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Resonating with the World: Thinking Critically about Brain Criticality in Consciousness and Cognition

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Abstract: Aim: Biofields combine many physiological levels, both spatially and temporally. These biofields reflect naturally resonant forms of synaptic energy reflected in growing and spreading waves of brain activity. This study aims to theoretically understand better how resonant continuum waves may be reflective of consciousness, cognition, memory, and thought. Background: The metabolic processes that maintain animal cellular and physiological functions are enhanced by physiological coherence. Internal biological-system coordination and sensitivity to particular stimuli and signal frequencies are two aspects of coherent physiology. There exists significant support for the notion that exogenous biologically and non-biologically generated energy entrains human physiological systems. All living things have resonant frequencies that are either comparable or coherent; therefore, eventually, all species will have a shared resonance. An organism's biofield activity and resonance are what support its life and allow it to react to stimuli. Methods: As the naturally resonant forms of synaptic energy grow and spread waves of brain activity, the temporal and spatial frequency of the waves are effectively regulated by a time delay (T) in inter-layer signals in a layered structure that mimics the structure of the mammalian cortex. From ubiquitous noise, two different types of waves can arise as a function of T. One is coherent, and as T rises, so does its resonant spatial frequency. Results: Continued growth eventually causes both the wavelength and the temporal frequency to abruptly increase. Two waves expand simultaneously and randomly interfere in an area of T values as a result. Conclusion: We suggest that because of this extraordinary dualism, which has its roots in the phase relationships of amplified waves, coherent waves are essential for memory retrieval, whereas random waves represent original cognition.

Keywords: resonance; brain; consciousness; criticality; entrainment; continuum theory; biofield

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1. Introduction

1.1. Resonating with the World

The present study aims to integrate consciousness and cognition as a function of resonance, defined as an effect that is amplified when two systems are in harmony. A tuning fork set to 440 Hz, or tuned to concert pitch "A", as is currently done in symphony orchestras, would have a second fork vibrate in sympathy with or in phase with it if one were to tap it. If we were to silence the first tuning fork, we would still be able to hear the vibrations coming from the fork that we did not touch. We might say that the second fork is experiencing an induced sympathetic resonant vibration or frequency. Both forks are tuned to the exact same frequency. We are aware of instances where people have broken glass with just their voices. Whoever wants to try it should lightly tap the glass with a nail or finger and then listen for the glass's natural resonance or pitch. The next step would be to sing a long note in the person's voice. Until the glass is broken, the vibration's amplitude will increase steadily. Alternatively, a suspension bridge In Tacoma, Washington, built with steel and concrete, fell in 1940. On November 1 of that year, the bridge experienced a modest, seemingly negligible vibration along with a constant wind of about 45 mph. Unfortunately, some areas of the bridge's resonant frequency coincided with the vibration's frequency. The vibration increased until it reached a destructive resonance frequency, which caused the bridge to collapse. There is a video of the event available [1].

A big steel and concrete bridge was demolished by resonance in one instance, while a glass was broken in another. In light of this, we may destroy a minuscule object, perhaps a living bacterium. We might be able to modify the biological liquid crystal using a unique electronic signal, but this would require a device of some sort. A tool designed to cause a resonant vibration in a cell or other living entity was patented by James Bare [2–4]. For instance, a 100 Hz input would cause the resonating cell to output 100 pulses per second, similarly for 200 Hz, and so forth. Once the matching frequency is found that will entrain with the input frequency, we can start looking for the "magic frequency" 1 Hz at a time. One high and one low input frequency are required, with the higher frequency being 11 times greater than the lower or the 11th harmonic [5], where microorganisms start to break apart. The application matters a lot. Cancer cells of a certain type are sensitive to frequencies between 100,000 and 300,000 Hz [6,7].

We have long wondered how a biologically based machine could be built with billions of neurons that could outperform several of the most sophisticated computers. The brain has significant processing capability and nearly infinitely expandable storage [8–10]. The idea that the brain may tune itself to a level where it can be excitable without disorder in a manner analogous to a phase transition has recently been supported. Our neurological systems have a propensity to maintain a balance between rest and chaos. Information processing is optimized when there is a state of flux between quiescence and chaos [11]. This brings up the notion of criticality in the context of the resonance of living entities.

1.2. Schumann Resonance and Living

The "Schumann Resonance", often referred to as the "Earth's heartbeat" Refs. [12–14], is a naturally occurring electromagnetic resonance frequency in the Earth's electromagnetic field. Winfried Otto Schumann predicted it mathematically in 1952. The Schumann Resonance occurs due to the space between the Earth's surface and the ionosphere acting as a resonant cavity for electromagnetic waves.

The primary frequency of the Schumann Resonance is around 7.83 Hz Ref. [12], though it can vary slightly. It is influenced by various factors such as solar activity, lightning activity, and ionospheric conditions. Some people believe that these resonances can have effects on human health and consciousness, although scientific research in this area is ongoing and often controversial [12,13]. Some propose that these resonances may have an impact on our circadian rhythms [15] and overall well-being [13], but conclusive evidence is still lacking here as well.

The idea of resonance in relation to consciousness often refers to theories proposing that certain frequencies or patterns of electromagnetic activity in the brain might correlate with particular states of consciousness. For instance, some research suggests that brain wave frequencies, such as those associated with alpha, beta, delta, and theta waves, may correspond to different cognitive states, such as relaxation, alertness, deep sleep, or meditative states [16].

Some proponents of consciousness theories suggest that external electromagnetic fields, including the Schumann Resonance or other natural and artificial electromagnetic fields, could potentially influence or resonate with the brain's electromagnetic activity, leading to alterations in consciousness or cognitive states [17,18]. However, it is important to note that these ideas often remain speculative and are subject to ongoing scientific investigation and debate.

While there is interest in exploring the potential links between electromagnetic phenomena and consciousness, conclusive evidence for direct causation or significant influence remains elusive. Further interdisciplinary research involving neuroscience, physics, and psychology is needed to better understand the complex relationship between electromagnetic fields and consciousness. We will, however, attempt to integrate what is known about resonance related to both consciousness and cognition.

1.3. Resonance in Cognitive–Motor Interaction

Resonance in human motor function refers to the synchronization or amplification of movement patterns in response to external stimuli or internal processes. This concept is often studied in the context of biomechanics, neuroscience, and motor control to understand how the nervous system coordinates and modulates movements.

One example of resonance in motor function is the phenomenon of entrainment, where rhythmic external stimuli, such as music or a metronome, can synchronize and influence the timing and rhythm of movements. This is commonly observed in activities like dancing, where individuals coordinate their movements to the beat of the music.

Internal processes, such as emotions or intentions, can also influence motor resonance. For instance, when observing someone performing a specific action, mirror neurons in the observer's brain may fire, leading to a mirroring or resonance of the observed movement within the observer's own motor system. This phenomenon is thought to play a role in empathy, imitation, and social interaction.

Resonance can also occur within the motor system itself. When certain movement patterns or muscles are activated, there can be a tendency for nearby muscles or movement patterns to resonate or become activated as well. This can be advantageous for efficiency in movement execution but can also contribute to unintended movements or muscle co-activation in some cases.

Overall, resonance in human motor function involves the synchronization, amplification, or modulation of movement patterns in response to various internal and external factors. Understanding these mechanisms is crucial for optimizing movement control, rehabilitation strategies, and enhancing motor performance, but most importantly for cognitive function [19].

1.4. Criticality and Consciousness

The relationship between criticality and consciousness is a complex and multifaceted topic that spans various disciplines, including philosophy, psychology, neuroscience, and even physics. Briefly, *criticality* in physics refers to the point at which a system undergoes a phase transition, exhibiting properties that are neither completely ordered nor completely disordered. Criticality often refers to a state of a system where it operates at a point of instability or sensitivity, often at the boundary between order and chaos. Systems at criticality often display scale invariance, where patterns repeat across different scales. In neuroscience, criticality is a concept that describes the state of neuronal networks when they are balanced between order and disorder. It suggests that the brain operates most efficiently by optimizing information processing and is most adaptable when it is in a state of criticality.

In bringing these two concepts together, one area of interest is in exploring whether criticality in neural networks is somehow related to or necessary for consciousness. Some researchers hypothesize that consciousness may emerge from the dynamic patterns of neural activity that occur at the critical point [20]. In this view, criticality could be a fundamental property of neural systems that gives rise to conscious experience. However, this is still a highly debated and speculative area of research.

Furthermore, criticality and consciousness intersect in discussions about the nature of complex systems, emergence, and the relationship between physical processes and subjective experience. Understanding how criticality in neural networks or other complex systems might contribute to or correlate with consciousness could potentially shed light on the mysteries of the mind. However, it is essential to approach these topics with caution and rigorous scientific inquiry due to their complexity and the many unanswered questions surrounding them.

The relationship between criticality and consciousness lies in the idea that the brain, as a complex system, may operate near criticality to facilitate flexible and adaptive cognitive processes, including those associated with consciousness. Some researchers [21] propose that critical brain dynamics may be necessary for the emergence of conscious experiences, as they allow for the integration of information across different brain regions and the generation of complex patterns of activity.

