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Consciousness as the Final Beacon of Humanity

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ABSTRACT

This chapter critically questions the claim that there would be possibility of emulating human consciousness and consciousness-dependent activity by Artificial Intelligence to create conscious artificial systems. The analysis is based on neurophysiological research and theory. In-depth scrutiny of the field and the prospects for converting neuroscience research into the type of algorithmic programs utilized in computer-based AI systems to create artificially conscious machines leads to conclude that such a conversion is unlikely to ever be possible because of the complexity of unconscious and conscious brain processing and their interaction. It is through the latter that the brain opens the doors to consciousness, a property of the human mind that no other living species has developed for reasons that are made clear in this chapter. As a consequence, many of the projected goals of AI will remain forever unrealizable. Although this work does not directly examine the question within a philosophy of mind framework by, for example, discussing why identifying consciousness with the activity of electronic circuits is first and foremost a category mistake in terms of scientific reasoning, the approach offered in the chapter is complementary to this standpoint, and illustrates various aspects of the problem under a monist from-brain-to-mind premise.

Keywords: *Consciousness; Brain; Artificial Consciousness; Human Mind;*

1. 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

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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 and experience-dependent 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 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" [1]. 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" [2]. The astonishing plasticity of the 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. This article discusses previous attempts to "crack the code" to human consciousness under the light of what is known about the neurobiology of conscious behaviour, information processing, and neural theories of biological event coding, learning and memory. The conclusions from this analysis highlight why it is not likely that any machine will ever be able to successfully emulate these neurobiological functions and their interdependency. They are the grounds on which human consciousness has evolved. Essentially, the idea that any machine could ever possess such potential is based on several wrong assumptions about the nature of consciousness, or the processes from which it originates in the brain. One such wrong assumption is reflected in the belief that what we see, do, and decide, and how we learn to communicate and reason explicitly by spoken or written language, provides us with a key to the workings of consciousness.

2. CONSCIOUSNESS IS NOT CONSCIOUS BEHAVIOUR

Approaches where a specific conscious behaviour is considered as an indicator of consciousness [3] traditionally consisted of having human observers perform specific tasks that required focussed attention or selective memory retrieval. Experimental efforts in that direction [4] 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 [5]. Examining the conscious report of a human observer in a

psychological task to find out what consciousness is leads to several critical questions that remain to be answered [6, 7, 8]. Does information that is made accessible to conscious report correspond to present 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 and Koch [9] employed a working model in terms of “subliminal”, “preconscious”, and “conscious perception” which adopts a taxonomy that had been proposed by Kihlstrom [10] twenty years earlier. Crick and Koch [9, 11] subsequently claimed that top-down attentive selection is the key to conscious perception. Subsequently, phenomena such as change blindness [12], 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 [13]. Such belief would then block the attentive selection process that would otherwise enable the new information contained in a new visual scene [14] 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 [15], most have hitherto failed avoiding this trap. Thus, the difficulty of linking conscious behaviour to the mechanisms that generate consciousness is a major limiting factor. Technological progress in the imaging sciences has enabled scientists to visualize which parts of the brain are or are not activated when a human subject is or is not attentively (“consciously”) performing a behavioural task [16]. These new technologies raised high hopes that functional brain imaging correlated with behavioural designs would help to link the mental to the physical [17] and, ultimately, overcome this limiting factor. 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 a localization of 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 human consciousness, or how the brain may be able of producing it. Some observations suggested that conscious activity would correlate with occipital neural activity, while others seemed to point toward a correlation between conscious mental events and late parieto-frontal activity [18, 4]. 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 the functional locus of consciousness in the human brain on the basis of pictures taken from the brain has not happened. As

pointed out already more than a century ago by William James [19], consciousness encompasses far more than being able to effectively attend to, perceive, and describe stimuli. Baars [20, 2, 22] 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 [23] 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, neurobiologists discussed the concept of “Self” in relation with the concept of “consciousness”, 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 [24, 25, 26]. Understanding conscious imagination and creative thinking, or the striking similarities between object descriptions resulting from conscious perception and from pure imagination [27, 28, 29] requires going beyond studying actively and consciously behaving observers. When we dream intensely, we are not attentive to stimuli, but we are phenomenally conscious [30], and sometimes we may be able to access and report these phenomenal data several hours later, when we recount our dreams over breakfast. LaBerge [31] believed that, to the neuronal functions that produce consciousness, dreaming of perceiving and doing is equivalent to perceiving and doing. Thus, in line with Hume’s or Baars’ theatre metaphors, our dreams would be the dressed rehearsals in the theatre of our conscious mind. Such a view is supported by evidence for a functional equivalence of psycho-physiological correlates of consciousness in active wakeful observers and during lucid dreaming, which occurs in REM sleep phases. 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 [31]. Other work on anesthetized patients [32] suggests that different levels of consciousness 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.

