Article

The Temporal Gluing Problem of the Brain and the Paradox of Consciousness: Discretely Continuous?

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Abstract

Phenomenologically speaking, we see ourselves as a unified 'self' in the center of the world. However, the mechanism behind creating this existential unity is not integrated. Different regions of the brain are distributed spatially and temporally in building the edifice of 'conscious experience'. Putting aside the puzzle of spatial binding of consciousness, the brain functions in a temporally scattered way: conscious perception is discrete and temporally dispersed either in our inside world (different neuronal oscillations and also diverse transduction time) or the world outside (different speed of light and sound). Nevertheless, we perceive that we are moving in a sleek, continuous, and smooth tunnel of life and its events. How does the nervous system deal with these temporally scattered situations? Whence comes this fascinating experience of the smooth torrent of consciousness although its underlying neural mechanism is gappy, discrete, and bumpy? I argue that the answer lies in considering two important concepts which ultimately influence the integrity of brain organization and our flow of consciousness in time: Criticality of time and its relation to our brain and sensory information processing by the brain from the outside and inside world. I believe that it would be futile to concentrate on the puzzle of spatial binding without apprehending the temporal gluing problem. However, in recent years, there has been a tendency for understanding the spatial binding of consciousness, but the temporal binding has been underrepresented. This article is about revitalizing a crucial concept in understanding the conundrum of consciousness which is *time*.

Keywords: Consciousness, time, spatial binding, temporal gluing, self, temporally scattered, flow of consciousness.

1. Introduction

Putting aside the main puzzling issues about where and how consciousness arises, and many other questions such as whether consciousness is physical, whether it is epiphenomenal, whether it arises on a gradient (like sunrise, which comes in degrees) or is "binary" (like pregnancy, and is either there or it isn't), whether there is an explanatory gap, whether consciousness is an irreducibly fundamental aspect of reality, and the nature of the relationship between consciousness and intentionality, there still exists an opacity between consciousness flow and its association to time. In pursuing the neural correlates of consciousness, time (how consciousness

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arises in time) as an important variable has been ignored through history of science and most of thinkers concentrated more on where it occurs.

Imagine we have understood the whole mystery of consciousness and obtained a fine-grained knowledge about the brain network or any other breakthroughs about the underlying mechanism of the place of consciousness (we solve the spatial integration of consciousness which is called the binding problem). There are still some questions: if we take our brain as the emergence source of our conscious experience in a completely materialist term, how does the brain produce it in time? Is consciousness emerged in a continuous or discrete form? I mean that does the brain create it in a smooth, non-stop and continuous procedure (like when you switch on the engine of a car) or on the other side, the perception is a sequence of discrete conscious instants.

To answer these questions, we should dive into a much deeper parts of the ocean of life. I suggest that we had better begin with the concept of motion as Jean Paul Sartre maintains (1943) that everything is on the move and head forward, as a skier who must slide down the sleek slope of snow. Consider, for example, any organism's motion. At the first glance, we notice that motion is the essence of life itself. All living organisms move within the world. This motion could also be within themselves, in the circulation of blood, air and nerve impulses. Plants also move. Although they are rooted in the soil, they also move by bending to the wind, actions of photosynthesis and absorbing nutrients by osmosis. We also do feel motion. The awareness is deeply connected to our emotional experience of movement. We feel we go forward within time and through time. Time itself moves, according to some, with a unidirectional arrow that points only frontward. Moreover, many words in our languages contain aspects of movement. We report our qualitative sense of motion subjectively, by metaphors, adjectives and many other poetic means. Thus, motion is the quintessential property of time. It seems that everything is moving in the universe. Even, entropy, as the critical scientific measure of the capacity of the physical world with spontaneous changes, disorder or chaos is a kind of motion.

As a subjective experience, we move in time like a river, and events evaporate into the past. We often call this motion as passage of time— or let me call it the passage of subjective time. The world is not to be classified in any particular material, but rather with an ongoing progression governed by a law of change. Heraclitus, the Greek philosopher, is the pioneer of this idea that all things pass and nothing stops. He believed that 'there is nothing permanent except change' (540-480 BC/1987). For him, change is the only reality in nature. His analogy of the passage of time as the flow of a river is illustrious (panta rhei) "everything flows". He says "No man ever steps in the same river twice, for it's not the same river and he's not the same man." In plain words, he means that one cannot step into the same river twice because one is changing and the river too. The water one touched earlier will be downstream while one steps in water from up the stream. Just as water flows in a river, one cannot trace the exact same water twice when one steps into a river. Everything is constantly changing. Individuals are never the same, changing in some way from minute to minute to day-to-day experiences. There is a flow in which the world continuously changes and no two situations are exactly the same. It seems that every mortal moves ceaselessly in the river of time.

