronal Link. *Bulletin of Mathematical Biophysics*, 14, 127-135. <https://doi.org/10.1007/BF02477711>
- Mangan, B. (2003). The Conscious "Fringe": Bringing William James Up to Date. In B. J. Baars, W. P. Banks, & J. B. Newman (Eds.), *Essential Sources in the Scientific Study of Consciousness* (pp. 741-759). Cambridge, MA: MIT Press.
- Marchetti G. (2014). Attention and working memory: two basic mechanisms for constructing temporal experiences. *Front. Psychol.* 5:880. <https://doi.org/10.3389/fpsyg.2014.00880>
- McCullough, W., & Pitts, W. (1943) A Logical Calculus of Ideas Imminent in Nervous Activity. *Bulletin of Mathematical Biophysics*, 5, 115-133. <https://doi.org/10.1007/BF02478259>
- McFadden J. (2002). The conscious electromagnetic information field theory: the hard problem made easy? *J. Consciousness Stud.* 9 45–60.
- Merzenich, M. M., Nelson, R. J., Stryker, M. S., Cyander, M. S., Schoppmann, A., & Zook, J. M. (1984). Somatosensory Cortical Map Changes Following Digit Amputation in Adult Monkeys. *Journal of Comparative Neurology*, 224, 591-605. <https://doi.org/10.1002/cne.902240408>
- Mesulam, M. M. (1990). Large-Scale Neuro-Cognitive Networks and Distributed Processing for Attention, Language, and Memory. *Annals of Neurology*, 28, 597-613. <https://doi.org/10.1002/ana.410280502>
- Metzinger, T. (2009). *The Ego Tunnel: The Science of the Mind and the Myth of the Self*. New York, NY: Basic Books.

- Miller, G. A. (1956). The Magic Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information. *Psychological Review*, 63, 81-97. <https://doi.org/10.1037/h0043158>
- Milner, A. D. (1995). Cerebral Correlates of Visual Awareness. *Neuropsychologia*, 33, 1117-1130. [https://doi.org/10.1016/0028-3932\(95\)00052-5](https://doi.org/10.1016/0028-3932(95)00052-5)
- Moore, D. R., & King, A. J. (1999). Auditory Perception: The Near and Far of Sound Localization. *Current Biology*, 9, 361-363. [https://doi.org/10.1016/S0960-9822\(99\)80227-9](https://doi.org/10.1016/S0960-9822(99)80227-9)
- Nagel, T. (1974). What Is It like to Be a Bat? *The Philosophical Review*, 83, 435-450. <https://doi.org/10.2307/2183914>
- Natsoulas, T. (1983) Concepts of Consciousness. *Journal of Mind and Behavior*, 4, 13-59.
- Nedergaard, M., Ransom, B., & Goldman, S. A. (2003). New Roles for Astrocytes: Redefining the Functional Architecture of the Brain. *Trends in Neurosciences*, 26, 523-530. <https://doi.org/10.1016/j.tins.2003.08.008>
- Nelson, S. B. (2002). Cortical Microcircuits: Diverse or Canonical. *Neuron*, 36, 19-27. [https://doi.org/10.1016/S0896-6273\(02\)00944-3](https://doi.org/10.1016/S0896-6273(02)00944-3)
- Newman, J., & Baars, B. J. (1993). A Neural Attentional Model for Access to Consciousness: A Global Workspace Perspective. *Concepts in Neuroscience*, 4, 255-290.