3. CONSCIOUSNESS IS NOT REPRESENTED BY A NEURAL FIELD WITHIN THE BRAIN

In the so-called field theories [33, 34], 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 [33, 34, 35, 36, 37, 38, 39, 40]. These will not be reviewed in detail again here, as an excellent review has been provided earlier by Pockett [41] earlier. Libet’s Mind Field Theory of consciousness, carved out in his book *Mind Time* [42], 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 [41, 42, 43] 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 [41] 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 seen as reflecting the very nature of consciousness, occupying a presumed spatio-temporal brain field generating electrical brain states [34], or to the functionally specific spatio-temporal structure of an electromagnetic field in the brain [38, 39, 40] only account for specific aspects of brain-behavior function while humans are in a conscious or non-conscious state. Yet, as already clarified here above, consciousness is a complex product of a long process of brain evolution, at the phylogenic [44] and ontogenic [45, 46] scales. The problem of a scientific account for the origin of mind or, more specifically, the origin of consciousness, has arisen some time ago. Where and how in evolution it has begun to emerge, and how it could be measured scientifically, remains unknown. 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 human *Self* to know and analyze its own condition and existence in space and time, and to project this knowledge into a future that has not yet happened. Why it may not be possible to render the whole complexity of the phenomenon of consciousness scientifically operational has been discussed elsewhere [47, 48,

49, 50]. Ontological links between mind, time, and the *Self* as a window to understanding a specific aspect of human consciousness, which is the ability to project one's own existence into the future, may be brought forward. Finally, none of the field theories of consciousness has succeeded in even providing a definition that would be both scientifically operational and, at the same time, capture the complex nature of this phenomenon. This was already pointed out some time ago [5] as a clear limitation to any theory of consciousness, calling for an abstract solution given that phenomenal consciousness by far exceeds awareness, perception, cognitive accessibility and performance, and any directly measurable brain correlate thereof [5, 49, 50]. What others have referred to as the "hard problem of consciousness" [51, 52] 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). If a representational or neural field of consciousness occupying a presumed space-time continuum inside the brain, or outside the brain, as suggested by Sheldrake [53] among 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 memory recall may be measurably correlated with a specific brain activity [54], interpreted adequately as the neural correlate of the particular conscious behavior, this brain activity is not the neural correlate of consciousness as such.

4. CONSCIOUSNESS IS NOT AWARENESS

Consciousness is a complex product of a long process of brain evolution [44, 45]. Since the theory of evolution was carved out by Darwin [55], 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 [34] groundbreaking experiments 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 [56, 57] 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 [58], linked to the higher level motivated agential involvement of humans [56, 59]. The interaction between aware representations [60], 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 [61, 62]. 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. This raises 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 [46], 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 [49, 50]. Ontological links between mind, time, and the *Self* [63] as a window to understanding specific aspects of consciousness as a unique property of the human mind, which has the ability to project one's own existence into the future, are properties none of the theories of consciousness has succeeded to explain. The so-called "hard problem of consciousness", relating to the difficulty of finding brain measures for a 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 behaviour remains essentially unresolved. As a pragmatic solution, the notion of a conscious state, with an operational approach to the problem of consciousness in terms of information processing, was then proposed and discussed by Tononi and Edelman [64]. Yet again, this framework offers no account for the potential of consciousness as a driving force of human endeavour, with a capacity to project representation onto future possible worlds well beyond what some refer to as the global neuronal workspace of consciousness [65, 66].