But how we move in time is still an enigma. What is the element that provides our sensation of movement in a smooth way? How is it possible that we perceive these periodic movements as a whole? How does this motion happen in time? Is it continuous like the stream of a river or gappy like a bumpy road? Our intuition says that psychological time is continuous rather than discrete (James, 1890). But it seems that our intuition is wrong. We should be aware that subjective experience of time or intuitionistic understanding of it might not be the best timing gauge (Pöppel, 1996). In fact, what we lack is a qualitative sense of connection between units of time. In other words, we need a scientific explanation of our motion in time. Nevertheless, we should not be hopeless. Lots of new scientific advances in different fields proclaim that continuity is just an illusion. Everything in our world moves in a discrete, gappy rhythm. According to numerous scientific proofs, this motion divides into periodic units to guarantee survival/adaptive strategy and minimize energy expenditure. Surprisingly, the periodic unit strategy is not restricted to living organisms. Much of the world displays periodic movements: packages of energy (quanta), electron spin in the subatomic universe, revolution of the planets on their axes, biological rhythms and so on.

Because this article is about the relation of the brain and time— our existence in time, in the upcoming sections, I concentrate on the flow of our consciousness in time (or, flow of our subjective time) and whether it is discrete our continuous. It has become very important topic in neuroscience and psychology (also in philosophy of mind discussions) in recent years. In the forthcoming section, I convey some discussions in the course of history about this concept. Furthermore, I will bring lots of findings in neuroscience and psychology that confirm the discrete form of conscious perception.

2. A Historical Overview on Different Opinions (Discrete or Continuous?)

Historically speaking, whether consciousness emerges in a discrete form seems not a new question and we can spot the trace of it in the third century BC among Buddhists. The idea that experience is indeed a set of distinct conscious moments can be found in the Abhidharma texts of the Buddhist tradition. Moreover, in some near eastern mystical schools like Sufism, especially Rumi and Shabistari's mysticism, the concept of consciousness comes always with the discrete instants from what they call 'the innermost consciousness'. Also, the 13th century Japanese philosopher, mystic and poet, Eihei Dogen, in his lifework, Shobogenzo, discusses the essence of time and being. The chapter starts with a poem that portrays each moment of existence's independence. Time-present, from his viewpoint, means that time is the present and the present is time. He says:

"Time-present is standing on the mountain heights. Time-present is sinking to the depths of the ocean. Time-present is an angry demon, time-present is a buddha. Time-present is a formal ceremony, time-present is the temple compound. Time-present is an everyday individual, time-present is pervading the whole Universe".

In the western world, Karl Ernst von Baer presented discrete theories of perception in 19th century by devising the term "moment" as the boundary between the past and the future. In 1865, Ernst Mach showed that there is a perceptual time interval. He discovered that although this time

interval exists in human consciousness, it is not perceivable due to some human limits. Also, in 1868, we have Karl von Vierordt who proved the discrete form of consciousness by many empirical facts.

In the realm of philosophy, Gottfried Wilhelm Leibniz, by examining the notion of substance and influenced by Aristotelian tradition, proposes that all substances are exposed to unceasing change. In other words, that the principle of change is interconnected with substance itself. He believed that nobody in Nature is continually maintained in a state of rest. Leibniz once said that nature makes no leap— "natura non facit saltus". It is a principle which it is known as *The principle of Continuity* (1687). In the second part of Specimen Dynamicum, saying that the law of continuity is the fundamental principle of an original and general order in Nature, being infinite from the very beginning. He thought that bodies are in a form of continual, continuous change, similar to the course of a running river (he also applied it in his theory of consciousness as Spatiotemporal Continuity and Continuity of Actual Existents). It is just birth and death which are relative phenomena comprising of a constant passage from one state to another. However, according to the new discoveries in the brain sciences, it seems he was mistaken.

David Hume, the prominent British philosopher, believed that conscious perception is discontinuous—each perception arises independently. For him, perception is fundamentally fluid; it arises and then perishes. "Every distinct perception, which enters into the composition of the mind, is a distinct existence, and is different, and distinguishable, and separable from every other perception, either contemporary or successive" (David Hume, A Treatise of Human Nature, 1739). Puzzled with the continuity of identity (despite its discrete and independent essence), Hume expresses his idea about consciousness with the claim that a substantial unified self does not exist— it is discrete, atomic and linearly successive.

Years after, Immanuel Kant (1781) described that our knowledge of the objects constituting natural phenomena; our perceptual experiences and theoretical reasons in understanding them are completely structured in temporal frames. He demonstrated the ubiquity of time in the performance of cognitive reason. In a more concerned theme of today's scientific jargon, it can be paraphrased in this way that all of our actions are bound to a timing frame. They are all grounded in the form of time which constructs human cognitive experience. We perceive the world in somewhat fixed temporal parcels which are discrete and gappy. His only exceptionally detemporalized concept was human's ethics. Although this idea gives Kant's moral philosophy impractical, it seems he was forced to do it because by denying the temporality of moral conscience and practical reason, he saves the notion of autonomous self and the essential freedom which grounded them.