- NG, Yew-Kwang (2023). Could artificial intelligence have consciousness? Some perspectives from neurology and parapsychology. *AI & Society*, 38 (1): 425-436. <https://link.springer.com/article/10.1007/s00146-021-01305-x>
- Nielsen, T. A., & Stenstrom, P. (2005). What Are the Memory Sources of Dreaming? *Nature*, 437, 1286-1289. <https://doi.org/10.1038/nature04288>
- Oberly, H. S. (1928). A Comparison of the Spans of Attention and Memory. *American Journal of Psychology*, 40, 295-302. <https://doi.org/10.2307/1414490>
- Page, M. P. A., & Norris, D. (1998). The Primacy Model: A New Model of Immediate Serial Recall. *Psychological Review*, 105, 761-781. <https://doi.org/10.1037/0033-295X.105.4.761-781>
- Parkin, A. J. (1999). Human Memory. *Current Biology*, 9, 582-585. [https://doi.org/10.1016/S0960-9822\(99\)80378-9](https://doi.org/10.1016/S0960-9822(99)80378-9)
- Pascual-Marqui, R. D., Michel, C. M., & Lehmann, D. (1995). Segmentation of Brain Electrical Activity into Microstates: Model Estimation and Validation. *IEEE Transactions on Biomedical Engineering*, 42, 658-665. <https://doi.org/10.1109/10.391164>
- Paoletti P., Ben-Soussan T. D. (2020). Reflections on inner and outer silence and consciousness without contents according to the sphere model of consciousness. *Front. Psychol.* 11:01807. <https://doi.org/10.3389/fpsyg.2020.01807>
- Paulson S., Berlin H. A., Ginot E., Makari G. (2017a). Delving within: the new science of the unconscious. *Ann. N. Y. Acad. Sci.* 1406 12–27. <https://doi.org/10.1111/nyas.13390>
- Paulson S., Hustvedt S., Solms M., Shamdasani S. (2017b). The deeper self: an expanded view of consciousness. *Ann. N. Y. Acad. Sci.* 1406 46–63. <https://doi.org/10.1111/nyas.13403>
- Pepperell R. (2018). Consciousness as a physical process caused by the organization of energy in the brain. *Front. Psychol.* 9:2091. <https://doi.org/10.3389/fpsyg.2018.02091>
- Pockett, S. (1999). Anesthesia and the Electrophysiology of Auditory Consciousness. *Consciousness & Cognition*, 8, 45-61. <https://doi.org/10.1006/ccog.1998.0373>
- Pockett, S. (2004). Does Consciousness Cause Behaviour? *Journal of Consciousness Studies*, 11, 3-4.

- Pockett S. (2013). Field theories of consciousness. *Scholarpedia* 8:4951. [10.4249/scholarpedia.4951](https://doi.org/10.4249/scholarpedia.4951)
- Pollen, D. (1999). On the neural correlates of visual perception. *Cerebral Cortex*, 9, 4-19.
<https://doi.org/10.1093/cercor/9.1.4>
- Pöppel, E., & Logothetis, N. (1986). Neuronal oscillations in the human brain. *Naturwissenschaften*, 73, 267-268.
<https://doi.org/10.1007/BF00367781>
- Posner, M. I. (1994). Attention: The Mechanisms of Consciousness. *Proceedings of the National Academy of Sciences of the USA*, 91, 7398-7403. <https://doi.org/10.1073/pnas.91.16.7398>
- Potter, M. C. (1993). Very Short-Term Conceptual Memory. *Memory & Cognition*, 21, 156-161.
<https://doi.org/10.3758/BF03202727>
- Prinz, J. (2000). A Neurofunctional Theory of Visual Consciousness. *Consciousness and Cognition*, 9, 243-259.
<https://doi.org/10.1006/ccog.2000.0442>
- Ramachandran, V. S. (1998) Consciousness and Body Image: Lessons from Phantom Limbs, Capgras Syndrome and Pain Asymbolia. *Philosophical Transactions of the Royal Society of London B*, 353, 1851-1859.
<https://doi.org/10.1098/rstb.1998.0337>
- Ramachandran, V. S., Rogers-Ramachandran, D., & Cobb, S. (1995) Touching the Phantom Limb. *Nature*, 377, 489-490. <https://doi.org/10.1038/377489a0>
- Ramachandran, V. S., Rogers-Ramachandran, D., & Stewart, M. (1992) Perceptual Correlates of Massive Cortical Reorganization. *Science*, 258, 1159-1160. <https://doi.org/10.1126/science.1439826>
- Ramsey, N. F., Jansma, J. M., Jager, G., Van Raalten, T., & Kahn, R. S. (2004). Neurophysiological Functions in Human Information Processing Capacity. *Brain*, 127, 517-525. <https://doi.org/10.1093/brain/awh060>
- Ransom, B., Behar, T., & Nedergaard, M. (2003). New Roles for Astrocytes (Stars at Last). *Trends in Neurosciences*, 26, 520-522. <https://doi.org/10.1016/j.tins.2003.08.006>
- Raz, A., & Buhle, J. (2006). Typologies of Attentional Networks. *Nature Reviews Neuroscience*, 7, 367-379.
<https://doi.org/10.1038/nrn1903>
- Rees, G., Wojciulik, E., Clarke, K., Husain, M., Frith, C., & Driver, J. (2002). Neural Correlates of Conscious and Unconscious Vision in Parietal Extinction. *Neurocase*, 8, 387-393.
- Revonsuo, A. (2000). Prospects for a Scientific Research Program on Consciousness. In T. Metzinger (Ed.), *Neural Correlates of Consciousness: Empirical and Conceptual Questions* (pp. 57-75). Cambridge, MA: MIT Press.
- Rieke, F., Warland, D., de Ruyter van Steveninck, R., & Bialek, W. (1997). *Spikes: Exploring the Neural Code*. Cambridge, MA: MIT Press.