5. CONSCIOUSNESS IS NOT CONSCIOUS INFORMATION PROCESSING

The conscious state concept is based on the idea that consciousness would be reflected by conscious information processing capacity. It encompasses what had been proposed earlier by von der Malsburg [67] in terms of a continuous process with a limited duration. The idea, here again, is reductionist. Conscious brain states are neither identical nor reducible to states of awareness or vigilance

[68, 69, 70], nor do they account for the workings of consciousness in the larger sense. While they may involve cognitive processes such as memory [71], attention [72, 73], conscious perception [74], or volition [75, 76], these are correctly conceived as possible expressions of a conscious state, but not to be confounded with the state as such. Rather, a conscious state would correspond to a specific functional state of the brain [77] that enables the experience of phenomenal consciousness. John [36, 37] 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 have suggested approaching consciousness in terms of brain states or conscious states [10, 78]. A generic conscious state appears to have two major functional characteristics: limited information processing capacity [79, 80, 81, 82] and representational content for a limited and relatively short duration [83, 84, 85, 86]. 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 [87, 88, 89, 90, 91, 92, 93]. 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 [94]. Conscious “seriality” undeniably constrains information processing theories of consciousness [95, 96, 97, 98, 99]. Non-conscious activity, on the other hand, is largely based on massively parallel processing and can therefore handle a lot more information [100, 101]. The function of serialization in terms of an ordered list of conscious events [102, 103] 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 [104]. 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 [105, 106, 107, 108]. Such a limitation severely constrains the top-down processes that can effectively operate within the temporal window of a conscious state. 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 suggested by Koch and Crick [109], 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 by Churchland [47] 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. Specific theoretical approaches in terms of neural signal exchanges in the brain as the basis of selective memory processes [110-118] have led to the idea that selective retrieval of temporal activity patterns may be the most parsimonious explanation for conscious brain states. These approaches have promoted the idea that consciousness would be based on the mechanisms and functional properties of working memory, attempting 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 to conceive possible world states. Such is the basis of all human imagination and creativity at the centre of the development of cultures and societies across the ages.

6. CONSCIOUSNESS IS NOT MEMORY

Inspired by some of the experimental data and theories discussed here above, the biological memory models referred to above consist of a working memory architecture with a maximum processing capacity of 7 ± 2 items [110-118]. Each such item is represented by the firing of a cell assembly (the so-called “coding assembly”) during one gamma period [119] (Herrmann, Munk, and 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. Basar [120, 121] considered the cognitive transfer activities to be based on oscillations at specific temporal frequencies [122]. 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 [39, 40], novel EEG studies analyzed and modelled event-specific signal sequences further in that direction. These models highlight what is called “the nested hierarchy” of unconscious and conscious processes, where higher levels are physically composed of lower levels [123-126], 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 [127, 128, 129], the temporal signature of a conscious state would also be linked to its duration, the so-called “psychological moment”, with variations in the limited dynamic range of a few hundreds of milliseconds [130-134]. This estimate was established decades ago on the grounds of a considerable body of psychophysical and neurobiological data [135-145]. Experiments by Libet [42, 43, 44] have 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 [146]. Helekar [147] 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 in the relevant literature [148, 149, 150]. Singer [151] subsequently suggested bin durations of up to, but no longer than 10 milliseconds, given that interspike intervals and integration times of cortical neurons display a similar dynamic range [152]. Under the simple assumption that within each such “bin” there is either a signal or no signal, derived from McCulloch and Pitts’ [153] 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 [147], 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 and McCulloch [154]. 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 [150], 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, as given in [155], which correspond to information contents of 17 to 23 bits. Approaches in terms of dynamic analyses of correlated oscillations in cortical areas at various frequencies [156] and functional interactions between gamma and theta oscillations in different structures of the brain [157] are consistent with these estimates. How such purely temporal functional aspects of an immense variety of neural signals produce a temporal code for conscious state access is discussed in [49]. This can be understood as a result of the properties of reverberant neural circuits in the brain, functionally identified previously in neurobiology [158-163]. The reverberant circuits or loops thus far identified in the brain appear to have their own intrinsic topology [164, 165, 166, 167, 168]. Reverberant neural activity is found in thalamo-cortical [169] and cortico-cortical [170] pathways. Reverberant neural activity as such is a purely temporal process that generates feed-back loops in the brain. These latter are also sometimes referred to in terms of "re-entrant circuits" [171, 172, 173, 174, 175]. Reverberation is an important functional property of the brain because without it, the conscious execution of focussed action would be difficult, if not impossible. Some [4, 13] have argued that conscious perception and conscious 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. From this viewpoint, conscious information processing in the brain would be associated with the parieto-frontal pathways of the brain [176], which are protected from fast fluctuations in sensory signals and would allow information sharing across a broad variety of cognitive processes. While it seems straightforward to agree with the 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 the 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. Work described in [177] 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 suggests is compatible with such a mechanism. Conscious information processing is, in summary, described by brain processes that may correlate with cognitive states or ability. These states, however, do not account for consciousness as such. Similarly, considering intelligent behaviour and capabilities that require flexibility, improvisation, spontaneous problem-solving typically associated with conscious experience [178], does not suffice as an account for consciousness as such.