William James (1890/1950) is also one of the pioneers of consciousness who grasps it as "sensibly continuous". He meant that the flow of time as we experience is not prominently interrupted by regular indicators. From James's viewpoint, if we take motor behavior as an instance, as well as in perception, timing appears to be continuous. In other words, when we pedaling a bicycle, or adjust to different musical tempos in dancing or playing an instrument, we are able to speed up or slowdown in it. Besides, what he describes the experience of time as a stream of consciousness is comprised of a series of moments in which each moment comes into existence and disappears only to be replaced by another. The thoughts and conscious reactions to

events that encompass those moments are supposed as a continuous flow. But, if the description of the stream of consciousness, like that James proclaims is true, why do we have detours and breaks of thoughts during reverie or relaxed thinking? Besides, the flickering, perseverative, time-blurred images experienced in certain intoxications or severe migraines give credibility to the idea that consciousness is not river-like as it is perceived. It looks James's (stream of river) and Sartre's (a skier who slide down the sleek slope of snow) metaphors fail to answer these questions.

Edmund Husserl the German philosopher in mid-20th century who established the school of phenomenology considers the same general experience as inner time consciousness, an element of his definition of the flow of time. Inner time consciousness is a capability to perceive both sequence and length of events, both of which contribute to the specious present. For Husserl, it was a puzzling issue that the human brain experiences objects of the world in sequential order, while it also experiences time during viewing immobile or stationary objects. This idea is like James's (1890) stream of consciousness.

In line of supporting river-like argument of consciousness, Bergson (1889) believed that the moments of consciousness are not detached from each other— "there are no snapshots cut off from the rest; there is simply the continuous flow of our awareness". The continuous becoming of continuity has an organization which he calls "rational evolution". For Bergson consciousness is "an inner life that is ceaselessly changing an inner world in which one state of consciousness flows into the next". Bergson's moment never dies, his is "an idea without demise". To Bergson's and James's conjecture, time is precisely a continuous becoming which are never manifested as a discrete shape— time is not a series of droplets.

Among 19th century philosophers like Alfred Whitehead (1938), the English philosopher and mathematician, time is comprised of discrete atomic durations, each categorized by internal indivisible characteristics. From his view, these durations are non-mathematically continuous. Each interval has an immediate successor and predecessor, from which it is detached by absolute discontinuity. Time is a course of "creative advance" in which reality becomes present in discontinuous spurts of creation. Whitehead believes that there exists a creative becoming of atomic continuities which he calls discrete durations or "droplets" of time. However, he adds that the process of that becoming happens with no continuity, no smooth move from one discrete form to the next.

It appears that theorizing about the nature of time and consciousnesses is not restricted to philosophers and brain scientists. Julian Barbour is a British physicist (influenced by Ernst Mach) who also theorized about this concept in his book The end of time: The next revolution in physics (2001). Barbour's popular quantum gravitational theory suggests that the universe is jam-packed with what we call nows. Each now looks like a point in spacetime. Metaphorically, it can be thought of as a snapshot including information such as the brain's memories at that instant moment. There is no connection between the snapshots. According to quantum wave reduction theory, each snapshot provides information about the occasion and memories of prior snapshots at that moment.

Besides, the analyses of Hameroff (2003) is another example of hypothesizing on time and consciousness which roots in physics. It is somehow coherent with James's view of consciousness as "continuous flow". Their quantum-based consciousness claims that consciousness is the outcome of discrete physical events which is always present in nature as non-cognitive and proto-conscious event. For instance, the percept of a light flash is like a perceptual moment resulting from a quantum reduction. Furthermore, the brain smears the perceptual illusion of continuity to all those moments which is referred to as flow. For them, consciousness is the constructor of both a series and the flow of moment: they believe that "consciousness creates time".

Francis Crick and his colleague Christof Koch, from their first collaborative work in the 1980s, concentrated more closely on elementary visual perception and processes as a means for studying and understanding consciousness. Their investigations brought them to the idea— in a paper in 2003 called A Framework for Consciousness— that "conscious awareness (for vision) is a series of static snapshots, with motion 'painted' on them…[and] that perception occurs in discrete epochs." The idea of "snapshots" that Crick and Koch postulated was a requiem for James's and Bergson's theory of the riverlike consciousness— smooth and without interruption. However, the "snapshots" that they assume are not uniform, like the negative sheets of a photographic camera and the length of successive snapshots is not likely to be constant. In addition, the time duration of these snapshots for shape and color are not simultaneous. Although they show in their study that this "snapshotting" mechanism for visual sensory inputs is probably a simple and automatic procedure, they do not explain clearly how each percept that include a great number of visual features, all of which are bound together. Are the several snapshots "assembled" to achieve specious continuity, and how do they catch the level of consciousness?