However, the precise mechanisms by which criticality and consciousness are related are still not fully understood and remain the subject of ongoing research and debate. It is an exciting area of inquiry that continues to push the boundaries of our understanding of the brain and the mind.

1.5. Criticality in Consciousness and Cognition

Consciousness and cognition are fascinating aspects of human existence that ought to be broken down. Consciousness, for our purposes, refers to the subjective awareness of ourselves and the world around us [22]. It involves our thoughts, perceptions, feelings, and experiences. Consciousness refers to the state or quality of being aware of and able to perceive one's surroundings. It involves a range of cognitive processes, including attention, perception, memory, and self-awareness. Despite decades of research, the nature of consciousness remains one of the most challenging problems in science and philosophy. There are various theories about consciousness, including the integrated information theory [16], the global workspace theory [16], and panpsychism [16], each offering different perspectives on how consciousness arises and functions. A more in-depth discussion is beyond the scope of the present paper.

Consciousness is often described as the "hard problem" in philosophy because it is challenging to understand how subjective experiences arise from physical processes in the brain. *Cognition* refers to the mental processes involved in acquiring, processing, storing, and using information. It encompasses a wide range of mental activities, including perception, attention, memory, language, reasoning, and problem solving.

These two concepts are deeply intertwined. Consciousness is closely related to cognition because our conscious experiences are shaped by our cognitive processes, and vice versa. For example, our perception of the world around us is influenced by our cognitive abilities to interpret sensory information, and our conscious thoughts can influence our cognitive processes like attention and memory. Researchers in neuroscience, psychology, philosophy, and other fields continue to explore the relationship between consciousness and cognition, seeking to understand how they interact and how they emerge from the underlying biological mechanisms of the brain.

Criticality in cognition and consciousness refers to the idea that these processes exhibit a state of dynamic balance between order and chaos, where they operate at an optimal point between too much rigidity and too much randomness.

In cognitive science, criticality suggests that the brain operates near a phase transition point where it can quickly adapt to changing circumstances and efficiently process information. This state is often associated with complex behaviors, learning, and creativity. It is like the brain is finely tuned to the edge of chaos, where it can both maintain stability and exhibit flexibility.

Similarly, in consciousness studies, criticality implies that consciousness emerges from the collective activity of neurons operating at this critical state. This perspective suggests that consciousness is not a binary phenomenon but rather a continuous spectrum that emerges from complex interactions within the brain.

Understanding criticality in cognition and consciousness is crucial for unraveling the mysteries of how our minds work and how consciousness arises from neural processes. It provides insights into phenomena such as learning, memory, decision making, and even disorders like epilepsy or schizophrenia, where deviations from criticality may occur.

2. Resonating with the Brain in Consciousness and Cognition

2.1. Thinking Critically about Brain Criticality in the Context of Resonance

Complex systems that are on the verge of a phase change between randomness and order are said to be in a critical state. There is a unique improvement in information-processing abilities in this kind of system, and we might even speculate that the brain may play a key role in it. Criticality, computation, and cognitive processes are beginning to show linkages. We can better grasp the nature of cognition and neural processing by comprehending the concept of criticality.

Neurons that fire simultaneously link together, according to Hebb [23]. We now understand that neurons seek a key set point and regime when they functionally join with others [11]. Ma and colleagues have backed the idea that criticality is subject to active regulation. Criticality is mediated by inhibitory neurons in both Ma and colleagues' models and in our own [24–26]. Larger brain networks seem to be regulated by these neurons. According to Koch and Leisman [25], the function of criticality is to develop a computational model that may be used to optimize information processing, including the storing and transmission of intricate sensory patterns and parts of memory.

Power laws serve as the foundation for the majority of measurements in clinical neurophysiology and psychophysics. These power laws are used to separate background activity from noise using a variety of methodologies, such as the Fast Fourier Transform, signal averaging techniques, coherence, dipole source localization, and Hilbert–Huang transforms, among others. The exponent relation is a good substitute for direct use in information processing. We might want to look into biofield physiology as a way of explaining the process of living to better comprehend the relationship between criticality, resonance, consciousness, "awakeness", awareness, and integrated brain function.

2.2. Critical Biofield Systems and Information

Biological systems generate a variety of fields that are only partially diffused so that they can more effectively self-regulate and organize their physiology. This is done to make physiological organization more efficient. Alterations to physiological regulatory systems can be brought about by biofields in a manner that is comparable to alterations brought about by molecular control systems. Electroencephalograms (EEGs) and magnetoencephalograms (MEGs) are two examples of the types of biofields that can cause changes in the synchronization of the brain's electrical activity (EEG).

It has been demonstrated that biofields are made up of forces that are dispersed across a broad region and can encode information [27,28]. These pressures, which also affect physiology, can control and affect the physiology of tissues and cells. As a complementary function of physiological coherence for metabolic processes, biofields coordinate the integration of several different levels of physiological activity, both temporally and spatially [29]. This is done as a result of a biofield's ability to maintain physiological coherence. When referring to the qualities that constitute a living creature, the terms "biofield activity" and "resonance" can be used interchangeably in this context because they mean the same thing.

Analyzing the functional connection while at rest using MRI helps us understand the brain's functioning architecture better. The technique depends on slow correlations in the blood oxygen level-dependent signal (BOLD) (e.g., 0.01–0.1 Hz) in the brain. These gradual correlation patterns have been utilized to identify functional networks and to explain how they grow, alter with age, differ between people, and get disrupted in disease [30–36]. Though the fundamental mechanisms remain unclear, it is thought that delayed BOLD fluctuations and their associations represent brain processes [37,38].

Two distinct types of often-seen dynamics in the brain may be related to two separate underlying systems or processes. The pacemaker may affect dynamics that show a narrow band-limited power [39]. For example, the dominant occipitally recorded EEG alpha rhythm during restful wakefulness may be generated by an alpha pacemaker. A particular subset of thalamocortical neurons with inherent rhythmic bursting at alpha frequencies and gap junction couplings make up alpha pacemakers [40]. Even though this model of oscillating resting-state activity is well supported, e.g., [39,41], the most commonly recognized hypothesis in the field holds that brain activity propagates within an anatomically limited small-world network to produce correlations [42,43]. Scale-free dynamics, or 1/f dynamics, are predicted by this model [44–46]. Large events are rare, whereas little events are frequent in 1/f dynamics because of the inverse relationship between event amplitude and frequency. More specifically, as frequency is increased, even by a small exponent, power can change inversely ($P \propto 1/f^{\beta}$, with exponents ranging from 0 to 3) [47]. Though they can also happen in other noncritical systems, complex dynamic systems possess 1/f dynamics when operating at a critical point, when ordered and disordered phases of the system are balanced [48,49]. The 1/f features of many neural signals, including local field potentials, have supported the development of brain activity models critically operating by self-organizing properties [50–52].

A high level of sensitivity to particular stimuli, and by extension, particular signal frequencies, is necessary for coherent physiology. This sensitivity is required, among other things, for the effective coordination and integration of internal biological systems. Coherent physiology requires not just the efficient coordination and integration of the body's internal biological systems, but also a significant sensitivity to particular stimuli and, as a result of this, particular signal frequencies. Exogenous energy that is generated either biologically or non-biologically appears to be vulnerable to and entrains human physiological systems, according to a significant body of research in this area. During physiological activity, it is possible to collect measurements of electrical and magnetic fields; however, this may lead to confusion, since metabolic processes or the outcomes of physiological action are not completely known [30,31].

It is recognized that there will eventually be shared resonance, both within and between individual species, because all living things resonate at comparable or coherent frequencies. In the neurosciences, resonance theory has long been noted. Crick and Koch [32], Fries [33,34], and Koch [35] have studied the concept of resonance. According to Fries, a critical component of the nervous system's operation is brain synchronization, resonance, or "communication through coherence".

2.3. Consciousness as a Function of Resonance

Resonance is thought by many theorists to contribute to conscious states. According to Dehaene's global workspace theory, integrated conscious activity is the outcome of long-distance connections between synchronous and resonant cortical areas [35,36]. By claiming that while consciousness, which is associated with being awake and aware, is a function of resonance, it is not always a property of all resonant states, Grossberg [37] extended the idea of brain-communication-based resonance. Phase changes in resonance were also considered vital for understanding brain function by Freeman and Vitiello [38]. When Pockett proposed an electromagnetic field theory based on the synchronization from movement feedback when differentiating between conscious and non-conscious fields, she raised the significance of resonance in understanding integrated brain activity [39,40]. Others have developed further resonance-based theories of brain integration, such as Bandyopadhyay and colleagues' [41] Fractal Information Theory [42–44]. As a result, albeit still in theory and without practical application, resonance's importance in comprehending brain communication systems has begun to gain some traction.

The concept of resonance is intimately connected to awareness, inter-regional connections or disconnections in the brain, and its integrative function. It can be used to describe synchrony, vibration, or harmony more broadly. Similar resonance patterns can be found in the brain's synchronized electrical cycles. Resonance's significance in fostering integrated brain activity must also be properly understood in the context of death.

3. Resonating with Life (and Death): Gaps in Current Understanding

One of the numerous hypotheses that try to explain life and living is the assumption that life function comes from organized computer-like activity in the brain's neural networks that are connected with mental states. Another notion is that the temporal binding of information in these networks is associated with synchronous oscillations between the cortex and thalamus. How we consciously think may be impacted by the complexity of neural computing.