7. CONSCIOUSNESS IS NOT INTELLIGENCE

Intelligence in its most general definition refers to, as proposed in [179], the ability to learn from experience and to adapt to, select, and design environments. Intelligence is scientifically measured in terms of raw scores in conventional, standardized tests and as such varies across the lifespan and across generations. Measures of intelligence are therefore intrinsically biased. Intelligence can be understood only partly in terms of the biology of the brain—especially with regard to the functioning of the prefrontal cortex. Studies of the effects of genes versus those of the environment (*“nature versus nurture”*) suggest a ratio of genetic to phenotypic variability between .4 and .8, bearing in mind that heritability varies as a function of socioeconomic status and a variety of other factors. Theories of consciousness all too often refer to cognitive faculties such as attention, awareness, and intelligence. Theories solely based on the problem solving capabilities of living brains, placed under the light of the global workspace hypothesis of consciousness proposed in [180] and subsequently adopted by others, do not explain consciousness. Consciousness doubtlessly enables the development of intelligent abilities. Intelligence refers to many such abilities (Figure 1), as others and in particular Gardner [181] have very well explained previously under the light of pertinent categories proposed. Consciousness, on the other hand, under the consensus of the most recent theoretical efforts, would be best described in terms of a continuous stream of mental energy and as the pre-requisite to the further development of intelligent capacity in the human species. This places consciousness as a uniquely human faculty beyond predictable limitations. While self-awareness is part of consciousness, it does not define the latter. In transcendental Buddhism and recent research efforts on mindfulness, deep meditation, or mind-wandering, moments of pure consciousness are often described as states of total selflessness. While intentionality and free will are motors of intelligent behaviour and decision making, they do not account for consciousness either. Some neuroscientists have even argued that free will does not exist, a viewpoint that is claimed to be supported by experiments that seem to have shown that the brain thresholds of conscious decision making are attained in milliseconds and well before the decisions become consciously accessed [182]. This would then imply according to some [92] that consciousness is nothing but an epiphenomenon. These intriguing controversies are rarely discussed in the current literature on the

implications of what some have termed Artificial General Intelligence (AGI). Intelligence relates to cognitive abilities, while consciousness relates to the potential for further development thereof, as a uniquely human source of unlimited creativity and imagination beyond current capacity (intelligence). Finally, another issue that deserves a clear stand when discussing the difference between natural forms of intelligence, human consciousness, and AGI is the so-called category problem. The idea that AI may one day be able to emulate human intelligence and ultimately consciousness stems from an epistemological category error of the first order which consists of assimilating the biological ("natural") brain to an open physical system. This category error is frequently made by physicists and engineers. It constitutes, indeed, the root cause of most of the current confusion about the human brain, intelligence, and AI.

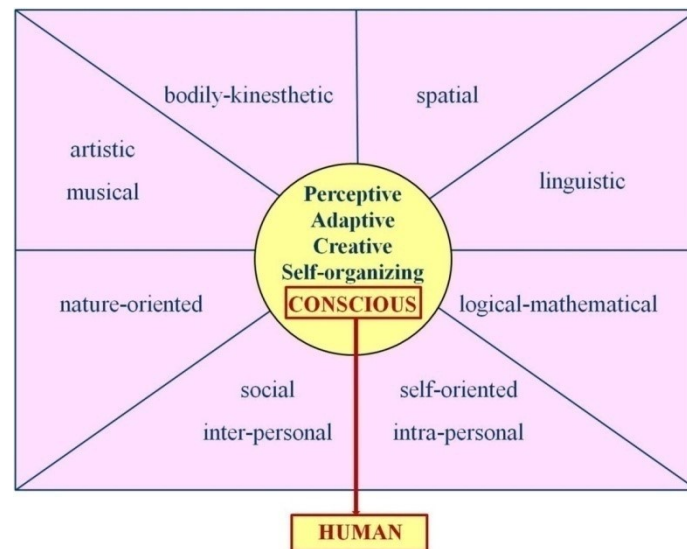


Fig. 1. Intelligence as a multidimensional array of cognitive abilities. Non-human animals may be aware ("sentient") of their immediate environment, but fully conscious perception and creative projection are present in humans only. Some forms of intelligence (spatial, bodily-kinesthetic, social) exist in animal species, to a greater or lesser extent. The further development of intelligence beyond clearly predictable limits, enabled and driven by consciousness, is possible only in humans