The discussion is much deeper and broader than what I covered here. In any case, continuous and discrete models of consciousness are two different poles which change our standpoint towards our existence. Furthermore, it was a philosophical challenge for the past thinkers and it has also become a controversial research question for a vast majority of contemporary neuroscientists/psychologists in modern era. In recent years, we have witnessed a kind of favor of discrete form of conscious perception among modern researchers. They have come to this conclusion that continuous representation of conscious perception "cannot satisfactorily account for a large body of psychophysical data" (VanRullen and Koch, 2003).

3. Findings in Neuroscience and Psychology Supports Discrete Form of Conscious Perception

For some people, passage of time is a perceptual accomplishment that provides continuity to discrete observation. Nonetheless, most of what we see is a reconstruction— by filling in the incompleteness of what is observed. The process of filling in the incompleteness of perception creates a world which appears to be complete. What we perceive of the world are illusory percepts. What we feel is not as rich in detail as it seems. In other words, consciousness is not necessarily continuous in time although it seems like that it is— its subjective side is completely different from its objective side. It is a chain of moments in which each moment comes into existence and disappears with gaps in between. Moment by moment replacement in the arrow of

time are perceived as an illusory continuous flow. The brain has the challenge to fill the gaps of these discrete experience of perceptual events. These discrete perceptual events can happen in different levels like sensory process, higher cognition, movement control, physiological data, speech and language, and cultural artefacts. But, one may ask whether these claims could be proven. How did we know that perception is formed in a discrete form? Why is there the smoothness of our perception of reality versus the discreetness or discontinuity of its origins at the microscopic brain level? Many psychological and neuroscientific discoveries have hinted that much of the continuity of perception is an illusion because the brain exhibits perceptual completion from a discrete form.

To answer these questions, firstly I encourage to notice that each of the body's organs and biological processes have been coupled in a nested time cycle. There is a time frame for all of them: the beating of the heart, the pulsing of the breath, the cycle of the digestive system, the action of the liver, the rhythms of the sleep/awake cycle, so the brain. All of them have been fixed with a demonstration of time windows. Isn't it worth considering? Besides, there exists a wealthy of experimental findings from neuroscience and psychology show that mental activities, including cognitive activities, have discrete, separated functions— they are implemented in a somewhat assigned time frame. All these assigned time frames imply to this fact that conscious perception is gappy, discrete and bumpy and continuity is just a trick of our brain—an illusion.

By pondering in the microlevel of life, we find out that because of some neurophysiological or even survival necessity (evolutionary perspective), discrete timing of consciousness can serve better to the organism rather than a "sensibly continuous" time (Varshney et al., 2006). Varshney suggests that neurons with discrete synaptic states may function better than neurons with continuous synaptic states. In another case, Abbott and his colleagues (2016) maintained that neurons converse with one another "almost exclusively through discrete action potentials".

Another reason for favoring discrete form of consciousness is noise tolerance (Chaudhuri and Fiete, 2016). There are many causes of noise in the brain such as sensory noise, cellular noise, motor noise. Due to these noises, information that is transported or transferred in continuous form unavoidably lose its quality and becomes corrupted. For example, let's take one of visual paths: information in human vision originates at the retina, then it is carried to the LGN via the optic nerve, before reaching the visual cortex. Applying Shannon's communications theory (Shannon, 1948) to communications in the brain, the presence of noise throughout such a transmission chain makes it implausible for the brain to retain continuous representation; noise will always accrue and accordingly corrupt the information, no matter how small the noise is.

Furthermore, Pöppel (1985) indicated with a neuroscientific method that how our perceptual constraints create a horizon of simultaneity— at which we distinguish audio and visual stimuli as occurring simultaneously, although the speed of sound and light are different in our physical world. We recognize audio signals as non-simultaneous when they are detached by an interval of about 6 milliseconds. If that splitting interval is shorter, we perceive audio signals as being simultaneous. Visual signals which are separated by an interval of 20 to 30 milliseconds are experienced as non-simultaneous. Below this threshold, they are perceived as simultaneous. In tactile impressions, the simultaneity threshold sets at approximately 10 milliseconds. According to these experiments, we perceive tactile, visual and audio events in a temporally restricted mode.

According to Pöppel, this temporally restricted structure is perceived as one 'now' which are based on a clustered perception-related experiences constructed by our brains.

Evidence for discrete form of conscious perception also derives, for instance, from studies on temporal order thresholds. If subjects are requested to show the sequence of two sensory stimuli, temporal order thresholds in the domain of nearly 20 to 60 milliseconds are observed independent of the sensory modality (Hirsh and Sherrick, 1961; von Steinbüchel, 1995; Wittmann and Szelag, 2003; Fink and Neubauer, 2005). To measure auditory order thresholds, for instance two clicks are sent to subject's ears (both ears). If the stimuli are presented simultaneously, the subject will blend the stimuli perceptually so that only one stimulus is heard. A delay of one stimulus results in hearing the two clicks separately in each ear if the interval between the two surpasses 2 to 3 milliseconds. Although the subject hears two clicks and might even distinguish they are no longer simultaneous, she will unable to specify their temporal order correctly. The delay between the two clicks must exceed approximately 20 to 60 milliseconds that a subject can indicate the correct sequence. Similar threshold domains have been observed both for the visual and the tactile modality in similar experimental situations.