Death itself is not noteworthy until a clinical definition is required. However, it is more important to comprehend the mechanisms at play during a lack of consciousness. Although death seems to us to be a real event and an undeniable state, a corpse, whether human or otherwise, continues its life functions even after it has been proven to be dead. There is minimal disagreement that the person is dead despite a few isolated cells, nests, or cell subnetworks that continue to function.

As we continue, the argument becomes more challenging, since, despite the brain having "died", peripheral bodily organs like the heart, lungs, liver, and others still function due to modern developments. In the past, we had thought that the body perished when the entire brain expired, and consequently, physical functions ceased. Nevertheless, the development of modern technology has made it difficult for us to determine the precise moment of death. The constituent components of conscious or micro-conscious entities need to combine to provide us with the vividness of the conscious experience, bringing us to the combination problem.

3.1. The Combination Problem in General Resonance Theory

Can components of lower-level micro-consciousness join together to produce higher-level macro-consciousnesses? According to the suggested explanation, distinct brain regions may undergo bandwidth phase shifts and changes in the speed of information transmission between regions through common resonance in the context of mammalian consciousness. More complicated variations of consciousness may form as a result of this phase transition, and the nature and content of those varieties will rely on the specific combination of component neurons that are present at any one time. To distinguish this perspective from emergent materialism, we can provide a more thorough understanding of the comparative development and categorization of consciousness and propose that in all physical processes, awareness appears as a continuum of increasing richness. This can be referred to as a metasynthesis, and it is also known as general resonance theory.

3.2. Everything Has a Unique Resonance

Everything in the universe is always changing and evolving. Certain frequencies cause even seemingly immovable things to vibrate, oscillate, or resonate. As a result, everything is genuinely oscillating, and coordinated oscillation between two states is what defines resonance. Different oscillating processes often start vibrating at the same frequency when their frequencies are close enough [45]. Sometimes they "sync" in unexpected ways that accelerate and enrich the flow of energy and information. By examining this occurrence, significant insights into the nature of consciousness—both to humans and other mammals, and on a more basic level—may be gained. Using a range of resonant examples from biology, physics, chemistry, and neuroscience, the authors of [35] aimed at describing the nature of synchrony in the experience of consciousness, and have included certain species of fireflies that start to flash their bioluminescent parts in unison when they are in large groups. Mammalian awareness and the ability of human brains to fire large numbers of neurons at specific frequencies are believed to be closely related to various forms of neural synchronization [32–36]. We always see the same face of the moon because its spin precisely matches its orbit around the planet. When photons with the same frequency and power are discharged simultaneously, a laser is produced. At this point, it can be helpful to consider how resonance and synchrony differ concerning our inquiries.

3.3. What Is Resonance and Synchrony?

Resonance or synchronization is the propensity for several processes to move in unison, or oscillate, at the same or at a similar frequency. Synchrony, also known as the harmonic oscillator theory or complex network theory, is the study of how connected oscillators behave around one another.

The following two queries are raised by numerous instances of resonance: how do the constituent elements of resonant structures—a phrase that refers to any grouping of resonating components—interact with one another, and, once achieved, how do they reach resonance? Examining each question individually, we need to pay close attention to the two examples above by examining (1) the significant neural synchronization in mammalian brains and (2) the synchronization of flashes in fireflies.

The sort of communication between each resonant structure will vary depending on the scenario being studied, and in many resonance cases, clear conclusions are difficult to derive. Each firefly has access to visual signals, but it is also likely that it has access to olfactory, chemical, and perhaps electrical or magnetic stimuli. One of the two examples of intricate resonant structures we can utilize is fireflies. Based on empirical studies, it seems that a key factor in how firefly populations coordinate the synchronization of their bioluminescent flashing is through visual perception [45].

It is less clear how each neuron communicates with the others when neuronal synchronization occurs in the brain. Neural synchronization that happens too quickly, relying solely on electrochemical neuronal communication, is known as electrical field gamma synchrony; it requires electrical field signaling, according to Freeman's studies of the brains of rabbits and cats. As noted by Freeman and Vitiello [38], the beta and gamma bands of carrier waves often re-synchronize over large distances in minuscule time lags, according to high-temporal-resolution EEG readings, providing evidence for a variety of intermittent spatial patterns. Axodendritic synaptic transmission, the predominant mechanism for brain interactions, should cause the EEG oscillations to experience distance-dependent delays because of successive synaptic delays and restricted propagation velocities. The coherence of global brain gamma "synchrony" cannot be adequately explained by gap junction coupling alone, according to Craddock et al. [46]. However, what is currently known suggests strongly that shared resonance plays a critical role in the development of mammalian consciousness, including human consciousness.

3.4. How Is Shared Resonance Attained in Resonating Structures?

How do entities that are in communication with one another through resonance modify their resonance frequencies to reach resonance with one another? In many circumstances, entities that are initially unsynchronized manage to become entrained. What driving forces are behind these processes?

We may compare the mechanisms that enable firefly synchrony to conscious human activities in terms of how fireflies time their flashes. For instance, our brains send a series of neuronal pulses to our fingers when we wish to lift them, causing the desired action. Similar to fireflies, it is conceivable that when a fly decides to flash its lights, its brain sends an electrical pulse to its abdomen. At that point, there are chemical and physiological mechanisms supporting the fly's bioluminescence.

It might seem unusual to attribute intent to fireflies. Nonetheless, it would make sense that fireflies would be aware of and able to intentionally manage their physiological functions, especially those associated with large organs such as their light-producing organ. Their actions are intricate and show a variety of "behavioral correlates of consciousness". By comparing the different neurological and behavioral similarities between humans and other mammals, we may recognize that fireflies probably only have a basic level of conscious awareness without implying that they have anything close to the depth of human consciousness.

Based on the supposition that fireflies possess a primitive kind of consciousness, compared to human consciousness, we may provide a high-level explanation for how their flashes are synchronized without considering the intricacies of sub-level mechanisms. This makes an explanation relatively simple: the body obeys the will of the brain, in the same way that any conscious activity in a person, dog, cat, etc. would be explained. However, the synchronized flashing of fireflies without intellect or consciousness can also be explained. Strogatz and his colleagues proposed that firefly synchrony can be explained by intrinsic biological oscillators that naturally synchronize with nearby additional oscillators [45].

It would be difficult to argue that individual neurons want to be in synchrony, but there is evidence for some form of neuronal consciousness, however basic in comparison to whole-brain consciousness. How is it that neurons synchronize swiftly and regularly? Although numerous indications point to different kinds of field effects, these are still unknown. How this communication occurs in each neuron, allowing them to quickly adjust their electrical cycles to meet rapidly changing macroscopic patterns, is still unknown.

Keppler [47] focused on phase changes observed in mammalian brains and the general "criticality" in which these brains appear to be, meaning that they are very sensitive to even minute changes. It is possible to think of the brain mechanisms underlying conscious activities as a complicated system that functions close to a key point of a phase transition. With appropriate stimulation, the brain can transition from a disordered phase with irregular dynamics and spontaneous activity to an ordered phase with long-range connectivities and stable attractors.

The idea of a "phase transition" could be significant when thinking about the combination problem and macro-consciousness. Phase transitions include the freezing of water into ice and the condensation of water vapor into droplets. Similar to brain states, neural states can oscillate in reaction to seemingly unimportant inputs. Dehaene [36] provides evidence in favor of the theory that mammalian consciousness depends on phase transitions.

Fries describes a trio of the cognitive frequencies of specific electrical brain wave combinations [33,34]. He notes that gamma-band synchronization carries out the attended stimuli's selective communication, beta-band synchronization mediates top-down attentional influences, and a 4 Hz theta rhythm resets the gamma band regularly. Because nature is made up of numerous lawful processes, each will resonate at different frequencies. Additionally, processes that are close to one another may eventually synchronize and resonate at the same frequency.

4. Criticality of Resonating Consciousness

4.1. Interaction of Physical Systems and Consciousness

Hunt [48] and Schooler and associates [49] proposed a set of psychophysical ideas that would clarify how consciousness and physical systems interact. They elaborate on why it is that resonance is essential for establishing macro-scale awareness by combining several micro-conscious entities at different organizational levels.

Without subscribing to panpsychism or panexperientialism [50–53], we can state that connected consciousness is significantly primitive in the vast bulk of matter, with maybe only an electron's or an atom's primitive humming of awareness. However, in certain kinds of groupings of matter, as in sophisticated biological life forms, awareness can grow notably richer in comparison to the bulk of matter [54,55].

All objects could be considered to be at least somewhat conscious based on the observable behavior of electrons, atoms, molecules, bacteria, paramecia, mice, bats, and rats. An emergentist perspective contends that consciousness appeared where it had not before existed and arose at a specific period in the history of each species that experiences consciousness. Panpsychism is the opposing position to this theory.