- Robertson, L. C. (2003). Binding, Spatial Attention and Perceptual Awareness. *Nature Reviews Neuroscience*, 4, 93-102. <https://doi.org/10.1038/nrn1030>
- Rosenthal, D. M. (1986). Two Concepts of Consciousness. *Philosophical Studies*, 49, 329-359.
<https://doi.org/10.1007/BF00355521>
- Rosenthal, D. M. (2002). How Many Kinds of Consciousness? *Consciousness and Cognition*, 11, 653-665.
[https://doi.org/10.1016/S1053-8100\(02\)00017-X](https://doi.org/10.1016/S1053-8100(02)00017-X)
- Roth, G. (2000). The Evolution and Ontogeny of Consciousness. In T. Metzinger (Ed.), *Neural Correlates of*

- Consciousness: Empirical and Conceptual Questions (pp. 77-97). Cambridge, MA: MIT Press.
- Schneider, W., & Shiffrin, R. M. (1977). Controlled and Automatic Human Information Processing: 1. Detection, Search, and Attention. *Psychological Review*, 84, 1-66. <https://doi.org/10.1037/0033-295X.84.1.1>
 - Schwartz, S. (2003). Are Life Episodes Replayed during Dreaming? *Trends in Cognitive Sciences*, 7, 325-327. [https://doi.org/10.1016/S1364-6613\(03\)00162-1](https://doi.org/10.1016/S1364-6613(03)00162-1)
 - Searle J. R. (1998). How to study consciousness scientifically. *Philos. Trans. R. Soc. B* 353 1935–1942. <https://doi.org/10.1098/rstb.1998.0346>
 - Seth, A. K., & Baars, B. J. (2005). Neural Darwinism and Consciousness. *Consciousness and Cognition*, 14, 140-168. <https://doi.org/10.1016/j.concog.2004.08.008>
 - Seth, A. K., Izhkevich, E., Reeke, G. N., & Edelman, G. M. (2006). Theories of Measures of Consciousness: An Extended Framework. *Proceedings of the National Academy of Sciences of the USA*, 103, 10799-10804. <https://doi.org/10.1073/pnas.0604347103>
 - Shastri, L., & Ajjanagadde, V. (1993). From Simple Association to Systematic Reasoning: A Connectionist Representation of Rules, Variables, and Dynamic Bindings Using Temporal Synchrony. *Behavioral and Brain Sciences*, 16, 417-494. <https://doi.org/10.1017/S0140525X00030910>
 - Sheldrake R. (2013). Setting science free from materialism. *Explore (NY)* 9 211–218. <https://doi.org/10.1016/j.explore.2013.04.004>
 - Shiffrin, R. M. (2003). Attention, Automatism, and Consciousness. In B. J. Baars, W. P. Banks, & J. B. Newman (Eds.), *Essential Sources in the Scientific Study of Consciousness* (pp. 631-642). Cambridge, MA: MIT Press.
 - Shiffrin, R. M., & Schneider, W. (1977). Controlled and Automatic Human Information Processing: 2. Perceptual Learning, Automatic Attending, and a General Theory. *Psychological Review*, 84, 127-190. <https://doi.org/10.1037/0033-295X.84.2.127>
 - Silverman, M., & Mack, A. (2006) Priming by Change Blindness: When It Does and Does Not Occur. *Consciousness & Cognition*, 15, 409-422. <https://doi.org/10.1016/j.concog.2005.08.003>
 - Singer, W. (2000). Phenomenal Awareness and Consciousness from a Neurobiological Perspective. In T. Metzinger (Ed.), *Neural Correlates of Consciousness: Empirical and Conceptual Questions* (pp. 121-137). Cambridge, MA: MIT Press.
 - Steriade, M. (1997). Synchronized Activities of Coupled Oscillators in the Cerebral Cortex and Thalamus at Different Levels of Vigilance. *Cerebral Cortex*, 7, 583-604. <https://doi.org/10.1093/cercor/7.6.583>
 - Stockmanns, G., Kochs, E., Nahm, W., Thornton, C., & Kalkmann, C. J. (2000). Automatic Analysis of Auditory Evoked Potentials by Means of Wavelet Analysis. In D. C. Jordan, D. J. A. Vaughan, & D. E. F. Newton (Eds.), *Memory and Awareness in Anaesthesia IV* (pp. 117-131). London: Imperial College Press. https://doi.org/10.1142/9781848160231_0010
 - Taylor, J. G. (2002). Paying Attention to Consciousness. *Trends in Cognitive Sciences*, 6, 206-210. [https://doi.org/10.1016/S1364-6613\(02\)01890-9](https://doi.org/10.1016/S1364-6613(02)01890-9)
 - Thorpe, S. J., & Imbert, M. (1989). Biological Constraints on Connectionist Models. In R. Pfeifer, Z. Schreter, & F. Fogelman-Soulié (Eds.), *Connectionism in Perspective* (pp. 63-92). Amsterdam: Elsevier.