Another proof comes from measurements of response latencies in pursuit and saccadic eye movements. When pursuit eye movements initiate, the latency of such eye movements has a strong tendency to be within 30 to 40 milliseconds intervals (Pöppel and Logothetis, 1986). Similar observations have been made on saccadic eye movements for human subjects (Fuchs, 1967; Ruhnau and Haase, 1993, Tanaka and Sengco, 1997).

In short-term memory investigations, Sternberg (1966), in an experiment which is known as Sternberg task (the experiment entails memorization of a positive set, a list of items such as numbers or words) discovered that the exhaustive scanning procedure through short term memory is disjointed, with approximate phase durations of 30 to 40 milliseconds.

There also exist some findings deriving from neurophysiological experiments which support the notion of discrete form of consciousness. Experiments on the brainstem auditory evoked potential prove that the midlatency response shows a clear oscillation in the first 100 milliseconds after stimulus onset (Galambos et al., 1981; Gray et al., 1989; Murthy and Fetz 1992; Podvigin and Pöppel, 1994).

Another example is apparent movement which is debated in terms of perceptual completion. For illustration, if one visual dot is tracked in time by another further away, they seem like separate dots, separate in time. But if they are close in distance and time, the brain connects the two events by making the one dot appear to move back and forth. In this illusion, known as beta movement (important for motion pictures), the brain fills the gap and perceives a movement sensation. A similar type of illusory perceptual connection is the phi phenomenon (seen at inter-stimulus intervals greater than those associated with beta) in which a sensation of motion is experienced between the images of consecutive stimuli without a change their spatial position (Steinman, 2001). Moreover, we can find this phenomenon also in the Necker cube, which can be seen under two different perspectives, (there is atemporal gap between changing two perspectives) and a phoneme sequence like CU-BA-CU-BA, where one hears either CUBA or BACU (Radilova, Pöppel and Ilmberger, 1990).

Another piece of evidence about the discrete form of vision perception roots in what it is called in magician world visual coin trick. A magician makes the illusion of transferring a coin from one hand into the other. The magical experience of the trick happens when the closed fist of the second hand is opened and revealed to be empty. It seems according to some experiments (Beth and Ekroll, 2015), if the time interval between the false transfer and the opening of the fist increases it would be probable that the magical experience evoked by this kind of trick becomes remarkably weaker. From finding of this experiment, by increasing the temporal interval from 1 to 32 s, they observed an average reduction of the strength of the magical experience of 38%. But, how is it possible? Beth and Ekroll's analysis make the possibility that the brain has a limit to create a perceptual completion for the intervals between discrete process of vision creation and also in seeing a stationary object.

Another proof of intermittent consciousness happens when the general anesthetic by Methohexital or Propofol is employed (usually for short surgery). This procedure results in a retrograde amnesia. Upon awakening from surgery after 5-15 minutes long, some patients report that what they recall is that they have being told that they will be given the drug and the next thing they recall is becoming awake and told that the surgical procedure is over. Furthermore, they were puzzled that "no time" elapsed between the two verbal events (Schwender et al., 1995).

To cover some instances of discrete form of conscious perception in the higher levels, it is worth mentioning the color phi experience (Dimmick, 1920; Kovaćs and Julesz, 1992). In this phenomenon, the mixture of spacing and timing of the two images, a person who views the wheel report a feeling of motion in the space between the two points. The first point begins to seem to be moving, and then change color sharply in the middle of its illusory path.

In behavioral levels, for instance in decision making, a person who decides to buy a product in 1.99 Euros refuse to buy the same product if priced 1 cent higher (2.00 Euros). Such a sudden change in the brain's purchasing decision making cannot be modeled by means of a continuous representation despite broad attempts to do so (Basu, 1997). Besides, in cultural artifacts, such as hugging or shaking hand, a temporal window (around 3 seconds) has been observed (Schleidt et al., 1987).

4. What do all these experiments imply?

From the speech of von Baer in 1860 at the founding of the Russian Entomological Society in St. Petersburg on subjective time (he came up with a definition of the moment, i.e. the longest possible period of time for an organism) to recent observations on the distinct type of conscious experience, all of them suggest this message: underlying machinery of any organism's cognition modalities (sight, hearing, smell, taste and touch), there exists a temporal frame for processing (conscious perception is discrete).

Besides, for a basic understanding of human cognition, it is necessary to adopt a concept of temporal processing. By a closer look at the visual system, for instance, we realize that the integration of spatially distributed functions in the different regions of the visual cortex are determined pre-semantically by using temporal network properties rather than the content of

what is processed. It is very significant to know the logistic machinery of temporal integration of spatially distributed activities in the brain prior to 'what' is processed. Having explained this cognitive process, one has to differentiate strictly, with respect to the mental machinery, between two mechanisms: one pre-semantic mechanism providing a temporal frame for processing, logistical function, and the other being responsible for the content of what is processed, content function (Pöppel, 1989).