8. BRAIN PLASTICITY AND SELF-ORGANIZATION

The human brain is the only system known capable of self-organization, enabled by brain plasticity and from-local-to-global functional neural network architecture [183, 184, 185]. Sensory, somatosensory, and proprioceptive signals may instantly be integrated into the immediate data of unified conscious experience

eliciting what psychophysicists call sensations. The integration of such a variety of signals into brain representations [186, 187, 188] relies largely on non-conscious mechanisms, which have to be sufficiently adaptable [189] 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 [183] 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 [18]. 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 [26, 190, 191] 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 [192]. 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 [193], Ramachandran and his colleagues proposed their “remapping hypothesis” [26, 190, 191]. The latter clarifies how spatial and topological representations are referred to other loci in the brain through massive cortical reorganization. The groundbreaking work by Ramachandran and colleagues 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 [36, 37] 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 [194]. 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 [195]. 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 [159]. 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 [31] that dreams and conscious imagination represent functionally equivalent conscious states. Phase-locking at the critical temporal frequency would be achieved through intra-cortical reverberation in the brain to establish 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 [75].

9. 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 [183]. Subsequently, the theoretical framework of ART was extended to account for learning-related phenomena such as attention, intention, and volition. 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. What is called "the resonant code" is therefore tightly linked to the functional topological organization of these pathways. 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, as suggested in [49]. 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 [196], or how such potential is derived from the brain processes enabling its development.

10. THE NEURAL DOORS TO CONSCIOUSNESS

The functions and abilities discussed here above neither define, nor explain consciousness; any of them may or may not relate to a conscious behaviour or state of the brain. A large amount of cognitive and brain function operates outside awareness and remains inaccessible to consciousness. Yet, consciousness emerges on the basis of brain function; at the same, it is not reducible to any single such function, nor to any sum thereof. The arguments and evidence summarized in the previous paragraphs lead us to consider that 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 inter-connected 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 brain signatures of a conscious brain state 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 events 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 [75]. 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 [197, 198, 199, 200, 201]. 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 proposed in the model by Gutig and Sompolinski [202]. 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 [147] proposed a genetically determined linkage, which appears controversial given that a large body of work had shown that brain processes are highly plastic and experience dependent. Also, linkage of subjective experience to specific temporal brain activities by innate or genetically determined mechanisms leaves the problem of explaining consciousness unresolved. 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. Ultimately, it links to the question at the beginning of the search for a scientific understanding [203, 204, 205, 206] of consciousness: what exactly is phenomenal consciousness? 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 either progressively consolidated or not, following the principles of Hebbian learning. Only once consolidated, the linkage of brain signatures to experience becomes non-arbitrary, or deterministic. This progressive consolidation as a function of context 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 Grossberg's ART.

11. ARTIFICIAL CONSCIOUSNESS, HOW?

The human brain is an astonishing system, with unparalleled functional capabilities. Multiple sensory, somatosensory, and proprioceptive signals are instantly integrated into an individual conscious experience. This integration largely 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 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 [63, 207]. Human consciousness has evolved from the ability to be aware of, to remember, and to predict temporal order and change in nature, which exists already in some animal species. In humans, the limits of this ability are pushed further and determined by the limits in functional plasticity of resonant brain mechanisms. The conscious Self of the individual as a result of non-conscious brain development and individual experience across time and context is the ultimate 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.

12. CONCLUSIONS AND PERSPECTIVES

From the neurobiological perspective it seems extremely unlikely that an artificial consciousness that emulates the properties of human 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. Capacity for consolidation and generalization is enabled in the human brain by complex neurobiological processes that are still not fully understood. Such processes are the ground condition for the development 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 [208], we should ask the question what consciousness is for [209], and why we would want artificial consciousness in the first place. Consciousness, as an ultimate and unique property of the human mind, is the final beacon of humanity in a world where some are dreaming of an AI that can be programmed to "take over". We, as humans designing AI, have the final say. We must either accept a vicious form of panpsychism wherein every open physical system can be phenomenally conscious, or reject the claim for artificial consciousness in computational accounts of phenomenal consciousness [210, 211]. 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. This last stand of human agency 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, we should focus on methods and techniques that expand our own human

consciousness [212, 213], 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 [214]. 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.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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