- Thorpe, S., Delorme, A., & Van Rullen, R. (2001). Spike-Based Strategies for Rapid Processing. *Neural Networks*, 14, 715-725. [https://doi.org/10.1016/S0893-6080\(01\)00083-1](https://doi.org/10.1016/S0893-6080(01)00083-1)
- Tononi, G., & Edelman, G. M. (1998). Consciousness and Complexity. *Science*, 282, 1846-1851. <https://doi.org/10.1126/science.282.5395.1846>
- Tononi, G., Sporns, O., & Edelman, G. M. (1992). Re-Entry and the Problem of Integrating Multiple Cortical Areas: Simulation of Dynamic Integration in the Visual System. *Cerebral Cortex*, 2, 310-335. <https://doi.org/10.1093/cercor/2.4.310>
- Treisman, A. (1998). Feature Binding, Attention and Object Perception. *Philosophical Transactions of the Royal Society of London B*, 353, 1295-1306. <https://doi.org/10.1098/rstb.1998.0284>
- Triesch, J., Ballard, D. H., Hayhoe, M. M., & Sullivan, B. T. (2003). What You See Is What You Need. *Journal of Vision*, 3, 86-94. <https://doi.org/10.1167/3.1.9>
- Tsotsos, J. K. (1990). Analyzing Vision at the Complexity Level. *Behavioral and Brain Sciences*, 13, 423-445. <https://doi.org/10.1017/S0140525X00079577>
- Van Rullen, R., & Thorpe, S. J. (2001). Rate Coding versus Temporal Order Coding: What the Retinal Ganglion Cells Tell the Visual Cortex. *Neural Computation*, 13, 1255-1283. <https://doi.org/10.1162/08997660152002852>
- VanRullen, R., & Koch, C. (2003). Is Perception Discrete or Continuous? *Trends in Cognitive Sciences*, 7, 207-213. [https://doi.org/10.1016/S1364-6613\(03\)00095-0](https://doi.org/10.1016/S1364-6613(03)00095-0)
- VanRullen, R., Guyonneau, R., & Thorpe, S. J. (2005). Spike Times Make Sense. *Trends in Neurosciences*, 28, 1-4. <https://doi.org/10.1016/j.tins.2004.10.010>
- Velmans, M. (1991). Is Human Information Processing Conscious? *Behavioral and Brain Sciences*, 14, 651-669. <https://doi.org/10.1017/S0140525X00071776>
- Vogel, E. K., Woodman, G. F., & Luck, S. J. (2001). Storage of Features, Conjunctions, and Objects in Visual Working Memory. *Journal of Experimental Psychology: Human Perception and Performance*, 27, 92-114. <https://doi.org/10.1037/0096-1523.27.1.92>
- Volterra, A., & Meldolesi, J. (2005). Astrocytes, from Brain Glue to Communication Elements: The Revolution Continues. *Nature Reviews Neuroscience*, 6, 626-640. <https://doi.org/10.1038/nrn1722>
- von der Malsburg, C. (1997). The Coherence Definition of Consciousness. In M. Ito, Y. Miyashita, & E. T. Rolls (Eds.), *Cognition, Computation and Consciousness* (pp. 193-204). Oxford: Oxford University Press. <https://doi.org/10.1093/acprof:oso/9780198524144.003.0013>
- von der Malsburg, C. (1999). The What and Why of Binding: The Modeler's Perspective. *Neuron*, 24, 95-104. [https://doi.org/10.1016/S0896-6273\(00\)80825-9](https://doi.org/10.1016/S0896-6273(00)80825-9)
- Wall, J. T., Xu, J., & Wang, X. (2002). Human Brain Plasticity: An Emerging View of the Multiple Substrates and Mechanisms That Cause Cortical Changes and Related Sensory Dysfunction after Injuries of Sensory Inputs from the Body. *Brain Research Reviews*, 39, 181-215. [https://doi.org/10.1016/S0165-0173\(02\)00192-3](https://doi.org/10.1016/S0165-0173(02)00192-3)
- Yamazaki, Y., Hozumi, Y., Kaneko, K., Li, J., Fujii, S., Miyakawa, H., Kudo, Y., & Kato, H. (2005). Direct Evidence for Mutual Interactions between Perineuronal Astrocytes and Interneurons in the CA1 Region of the Rat Hippocampus. *Neuroscience*, 134, 791-802. <https://doi.org/10.1016/j.neuroscience.2005.04.024>

- Zeman, A. (2001). Consciousness. *Brain*, 124, 1263-1289. <https://doi.org/10.1093/brain/124.7.1263>