So, we are led to the view that consciousness itself occurs in short pulses, each of which is experienced as a whole, from which it is but a short step to the view that a stream of consciousness consists of a succession of such pulses (like beads on a thread), each a short-lived total experience— 'islands of nowness' (Pöppel, 1997). But, there are still unanswered, puzzling, and abrasive questions: How are these 'islands of nowness', or 'specious present' connected together? How does the brain make this bumpy road as a flattened highway? What is the underlying brain mechanism (if any) for creating this illusion of continuity? In my poetic term, what (where) is the glue of our existence?

5. Conundrum of continuity

Zillions of electrical, chemical, and hormonal procedures happen in our brain every jiffy, but we experience everything as a smoothly running integrated whole. Likewise, during our life we experience changes each day, each minute, each second. Each year about 98% of our molecules and atoms in our body are changed in course of time (each minute 30 million cells die and are replaced), resulting in a new body about each year (van Lommel, 2006). But no one realizes this continuous and smooth change which in depth is gappy. More generally, we are constantly aware of phenomenal passage of time in which there is a continuous flow and recurrent renewal of content of our consciousness.

This experience of passage is both continuous and homogeneous— my experience was not packaged into discrete components. We witness a continuous change and we are alert of every part of it. For instance, I move my hand slowly but smoothly across my field of vision. Moment by moment I see my hand at a different location; I also see my hand continuously moving. Not only is the movement continuous, but my experience of the movement is continuous. Or, let's deliberate the case of hearing a melody. To suggest that we hear each of the sounds of a melody one by one is not wrong. Yet we generally say that, as a whole, we hear the melody. In the case of hearing a man utter a sentence, it is the same. How is it possible that, as a continuous form, we hear sentences and melody?

Furthermore, I have a sense of personal continuity in temporal directions (past and future), also depicted as an integration of the self in time, either as a phenomenological continuity—the experience of self-continuity that is felt through mental time travel or narrative continuity—arises from coherent life stories which maintains the continuity of my identity (Rose Addis and Tippett, 2008). How could this be, although our brain creates it in a discrete, gappy and fissionable procedure? Is there a link? A thread?

When we talk about a link, it is implied that there are some independent, far-away, and discrete packages that should be connected together so that the continuity happens. In this situation, the concept of continuity comes on top and the desire for finding the link initiates. The adventurous voyage for discovery of the underlying layers of continuity is commenced with these seemingly simple but deep questions: how is it possible those 'islands of nowness' create such a smooth continuity of consciousness? How can we explain the temporal continuity of the flow of time consciousness? How self-continuity (or personal identity) is preserved? How can we face with the question of discrete identity and its continuous experience? What is the relation between the discrete nature of our mental experience and this unified and continuous whole? What is the connector? What is the thread of our continuity in time? If our conscious perception is discretely continuous, what is the glue of our existence?

It seems to me that the questions are much more problematic than they appear. Or, perhaps, one might object and see them as pseudo-questions. Nonetheless, if we take these fundamental questions as pseudo ones, we have radically evaded a deep inquiry and ignored a profound concept. However, for Cartesian dualists, the question of consciousness continuity in time could be solved easily. In fact, it is not even an inquiry. What binds before and after, in the Cartesian definition of time, is time itself. A self-consciousness that recalls "myself of yesterday" and believes "myself of tomorrow" is inferred. In this sense, the memory of the past is limited to the consciousness of the present. The same applies to the current outlook for the future.

According to Cartesian dualism doctrine when we have the 'res cogitans'—an immortal soul (mind) which does not follow the natural laws and functions independently from the brain, why should we bother ourselves with these questions? But, from a realist scientific view which is based on experimentation, this is not the answer.

I suppose that we should take the above-mentioned questions seriously: Firstly, experience of time flow is profoundly embedded in the imagery of our culture. In music, for instance, rhythm refers to an organized movement in time. Human's rhythmic energies which root in her physiological and neural structure are intricately hooked up with her ability to generate time in music. By a closer look, musical rhythm on its various levels, are not necessarily interrupted. Besides, the word stems from the Greek verb "to flow". Secondly, conscious perception as I mentioned in previous sections takes place in discrete forms in time and there has to be a glue—a link to connect them all. A bond that gives a being the feeling of moving in a sleek vessel of time which all of us have strongly experienced. Thirdly, missing something is the best proof for its existence. In other words, we have lots of evidence that in some mental problems such as schizophrenia, patients suffer from being stuck in the moment and lose the experience of a smooth flow in time. So, it is the glue of our existence which should be understood from different angles. With understanding the concept of consciousness glue, we start a new story of our existence. It provides the key to open a new door, a new line into the world of time and a new tool to demystify the causes of many mental diseases which were strange for our previous scientists. But, whence comes this fascinating experience of smooth torrent?