Panpsychism contends that rather than emerging, matter and the mind have always been connected, and vice versa (these two sides of the same coin are equally significant). However, the mind, which is constantly connected to all matter, is typically quite primitive. Only a very small amount of consciousness exists within an electron or an atom. But as matter becomes more complex, so too does the mind, and vice versa. Nevertheless, in this situation, complexity does not matter. Instead, it is the result of stronger internal and external connections that resonate. A mathematical version of the concept was developed by Hunt [50,54], emphasizing how resonant connections result in larger-scale consciously aware beings and how relevant characteristics may be characterized and measured.

Although we will not go into great detail here, (see [48,50,52,55], supported by others [49,51,53]), according to Tononi and Koch [53], within the context of the integrated information theory, elementary particles are either charged or not. As a result, a proton has one positive charge, an electron has one negative charge, and a photon, which is a carrier of light, has no charge at all. According to Tononi and Koch, charge is a feature that these particles have. A charge is just present in uncharged materials; it does not arise from them. They reason that consciousness is no different. Matter is arranged to give rise to consciousness. It is ingrained in the system's architecture. It is a characteristic of complicated things that cannot be boiled down to the operations of more basic attributes.

When two entities resonate at the same frequency, they bond or join together in a variety of ways. Such common resonance and binding may sometimes lead to the blending of different characteristics of cognitive, perceptual, and motor elements into a more cohesive whole, depending on the entities under discussion [9]. According to the quantum field theory, at the most basic level, matter is more akin to a standing wave of concentrated energy. Each of these waves is regional in both distribution (spatially) and time (temporally).

Since matter is fundamentally wave-like, it is easy to understand how information transference, and ultimately the emergence of macro-conscious forms, are associated with shared resonance. All physical processes are fueled by waves of various kinds, at least partially. Waves collaborate instead of competing when multiple entities resonate at the same frequency. This leads to significantly faster energy and information transfers between the components of whatever resonant structure we are observing, as well as a much wider bandwidth. Subsequently, the information flows merge into a larger harmonic, and the resonant wave shapes of the micro-conscious organism become coherent rather than occurring out of phase (decoherently).

Furthermore, Christof Koch [35] suggested that feedback pathways may play a crucial role in producing a type of standing wave or resonance in the brain network if the information is amplified and sustained in the brain by top-down attention. Beyond the degree of synchronization generated by sensory input alone, neurons can coordinate their spiking activity if they receive more local and widespread feedback. This amplifies their postsynaptic impact in comparison to when they activate independently. On this basis, a significant network of neurons may be developed that is capable of exerting an impact throughout the cortex and between lower brain structures. This would be the slow mode upon which conscious awareness rests, according to Koch.

Expanding on Koch's theories, Fries [33,34] proposed a "communication through coherence" theory. Fries [34] offered the following example of shared resonance concerning neural resonance/coherence: Inputs happen at various times during the excitability cycle due to a lack of coherence, and their effective connection will be consequently reduced. Nonetheless, inputs will spread faster and over a wider bandwidth if they fall within the same excitability cycle.

Through a variety of biophysical information pathways, organisms gain from faster information sharing. More macro-scale levels of consciousness can emerge thanks to these speedier and richer information flows than would be feasible in similar-scale structures like sand heaps or rocks because biological structures are more active and more interconnected than rocks or sand. However, the kind of interconnectivity that is required has to be predicated on resonance processes, which usually cause a phase shift in the information flow rate as a result of the conversion of incoherent structures into coherent ones.

We know that gamma synchrony being a main neurological correlate of consciousness in human brains is a notion supported by Dehaene [36]. He was particularly interested in certain "signatures of consciousness", such as late-onset gamma synchrony [56]. However, a combination of gamma and lower harmonic frequencies is frequently linked to mammalian consciousness [34]. This common resonance creates an electromagnetic field that, through certain neuronal electrochemical firing patterns, might act as the source of macro-conscious information [39,57–60]. Gamma synchrony is used as an example of how more neurons get incorporated into the common gamma synchrony, which Hameroff [56] refers to as "the conscious pilot". This is backed up by other slower-frequency waves [34]. However, when the shared gamma synchrony recedes from specific neurons, it allows those neurons to return to their previous resonance state, resulting in a more localized pattern.

To entrain additional neurons, this moving large-scale wave absorbs them into a semi-stable gamma wave pattern. This allows the pace of information interchange to shift from being mostly electrochemical to electromagnetic and allows the capacity for information processing of the several micro-conscious entities made up by those neuron clusters to be combined into a macro-conscious entity. The larger harmonic is entrained with the smaller-scale harmonics through this process; hence, all of the constituents' "windows" are opened to one another, facilitating more fluid information transmission. The pace of change of macro-consciousness is precisely the same as that of its constituent neurons and associated fields. Figure 1 shows an example of such a procedure.

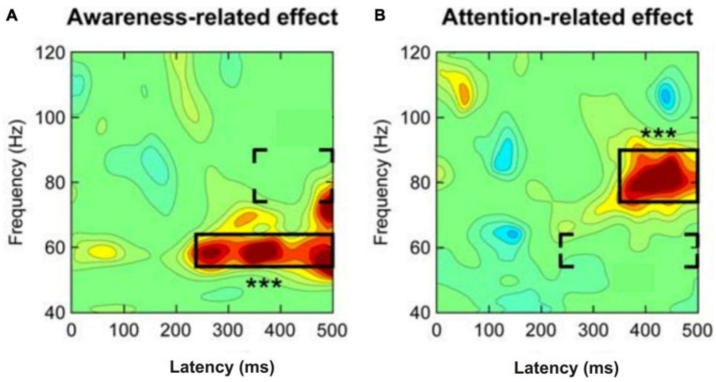


Figure 1. Division of human gamma-band activity in response to a mild visual stimulus into components associated with awareness (**A**) and attention (**B**). When attention is focused on the stimuli, there is strong gamma-band activity 200–250 ms after the stimulus initially appears. This is noteworthy because gamma-band activity associated with putative stimulus awareness started 350 ms post stimulus onset, and this was followed by gamma activity in a higher-frequency zone associated with stimulus-driven selective attention. Given this, while it may not be a reliable indicator of conscious experience, the probability of being aware of the stimuli appears to be correlated with local gamma-band activity in sensory cortical areas starting 200–250 ms after stimulus initiation. Regardless of whether the stimulus was attended to or not, it evoked mid-frequency activity in the gamma range (between 54 and 64 Hz) with a latency of approximately 240 milliseconds post stimulus (left panel). A 350 ms lag was seen in high-frequency gamma-band activity (approximately 76–90 Hz) if spatial (selective) attention was directed toward the stimulus (right panel). The three stars in each panel stand for the effects in the framed regions that are of utmost importance. Either the awareness effects in the regions included in brackets receive attention-related effects, or the awareness effects in the left panel receive attention-related effects (right panel). [Modified from Wyart and Tallon-Baudry [61]; Figure 3C is theirs].

Whitehead [62] indicated that the many become one and are augmented by one. In other words, lower-level entities are employed to create a new, higher-level entity; however, the lower-level entities are not eliminated during the binding process. Rather, they are bound into the new entity, hence increasing the number of entities by one. The many increase one by one until they achieve unity. Numerous subsidiary micro-conscious entities are included when the "conscious pilot" circumnavigates the brain; these numerous aspects of consciousness merge into a single dominating consciousness, leaving the subsidiary consciousnesses alone.

4.2. Connecting Biofield Resonance and Consciousness

Numerous natural phenomena, especially biological ones, appear to critically exist on the cusp of order and chaos [63–67]. It has been demonstrated that criticality-tuned models display brain-like dynamics [68,69], which has given rise to the Critical Brain Hypothesis [70–72]. A variety of helpful informational characteristics are displayed by systems that are tuned to criticality, facilitating the effective dissemination of and receptivity to information [73–76]. For instance, using data from the human connectome, Marinazzo and colleagues showed that information is maximized in an Ising scheme [77,78] at the critical temperature and that, beyond criticality, a law of marginal decreasing returns is attained [79]. These concepts have been expanded upon to more widely imply that critical systems are advantageous to evolution, since they are better at responding to their surroundings and guaranteeing their survival [80,81]. The Ising model is simple and applicable to numerous systems, including the integrated information theory (IIT).

Consciousness can be defined in the context of IIT either by top-down processing or phenomenologically [82–84]. Integrated information measures how processes inside a system interact and restrict one another in emergent, non-reducible ways. This enables us to quantify the characteristics of a system that its parts are unable to describe. For a system to be both highly connected and informative, it must find a balance between segregating forces that serve to distinguish the system and integrating forces that provide new types of information that are not nonexistent within the individual components. These precise characteristics are predicted to appear in Ising models at the beginning of a phase transition, close to the critical temperature.

It should be noted that there is nothing novel about the connection between IIT and the concept of criticality. Kim and Lee have observed that, in a Kuramoto model, criticality and EEG are connected. This describes synchronization [85–87]. The generalized Ising model, which simulates brain dynamics by displaying phase transitions and critical spots, is the simplest model linked to empirical pairwise correlation data [77,88]. Its dynamics have recently been shown to resemble those of the brain, leading to the development of the Critical Brain Hypothesis [89–91].