But, what do I mean by continuity? The definition would seem self-evident, but let me clarify what continuity denotes here. In a broad sense, I mean continuity of consciousness in time not space. Besides, I do not plan to explore the continuity of time which physicists discuss in their

jargon as a metaphysical concept. I empathically bring about this difference because I do not intend to confuse the readers with the concept of continuity of consciousness in space in an Aristotelian or Bergsonian notion. Aristotle's notion of continuity in space entails a procedure which is 'from something to something structure' as pertaining to physical motion repeating the continuity of space. Aristotle reduces the 'from…to' to a sum of spatial points. But he could not plausibly have maintained this to the qualitative change of an apple from green to red, or of a man from being happy to being sad. As you have noticed, neither of these transformations involve change of spatial position at all. Consequently, Aristotle's notion for continuity in this sense foreclosed. Bergson also with a narrow understanding of Aristotle, says that time, is space. This is the result of misleading apprehending Aristotle's continuity in the narrow sense of the wide-ranging magnitude of space. Additionally, with Bergson understanding of time, the Aristotelian concept of time was also misread, in so far as he from the beginning taken this dimensional character of time as spatial extension. You may consider, in an Einsteinian sense, space and time the same. It is also fine.

Thus, in overall, I intend to deal with two fundamental questions: Firstly, although conscious perception is discrete and temporally scattered either in our inside world (different neuronal oscillations and also diverse transduction time) or the world outside (different speed of light and sound), we perceive that we are moving in a sleek, continuous, and smooth tunnel of life and its events.

6. Experimental investigations in search for the continuity of consciousness conundrum

Augustine rescued temporal extension of our existence by putting it in "the distension of the soul" accomplished through memory. Surprisingly, Husserl too in his phenomenological approach takes "expand the soul" argument with the help of memory; only, with him, consciousness, which appears not to have been invented in Augustine's day, takes the place of the soul. But, can it be elucidated only by the role of the soul? And, we should ask both of them that what is the soul in the first place? It seems that their answers are not convincing and popped up from their religious minds, not on the basis of the empirical data (objective evidence). So, what about modern sciences like neuroscience and psychology? What do they present about this challenging and critical theme in our existence? It seems that recent advances in today's brain imaging technology in neuroscience, for example, has paved the road for us.

To the best of my knowledge, among psychologists and neuroscientists, most of their efforts have concentrated on spatial filling in our visual system and how visual system fills the gap between blind spots of retina (they have mostly overlooked the temporal filling of consciousness). They argue that although visual perception is discrete, the interval (gap) must be filled with something (Treisman and Gormican, 1988; VanRullen and Koch, 2003; VanRullen et al., 2007). And for some scientists like Niko Logothetis, vision is a window on consciousness which should be explored meticulously (1999). But, what is going on between snapshots of perception? How can we provide a schema to explain the experiential phenomena between these

gaps? Maybe, answering to these questions assists us in decrypting the temporal lags in our conscious perception.

To put this topic more precisely, I should mention here that apart from the illusion of the continuity of consciousness, how we see the world with our eyes in a smooth and continuous form is also an illusion. The continuous perceived image filling the blind spot of the retina is clearly an illusory percept. The brain is not physically capable of recording information from that area. Although tracking an object with different eye movements (saccadic or pursuing) in the world is fabricated discretely (because of blind spot in retina), the image is felt uninterruptedly and does usually agree with the local physical setting and is predictive and efficient for the observer. Noë (2002) notes that because more potential information exists than the brain can obtain, it is much more efficient for the brain to recreate the visual world from less information.

However, among theorists, it is debated as to whether there is actual filling in process and whether the brain simply ignores the blind spot and other regions (Ramachandran et al., 1992; Blackmore, 2002; Dassonville et al., 2004; Hafed and Clark, 2002; Henderson et al., 2007). But for J.J. Gibson (1975) the illusion of continuity of vision is something external. He argues that "A sequence of external stimuli or, at the very least, the rhythms of the observer's body, provide a flow of change, and it is this we perceive rather than a flow of time as such." He adds that "The observer perceives both what is altered and what remains unaltered in the environment".

In line of these arguments, Crick and Koch (1990) also have the same claim to explain the apparent continuity of visual consciousness. They suggest that "hysteresis," that is, a persistence outlasting the stimulus causes we see our surrounding uninterrupted and smoothly. This belief seems very similar, in a way, to the "persistence of vision" concepts advanced in the nineteenth century by Hermann von Helmholtz in his Treatise on Physiological Optics (1825). To put it in another form, according to Crick and Koch's and also Helmholtz's hypothesis, the sense of visual continuity is the final product of the continuous overlapping of consecutive perceptual moments. The only difference between Crick and Koch's and Helmholtz's assertion is that Helmholtz supposed that this aftereffect occurs in the retina, but for Crick and Koch it arises in the binding of neurons in the cortex.