Criticality may be useful for optimizing the brain's capacity to process information [92], for understanding learning [93], and for memory [25,94,95]. It has also been observed [79] that when characterizing consciousness using IIT with an Ising model as a substrate, "consciousness" experiences a phase shift at criticality in the studied neural network motifs. This suggests, not least because of studies pointing to a possible crucial role of the brain, that "consciousness" might merely be the product of the brain's innate propensity to self-organize towards criticality. Further research into the interdependencies between the two hypotheses in patient and simulation data is made possible by the apparent synergy between the Critical Brain Hypothesis and IIT.

4.3. Grossberg's Input Regarding the Connection between Awareness and Biofield Resonance

How to account for our qualia, or phenomenal experiences, or the mental states that correlate to our experiences, is the difficult problem of consciousness. These could be regarded as the fundamental elements of conscious experience. The study of subjective experience, which originated with Wilhelm Wundt's introspective approach in the late 1800s, is a similar concept in psychology. To answer this problem, a theory of consciousness needs to model how emergent properties (such as self-organization, chaos theory, and self-referentiality theories) of different brain systems interact to incorporate specific features of each conscious psychological experience. In this instance, emergent features function more as a research guide than as an analytical tool. This is achieved by Grossberg's [96] adaptive resonance theory, or ART. Advanced brains may be able to learn to pay attention to, recognize, and predict things and events in a changing environment on their own, according to the cognitive and neurological theory known as ART. As part of its explanation of the mechanical linkages between the processes of consciousness, learning, expectancy, attention, resonance, and synchronization, ART has projected that "all conscious states are resonant states". It offers functional as well as mechanical interpretations of the data, covering a wide range of topics, from the dynamics of conscious perceptual, cognitive, and cognitive–emotional experiences to the synchronization of individual spikes. With the advancement of ART-related science, it is now possible to categorize the brain resonances underlying conscious perceptions of seeing, hearing, experiencing, and knowing. This classification can provide insight into psychological and neurological data in both healthy and sick people. Moreover, not all brain dynamics can be characterized by ART, and not all resonances result in consciousness. Important elements of these explanations of conscious and unconscious processes include the cerebral cortex's organization into distinct cell layers (laminar computing) and the brain's global layout into computationally complementary cortical processing streams (complementary computing).

4.4. Formulating a Theory Linking the Conscious Mind and Resonant Brain Dynamics

Consider a theory in which the interactions of brain mechanisms produce dynamical states that approach the spatiotemporal dynamics and patterning of the resonant neural representations representing discrete conscious qualia, or the parametric properties of these qualia. Additionally, suppose that these resonant states produce observable data about these experiences that come from human subjects' non-invasive neurobiological and psychological experiments, and that these data are consistent with data from various types of neurobiological studies, including multiple-electrode neurophysiological studies on monkeys exposed to the same stimuli. Let us also assume that these resonant states resemble the qualities of the subjective reports of these qualia.

Considering their significant similarities to a variety of data types and experienced qualia, one could argue that these dynamical resonant states are more than just "neural correlates of consciousness" [97]. Instead, they are psychologically grounded, mechanical representations of the qualia that constitute each conscious experience. Strong proof that these brain representations are the sources and maintainers of these conscious sensations would be provided if there were a correlation of this kind between the detailed characteristics of conscious qualia and detailed brain representations for a significant enough body of psychological data. Such a theory would have yielded a hypothesis connecting the conscious mind to brain dynamics. Until the brain–mind connection hypothesis is validated, a "theory of consciousness" cannot be declared.

Should a scientist or philosopher maintain—despite a hypothesis of connection—that a theory of the hard problem cannot contribute to its solution until one can "see red" or "feel fear", then no scientific theory can aspire to resolve the hard problem. This is because current research only explains the dynamical processes involved in the experience of distinct conscious qualia using a mechanical theoretical framework. However, just as the theory of relativity transformed our understanding of space and time and the quantum theory of matter, so too can a well-founded, albeit slowly evolving, theory of consciousness fundamentally transform our understanding of consciousness as it begins to explain an increasing number of distinct psychological, neurobiological, and even biochemical processes. The process of measuring our minds has limits, just like quantum theories. We cannot personally enter a neuron that is involved in conscious experience, just as we cannot personally ride an electron. Despite their limited capacity for empathy, physicists believe they have a solid understanding of the physical world since they can explain and predict enough of it.

4.5. The Conscious Mind and Resonant Dynamics Are Linked by the Adaptive Resonance Theory

Many psychological data concerning an individual's conscious experiences, including their spatiotemporal dynamics, can be explained by ART, in addition to the psychological processes and physiological underpinnings of dynamic brain states whose characteristics resemble the subjective elements of unique conscious experiences. Additionally, ART determines which brain regions these states might occur in and how they might all originate from a single set of identical neural mechanisms, even though these dynamical states each perform distinct functional tasks and are adaptable to different brain regions.

In a dynamic state known as resonance, interactions between top-down and bottom-up pathways produce reciprocal excitatory feedback signals that amplify and synchronize neuronal firings throughout the brain network. Grossberg [96] refers to this type of dynamical state as "adaptive resonance". These synchronized cells frequently oscillate in synchrony with one another through their activity. Resonant cell activity also highlights some cells for attention processes, providing insight into how the brain stores attended events. Because learning can occur within the adaptive weights or long-term memory (LTM) traces that are present at the synapses of these pathways, it is known as an adaptive resonance. Separate conscious qualia, according to ART, may arise as emergent, or interactive, characteristics of specialized neural networks when various specialized anatomies experience an adaptive resonance and receive distinct kinds of input from the brain and the environment. Specifically, ART suggests that in addition to the ability to identify these sensations, brain resonances also serve as parametric components of conscious experiences of feeling, hearing, and seeing.

Most likely, not every cell that maintains an adaptive resonance represents the conscious elements of an event. The capacity to detect psychological discriminations (such as color or fear) that are components of conscious experience is restricted, according to ART, to cells that can only do so at specific brain processing stages. This is supported by neurophysiological data about perceptual experiences [98], which have been described and, in some cases, even predicted by neural models [99]. If resonance is a more general concept than consciousness, then a theory about this more general concept would have to explain why this is the case as well as how conscious states arise from that broader function. Accordingly, it is false to say that "all resonant states are conscious states", despite ART's prediction that "all conscious states are resonant states". Brain dynamics can also happen in the absence of resonance potential, particularly during the formation of motor and spatial representations. Certain conscious experiences might not be supported in this situation.

It is important to remember that awareness was not the initial intended application of ART, even though it can shed light on the brain's underpinnings of conscious experiences. Instead, it was intended to provide predictions and insights for large-scale databases pertaining to the understanding of learning, perception, emotion, and cognition in psychology and neuroscience. Reviewing aspects of how ART explains data whose features naturally lead to brain representations of conscious qualia is important to build a self-contained exposition, and in particular to allow for new data explanations and predictions about ART. It is also interesting that the current work accounts for a far greater amount of awareness-related evidence than prior research employing ART or any other concept does. It goes beyond summarizing ART; it accomplishes more than that. A large number of the conclusions regarding consciousness that the article makes also depend on the synthesis of different but concurrent streams of modeling research that are compiled into a single piece. Examining the salient characteristics of these several modeling streams is necessary to provide a self-contained description of their synthesis. To distinguish it from its forebears, this synthesis and expansion of the ART model is known as the conscious ART, or cART, model.

No other theory has been able to explain the functional significance of a wide range of neurobiological and psychological data, both normal and clinical, until the present cART theory. This holds regardless of whether one is interested in the hard problem or whether one's definition of the hard problem precludes any scientific theory.

4.6. The Conflict between Stability and Adaptability and Lifelong Learning

Throughout their lives, humans can quickly assimilate vast amounts of new information and integrate it into coherent conscious experiences that aid in the development of a sense of identity. All it takes to be amazed by this ability is to see an opera once, after which we can recall a great deal of information about it, including conscious moments of seeing, hearing, feeling, and knowing. Humans can pick up new information quickly without losing sight of what they already know, even in situations where we are unaware of how the laws of any given environment alter or evolve. When forgetting of this kind does happen, it is called catastrophic forgetting.

The phrase "stability–plasticity conundrum" was originally used by Grossberg [100] to describe how the brain learns new information rapidly and reliably without losing track of previously learned information. ART was created to explain how brains deal with the stability–plasticity dilemma. Over time, it has evolved into a neurological and cognitive theory that explains how the brain can learn to predict, identify, and pay attention to objects and events on its own in a changing environment, thereby preventing catastrophic forgetting. Of all the existing theories of cognition and neurology, ART offers the widest range of predictions and explanations.

How does the ART tale involve consciousness? ART allowed for the discovery of mechanical connections between learning, expectation, attention, resonance, and synchronization processes in the brain to explain psychological facts about seeing, hearing, experiencing, and knowing. The stability–plasticity problem was thus handled. Because similar resonances were seen in the spatiotemporal patterning of cell activity inside networks of feature detectors, it became evident from these findings that they also displayed parametrical properties of individual conscious experiences. The functional units of the brain's short-term memory (STM) and long-term memory (LTM) are distributed patterns across networks of feature-selective cells, as early mathematical studies have demonstrated [101]. Subsequent studies have demonstrated how these dispersed patterns facilitate synchronous resonant states that direct attention toward the brain's key information-representative characteristics, like feature patterns that reflect the parametric characteristics of distinct conscious experiences. These discoveries over several decades contributed to an increasing understanding of the connections among consciousness, learning, expectation, attention, resonance, and synchrony processes (CLEARS).

According to ART, any brain representation that resolves the stability–plasticity paradox uses a variation of the CLEARS process [96]. The reasons for why "all conscious states are resonant states", that a large number of animals are intentional beings that pay attention to salient objects, and that brains are capable of learning both many-to-many and many-to-one maps—representations that provide us with extensive information about specific objects and events—are all explained by CLEARS mechanisms.

Bhatt et al. and others claim that ART is responsible for achieving these qualities [102,103]. More specifically, when a top-down anticipation and a bottom-up input pattern sufficiently match, a synchronous resonant state incorporates an attentional focus. This also explains how top-down attentive matching may help to resolve the stability–plasticity conundrum by focusing attention on salient combinations of cues, known as critical feature patterns, which characterize how attention may operate via a form of self-normalizing "biassed competition". This resonance's capacity to accelerate learning suppresses unobserved outliers that might have led to catastrophic forgetting and incorporates the attended critical feature pattern into the top-down expectations that the recognition categories read out, as well as the bottom-up adaptive filters that activate them. Adaptive resonance comes from this source.

Research in the fields of psychology and neurobiology has confirmed several connections between the mechanisms represented in the CLEARS mnemonic. For instance, ART predictions for somatosensory learning [104,105] and auditory learning [106] are consistent with the link between attention and learning. From the normal and abnormal aspects of human and animal perception and cognition to the spiking and oscillatory dynamics of hierarchically organized laminar thalamocortical and corticocortical networks in multiple modalities, ART has been continuously developed to explain and predict ever-larger behavioral and neurobiological databases [100].

4.7. Why Not AI Representations?

We must explain why artificial intelligence (AI) and artificial neural network techniques are not a part of the paradigm being supported and developed here to fully justify our position. While being a major advocate of energy-based models, Yann LeCun [107] has given less attention to probabilistic graphical models that give a probability to each potential combination of relevant components that could exist. He has employed "energy-based models (EBM)" that establish a connection between energy and configurations that eliminate the need for suitable normalization of probability distributions. Such systems must be trained to be discriminative to associate lower energy with acceptable configurations and higher energies with bad configurations. While we briefly describe the overall problem with AI models below, the main issue is that they are undoubtedly artificial and not very intelligent in comparison with human neurocognitive functions [108].

It has been commonly thought that the mind functions in the brain similarly to a computer [108]. These theories overlook aspects of neurophysiology that conflict with the process of modeling the brain computationally. Glial cells comprise around 80% of the brain; at all levels of neural processes, such as dendritic–dendritic processing, electrotonic gap junctions, cytoplasmic/cytoskeletal activity, and living conditions (the brain is alive!), these cells demonstrate broad apparent randomness. Moreover, the emergence theory does not contain any testable hypotheses. We may process cognitive events when we have some degree of volitional control or coordination, knowledge of our senses and experiences (i.e., cognition), or both. Consciousness emerges spontaneously; no threshold or reason is required. The idea that the human brain functions similarly to a computer has been advanced for nearly fifty years by psychologists, linguists, and neuroscientists who study human behavior. Examining how the infant's brain develops refutes the computer analogy. Computers are guided in everything they do by algorithms. But that is not how people operate as individuals do.

In light of this, why do so many researchers discuss mental health and cognition using language that sounds like it was generated by a computer system? It is difficult, if not impossible, to comprehend intelligent human behavior without the problematic information processing (IP) model. A flawed syllogism with two reasonable premises and a fallacious conclusion forms the basis of the IP paradigm. The idea that all computers are capable of intelligent behavior is the first tenable assumption.

The idea that all computers contain information processors is a second tenable assumption. The erroneous conclusion: every organism capable of information processing is capable of intelligent action. Beyond technical terms, it is counterproductive to assume that simply because computers analyze data, so should humans. Historians will probably see the IP metaphor in the same way that we do with mechanical and hydraulic analogies when it is finally abandoned. Rather than utilizing a model more closely associated with physical ideas such as resonance to observe and quantify occurrences, let us employ a more intelligent and natural approach to "artificial intelligence".

5. Coherence in Resonance

Fries [34] uses his communication through coherence (CTC) paradigm to explain how resonance among various brain regions has a part in "selected communication" (i.e., when coherent and resonant, the "windows" are open; when incoherent and not resonant, they are closed). Furthermore, coherence enables certain neurons to synchronize with the main resonance frequency. Fries [34] states that communication requires coherence. When there is a lack of coherence, the excitability cycle experiences random inputs, which reduces effective connectivities. A postsynaptic neural group responds mostly to the coherent presynaptic group when it receives inputs from many presynaptic groups. Selective communication is thus accomplished by selective coherence.

A lack of coherence causes inputs to come at random times during the excitability cycle, which lowers effective connectivities. If one group of synaptic inputs, which collectively create one neural representation, can elicit postsynaptic excitation followed by inhibition, then further synaptic inputs will be unable to enter the cell because inhibition will have prevented that from happening. Consequently, these additional inputs are unable to inhibit themselves, and they cannot communicate the neuronal image that they generate. By entraining the postsynaptic neuronal group's perisomatic inhibition and instructing it to follow its rhythm, this tactic creates a selective or exclusive communication channel. Figure 2 is an example of optimizing inter-regional brain communication.

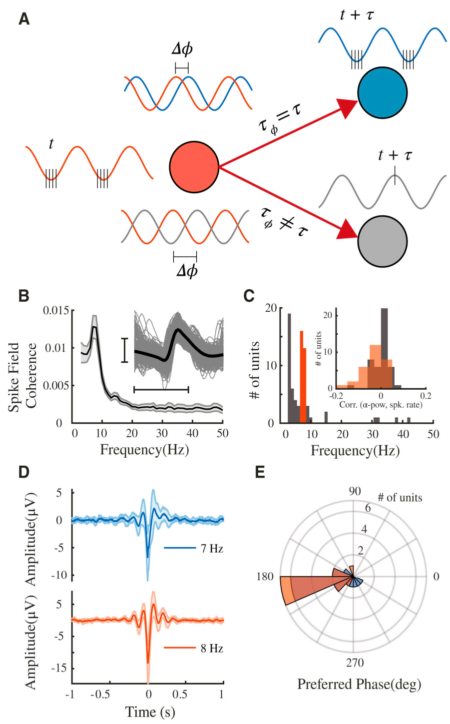


Figure 2. Diagram demonstrating the concept of communication through rhythm. (**A**) If neurons preferentially fire at a particular phase of an oscillation and the oscillations at two sites are coherent with a phase delay matching the conduction delay between them, spikes generated at the excitable phase in one region will arrive at the excitable phase in the downstream region. The construction of a communication line between two coherent zones is a feasible application for these periodic bursts of peak gain. On the other hand, if the phase and latency are not the same, spikes that occur outside of the excitable phase are less likely to result in firing (**B**) Average spike-field coherence (SFC) spectrum, with a distinct peak in the alpha band (f = [7, 8] Hz) for the average SFC spectrum across all units. The mean waveform (black) and individual spike waveforms (grey) for a single example unit are shown in the inset. The horizontal scale bar is 1.5 ms; the vertical scale bar is 10 SD. (**C**) Peak frequency histogram for each unit. Distributions of correlations between instantaneous firing rate and LFP alpha power are shown in the inset. For alpha coherent units (orange), alpha power and spike rate are generally negatively associated, while for all other units (grey), there is no correlation. (**D**) Spike-triggered average for the units at f = [7, 8] Hz with the maximum SFC. Multiple-cycle alpha oscillations are observed. (**E**) Phase preference for the alpha coherent units. (adapted from Chapeton et al. [109], with permission).

It is now thought that small organisms merged to create the organelles of highly developed eukaryotic cells, such as mitochondria, which subsequently came together to form multicellular organisms [110]. It seems plausible that life acquired the ability to incorporate subjective perceptions into hierarchically nested groups of more advanced consciousness at the same time that it obtained the ability to unite various living units into more complicated solitary life forms. The hypothesis that was suggested by Zeki and Bartel [111,112] to explain how consciousness develops from neuronal activity in the brain relies on this hierarchical view of awareness.

Zeki and Bartel [111,112] contend that the brain arranges multiple conscious experiences hierarchically to produce a single, cohesive experience using processing rate variations in various visual system components. They proposed that consciousness exists on three different hierarchical levels in the brain: unified consciousness, which corresponds to the experience of the individual experiencing the perception; micro-consciousness, which corresponds to the diverse visual system levels (for example, V4 processes color and V5 motion); and macro-consciousness, which combines numerous aspects of the system (e.g., color binding to motion).

Zeki further suggests that there is a specific temporal order in which each of these nested levels of awareness happens, with the lower-order levels coming before and influencing the higher-order ones. The reason for this is that the lower-order levels are more fundamental. Zeki's model can be explained as follows [112]. According to Zeki, there are three distinct hierarchical levels of awareness: micro-, macro-, and united consciousness. One level must depend on the presence of the level below it. One might imagine a temporal hierarchy at each level. For the micro-consciousness level, this has been demonstrated, since color and motion are perceived differently. Zeki [110] claims that it has been demonstrated that binding across characteristics takes longer than binding within attributes at the level of macro-consciousnesses". "Myself" is the perceiving individual, the product of individual temporal hierarchies of micro- and macro-consciousnesses leading to a final, combined consciousness.

The smallest sentient observers may be found exclusively in the inorganic world at the atomic and molecular levels. Life's evolution may have given rise to the capacity to organize conscious observers into hierarchies within other conscious observers, with each level embracing a more macroscopic perspective based on the (rudimentary) level of awareness intrinsic to atoms and molecules. When the organism's unified dominating experience occurs, this process ultimately reaches its greatest level.

Zeki divides his suggested levels into chronological sequences, with higher-order events taking place later in time. In other words, Zeki's hypothesis suggests that different brain regions that are involved in consciousness may go through the same experiences for slightly different times and for varied lengths of time, with the ultimate unified awareness involving the longest moments/duration of experience.

6. Integrating Consciousness and Cognition through Resonance

There is evidence that shared electrical resonance is probably the origin of this combination [33,34]. This shared electrical resonance may also be preceded and led by a shared quantum entanglement resonance. The largely unchanging physical structures can support several states of consciousness because of the constantly shifting energy and information fluxes that overlay the typically stable physical structures. This is excellently shown by Fries [33], who challenges whether brain communication is dependent on neuronal synchronization, suggesting that the communication pattern could be altered by dynamic shifts in synchronization. Stable structures are the "backbone" of conscious processes, according to Fries. He thinks that the fundamental components of cognition are these adaptive modifications to the brain's communication system, which are reinforced by the more inflexible anatomical structure, but operate through activity waves.

Constraints on the common resonance states may prevent physical materials from generating macro-consciousness. Situations that are disorganized and non-resonant hinder the exchange of information spatially. Dominant consciousness—like the waking consciousness that people experience—needs large-scale common resonance. There exists a hierarchy of resonance in brain networks [113,114]. Even when higher-level resonance, which represents more degrees of integration, is temporarily absent (such as during a seizure, sleep, or death), lower-level resonance may still exist, necessitating less information integration (death, in which case lower-level resonances may continue for some time but will also, before too long, dissipate). Small spaces may prevent physical materials from developing macro-awareness [113,114].

These mechanisms may account for the observed phenomenon of important brain regions synchronizing at regional levels during seizures in the absence of global consciousness [115]. Characterizing conscious experiences during absence seizures is often challenging since higher levels of organization lose their characteristic synchrony while lower-level systems (local and individual clusters of neurons) remain in synchrony [25,27,116]. Since resonance reflects the physical structure's dynamics, changes in resonance and awareness states do not affect the stability of the physical structure.

Some additional examples supporting the importance of resonance supporting physiological processes associated with consciousness and cognition might include a dyskinesic individual's symptoms being eradicated by light filters. We have also included references to the effects of transcranial DC magnetic stimulation (tDCS) on consciousness and cognition, which, although beyond the scope of the present paper, has garnered enough recent support to better understand the relation between resonance and physiological function [117–119].

7. Cortical Activity Waves as a Vehicle for Consciousness and Cognition

7.1. Continuum Waves in Consciousness and Cognition

The concept of "continuum waves" is not a well-established term in cognitive science or neuroscience. However, if we interpret it in a broader sense as referring to the continuous flow of neural activity and information processing in the brain, we can explore how it might relate to thought processes. In cognitive neuroscience, thoughts are understood to emerge from complex patterns of neural activity and information processing within the brain. This activity involves the coordinated firing of neurons across various brain regions, forming intricate networks that give rise to cognitive processes such as perception, attention, memory, reasoning, and problem solving.

If we consider "continuum waves" as metaphorically representing the dynamic and continuous nature of neural activity, we can think of thoughts as emerging from the modulation and interaction of these waves within the brain. Different types of thoughts, such as memories, emotions, or abstract reasoning, may correspond to distinct patterns or frequencies of neural oscillations and connectivity.

Furthermore, the concept of continuum waves could also encompass the idea that thoughts exist on a spectrum, ranging from automatic and subconscious processes to deliberate and conscious ones. Just as waves in the ocean vary in intensity and frequency, thoughts can vary in their level of awareness and control.

Overall, while the term "continuum waves" may not have a direct counterpart in cognitive science, we can conceptualize how the continuous flow of neural activity and information processing in the brain underlies the generation and modulation of thoughts across different domains of cognition.

7.2. Continuum Analysis Applied to Consciousness and Cognition

Mammalian brains differ from reptile brains in that they have a layered anatomy [120], which implies that possessing this structure has some evolutionary advantage. We here propose that the layered cortex structure permits a time delay in the interconnections between its layers and that this temporal lag efficiently controls brain activity waves, which are cortical tissue's resonant modes and the electrochemical energy they store. When enough energy is stored, these waves expand as they move to locations that are substantially farther from their origin than the normal axonal length, and they interact with most of the cells in their path until they reach their saturated amplitude.

The forgoing is grounded on the revolutionary continuum analysis of Wilson and Cowan [121,122], applied to a simple two-filamentary layered system separated by a uniform time delay in space and undergoing modest temporal variations [123]. In the Wilson–Cowan model, all other components are driven by synaptic flux into hypothetical "continuum elements", acting as reservoirs of energy; flux and stored energy are connected via what is compared to a "leaky capacitor". The energy is stored in the excitatory (e) and inhibitory (i) activities of the constituent cells, which are considered to be of these two types. The internal energy of each species is considered independently. Elements can be connected in four distinct ways: e-e, i-i, i-e, e-i, and i-e. The afferent species is indicated by the first index, while the efferent species is shown by the second index. The length of the typical connection probability of each afferent species is termed the connection range, which is the amount of time that decreases with distance along the layers [121].

The neuronal continuum can be impacted by waves of spreading and rising activity [124,125]. When one element exhibits some excess of excitatory activity, the return i-e connections lower the excitatory surplus in the originating element, while the e-i connections to adjacent elements raise the inhibitory activity. Oscillations are linked to an overcorrection, as is often the case. Meanwhile, e-e and i-i linkages stimulate development and proliferation by way of transmission to additional elements. Since the factors governing wavelength and frequency are essentially constant and only vary through synaptic modulation, this approach does not meet the requirements for carriers of cognitive processes [126].

Due to the phase relations necessary for the amplification of waves, the delay adds control. The wave is now generated as before by an excitatory surplus element, but it separates in two, with one half propagating to the opposite layer with a delay of T. The relationship between activity and flux in the second layer leads to a phase shift approximating $\pi/2$. A similar procedure is followed to return to the original layer. Amplification occurs only when the total phase shift is an even multiple of π. Consequently, the link between the delay and the angular temporal frequency of the favored wave is multivalued.

$$\omega T = (n + \frac{1}{2})\pi \quad n = 0,\ 1, \ldots \tag{1}$$

The integer n that yields the fastest growth—which is initially exponential—is the one selected in each given scenario [127]. The chosen mode typically becomes observably dominant at this growth rate. Nonetheless, both modes expand at those values of T where their growth rates are equivalent, and this situation continues until T reaches a point when the new mode takes precedence. When it comes to activity waves, the propagation speed increases with the wavelength, and the wavelength is a single-valued function of frequency. As a result, the waves move through space at various speeds and occupy various locations, creating a highly erratic pattern of activity in between.

7.3. The Wilson–Cowan Equations

The relative active percentages A_{sl} $s = e, i$, l = 0,1 at time t of the various species in the two layers, within an element centered at position x, are the dependent variables in our model (there are four in total).

$$\frac{\partial}{\partial t} A_{sl} + A_{sl} = S(N_{sl}) \tag{2}$$

Here, N reflects the synaptic flux into the element from all other elements, weighted by the inter-layer signal latency, and by the connection probability decreasing with distance.

$$N_{sl}(x,t) = \sum\nolimits_{u=e,i} \sum\nolimits_{m=o,1} \int_{-\infty}^{\infty} B_{us,ml} A_{u,m}(X, t - T_{ml}) e^{\frac{-|X-x|}{\sigma_{us,ml}}} \tag{3}$$

The connection coefficients $B_{us,ml}$ possess, when the cells are in the same position laterally, a cell of species u and layer m, with an afferent connection probability that is proportionate to the species and layer in question.

The connection probability between the afferent element at position X and the element at location x, which decreases with lateral distance, is described by the exponent; the connection range $\sigma_{us,ml}$ is considered to exclusively depend on the afferent species. All inter-layer connection parameters and connections within the layers, in this calculation, are assumed to be the same in both directions. Delay T_{ml} applies only if m and l relate to different layers when it equals T. A typical synapse's synaptic energy is represented by the attention parameter F. T and F remain constant here and the integral encompasses all of the space, whereas the sums cover both the species and strata.

The sigmoid function $\boldsymbol{S}$ must be used as a flow limiter, since, when all cells are active, the total stored energy cannot vary, nor can it decrease when none are. Since it is assumed that both species and layers have an equilibrium activity level, which is taken to be ½, the active fractions fall between −½ and ±½. When the synaptic flux is zero, ***S***'s functional form is zero with a slope of one. A decrease toward the equilibrium with a time constant of unity is represented by the second term in (2).

7.4. Numerical Results

$$N_{sl}(x,t) = \sum\nolimits_{u=0,1} \sum\nolimits_{m=e,} \int_{-\infty}^{\infty} dX B_{us,ml} A_{u,m}(X, t - T_{ml}) e^{\frac{-|X-x|}{\sigma_{us,ml}}} \quad (4)$$

The excitatory active fraction is considered to have been subjected to a δ-function impulse with amplitude of 0.0001 (above equilibrium) at time zero, and the first time step is carried out analytically to seed all the points. A convergence test is included in the Runge–Kutta–Fehlberg (RKF) method, which is used to simultaneously solve the equations in (2). A cubic spline integrated analytically is used to compute the integral in (3) at each function evaluation (using discrete approaches results in spurious spectral lines). The same-layer inhibitory connection range acts as the spatial unit and is used to represent all other ranges.

The 2048 amplitudes are written at intervals of several time steps in temporary files to account for the time delay; linear interpolation is employed to obtain the intermediate values required for the RKF test. To avoid end effects, the computation is terminated when a detectable signal reaches the final point. Fast Fourier Transform (*ff*t) is used after every time step; this establishes the connection between wavelength λ is $\lambda = 256/k$ and spectral variable k.

The findings for two values of delay are shown in Figures 3 and 4. Only positive amplitudes are displayed for clarity's sake. Since the neural refractory period is longer, the negative amplitudes are slightly bigger [121].

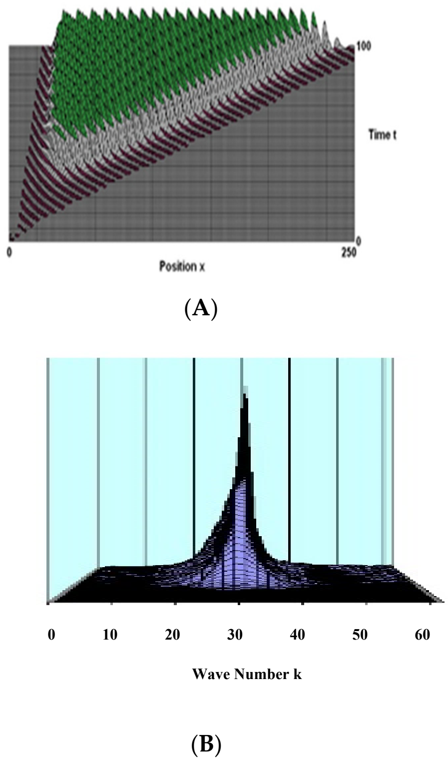
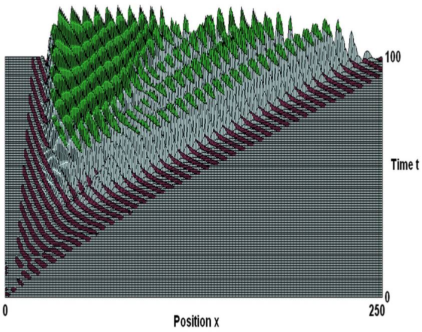
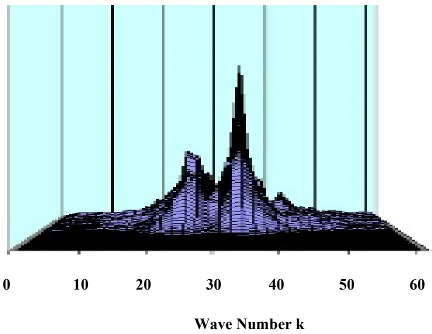


Figure 3. (**A**) The wave produced at time zero by a very slight variation (0.0001) in the excited fraction in an element located at layer 0 position. Here, we see the exponential growth of the wave amplitude in the stimulated layer, which is driven by the flux limit to saturation, with a maximum amplitude of around 0.4. Time units are decay durations, while spatial units are the same-layer inhibitory range. (**B**) The identical wave's spectral intensity is a function of time and wave number k (into the diagram). In the same layer, the connection parameters are the following: $\boldsymbol{B}_{ee}$ = 3.5, B_{ei} = 5.9, $\boldsymbol{B}_{ie}$ = −4.8, B_{ii} = −2.5, σ_e = 1.25, $\boldsymbol{\sigma}_i$ = 1.0; for opposite layers, $\boldsymbol{B}_{ee}$ = 3.0, $\boldsymbol{B}_{ei}$ = 1.1, B_{ie} = $\boldsymbol{B}_{ii}$ = −1.0, σ_e = $\boldsymbol{\sigma}_{ii}$ = 0.6. The attention factor $\boldsymbol{F}$ = 0.45, and the time delay $\boldsymbol{T}$ = 2.4.



(**A**)



(**B**)

Figure 4. Here, the parameters are the same as in Figure 3, except the delay *T* is 3.6 decay periods. The initial noise now generates two waves, with different wavelengths. The propagation speed increases with increasing wavelength so that the waves occupy different spatial regions. There is erratic activity in the intermediate space. The energy is spread between the two spectral peaks, as shown by their lesser amplitudes. Later on, a non-linear interference excites other waves with shorter wavelengths.

Figure 4 shows the scenario at a different value, in contrast.

The wave in Figure 3 is coherent due to its regularity and narrow spectral peak. Despite the random position of the starting noise, active and inactive elements behave in lockstep when they are one wavelength apart. Two waves are produced under the parameters shown in Figure 4; they propagate at different speeds and occupy various spatial regions, have different growth rates, and have different wavelengths. There is erratic activity in the middle space. Figure 5 depicts the influence the delay has:

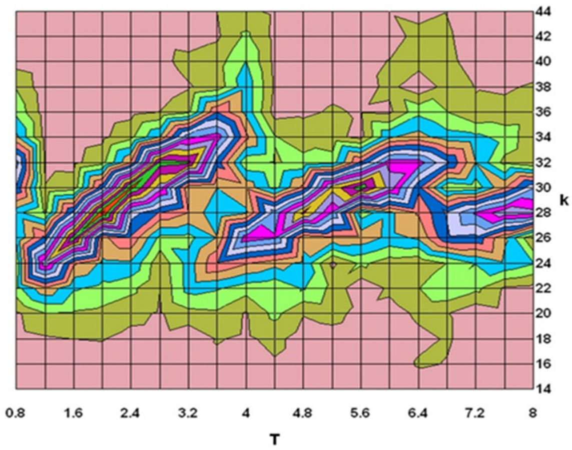


Figure 5. An example of a contour plot showing the spectral intensity against delay for a set of studies with constant delays after stimulation (80 decay periods). The remaining variables are the same as those in the figures that came before.

The preferred wavelength when just one wave is growing is a (decreasing) function of delay; altering the delay reorganizes the neurons into a subset that they were previously arranged into. Because the linked group is reconstituted (almost exactly) upon repeating a value of T, this procedure can be compared to a memory search. Regarding the theories of memory storage, we remain neutral and do not make any assumptions about the relationship between the waves and semantic content. However, since our simplistic model closely resembles the real cortex, these theories need to account for activity waves, which are the corresponding resonant modes.

8. Conclusions: Resonance Signatures Allow Us to Adapt and Effectively Interact with Our Environment

A multitude of delays and ensuing rhythms are possible due to the human cortex's six layers. There is currently no explanation for the different electroencephalographic frequency bands' origins [128,129]. It is evident that the current theory directly addresses that issue.

Since the location of the irregular wave pattern is fixed in only concerning the origin, the random placement of the first stimulus affects when two waves are produced. As a result, there are a wide variety of potential neuronal firing patterns in these situations. In the spirit of the continuum analysis, which divides cells into components, there are relatively fewer, but still a huge number of options, if each subset of individual cortical cells reflects a unique thought. There are about 106 billion such possibilities for about 20 billion cortical cells.

This hypothesis does not explain how these patterns are "decoded" into a combination of memories from the past and the semantic content of various wave memories or conscious awareness. It might, however, provide as an illustration of how cognitive research can benefit from the study of brain tissue as organized resonating media.

Each part of one's brain and body probably has its own resonance signature. These signals can fluctuate subtly from moment to moment, possibly fluctuating around the average frequency value. It has been hypothesized that the major cause of conscious experiences is the process by which our brains learn new knowledge about an ever-changing reality throughout our entire lives. Developing resonant states between bottom-up and top-down processes, learning top-down expectations, matching them with bottom-up data, and concentrating our attention on the predicted information clusters as they come to a consensus between what is expected and what is real in the outside world are examples of some of these processes.

Every conscious experience in the brain is thought to be a resonant condition, and learning, sensation, and their associated cognitive representations are caused by these resonant situations (see Grossberg [116]). As we gain more knowledge about the environment, our sensory and cognitive representations of it can hold true, according to Grossberg's idea. Our bodies can unlearn irrelevant learned maps as our motor and spatial representations develop from childhood to adulthood. This happens as a result of the brain trying to keep up with the body's changes. We conclude that procedural memories are not conscious because resonance cannot be produced by the inhibitory matching processes that underpin spatial and motor actions. Resonance, then, is the language that enables effective communication with our external and inner environments as well as with other people. Activity waves are how criticality is governed; but what governs them?

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