Koch also in another article (2004) proposed that perceptual completion or what I call vision gluing maybe "painted onto" the snapshots of visual perception— a kind of a superimposed percept or a quale, like that of music. Gruber and Block (2013) implemented some experiments that explain illusory perception between "snapshots" of stimuli and reached the same conclusion. Besides, Treisman's feature integration theory suggests that spatially focused attention is necessary bind the features of an object to the locus of focused attention (Treisman and Gormican, 1988; Treisman and Sato, 1990; Treisman and Gelade, 1980).

Interestingly, the flow of visual consciousness does not function for some organisms. Evolutionary speaking, it is probable that no such flow of visual consciousness exists in amphibians. A frog, for example, expresses no active attention and no visual flow of events. It does not scan its environments or look for prey. The frog does not possess a visual world or visual consciousness as we experience it. It seems that it is only a spontaneous reaction to an insect-like object to dart out its tongue in response if one enters its visual field. By taking the

frog's example, it might be that such a dynamic and continuous consciousness first evolved in reptiles around 300 million years ago (Krauzlis et al., 2018).

There is also an unusual neurological disorder that some patients experience 'snapshot visual frames' during attacks of migraine. Hence, they fail the sense of visual continuity and motion and see their surroundings as a flickering series of still pictures (Zihl et al., 1983). These still pictures seem sharp and clear-cut, succeeding one another without overlap. Most of the time these patients report that the still pictures are somewhat blurred and they are shown in the way that they endure long enough that each 'frame' is visible when the next one is seen. This situation continues till three or four frames is exposed to the patients and the earlier ones are progressively faded. This cinematographic style of vision of these patients is comparable to films run too slowly. According to these patients' report, these attacks are rare, brief and not readily predicted. It is argued that forms of cinematographic vision in which some patients experienced (sharply separated stills or blurred snapshots in their vision) characterizes abnormalities of excitability in the neurons binding.

Such instantaneous, static visual frames may also occur in certain intoxications (especially with hallucinogens such as LSD). They report an unusual visual effect of stirring objects which leave a trailing stain with images repeating themselves, and afterimages are significantly elongated.

Likewise, Josef Zihl and his colleagues (1983) published a very fully described case of motion blindness: a woman who, resulting a stroke, was unable to perceive motion. The clinical reports maintain that the stroke injured highly specific areas of the visual cortex which is crucial for motion perception. This patient experienced "freeze frames" lasting several seconds, during which could only see a lengthy motionless image and be visually unaware of any movement around her, although her flow of thought and perception was regular. She might begin a chat with a friend standing in front of her but not be able to see her friend's lips moving or facial looks shifting. If the friend moves behind her, she continues to "see" him in front of her, even though his voice now comes from behind. She might see a car "frozen" in a significant distance away but when she tries to cross the road, that it was now almost upon her. She would see a "glacier," a frozen arc of coffee coming from the coffeemaker, but then comprehends that she had overfilled the cup and there was now a pool of coffee on the table.

In fact, continuity of vision in ordinary conditions gives no indication of the fundamental processes on which it functions. To understand its underlying mechanism, it should be decomposed experimentally or in neurological disorders, to show the components that compose it. The side effects such as flickering, perseverative, blurred images experienced in some intoxications or severe migraines gives backbone to the idea that consciousness is comprised of discrete moments. Besides, these evidences show that although such standstills of consciousness happen in some situations for a substantial period, automatic, nonconscious functions like maintenance of position or breathing, for example continues as earlier. This puzzling phenomenon brings this question whether the flow of consciousness works independently from the rest of the body system.

In ambiguous figures, like Necker cube, one is able to switch the perspective every few seconds. At the first look, one aspect of the figure projects, then to retreat, and another perspective is shown without effort of will. The viewer is able to continue back and forth in seeing the figure. Although there is no change in drawing itself, nor its retinal image (the changing process happens in cortical levels), there are two perceptual interpretations which is fueled by the conflict in consciousness. This perspective change is observed in all normal subjects and can be seen in brain imaging technologies its underlying neural mechanism.

However, some Parkinsonian patients have problem during the perspective switching. They perceive the same unchanging view for minutes or hours at an instance. Necker cube experiment on some patients shows that the normal flow of consciousness could not only be split, broken into small, snapshot-like crumbs, but also suspended occasionally, for hours at a specific time span. These clinical experience casts doubt on James's cinematic vision that consciousness, in its very nature, is ever flowing. Besides, it is not just in perception, for example our visual experience, that we directly experience such a phenomenon. Thinking, for instance, also involves a continuous sequence of occurrent thoughts and mental images, regardless of whether the content these thoughts is continuous or fragmented.

As I mentioned earlier, most of experimental data on the flow of consciousness has been concentrated on the spatial filling in visual system. How consciousness flows in time is still an underrepresented topic. However, there are some experiments which challenge this question. For example, the most recent effort in understanding the temporal process of filling the gap in consciousness comes from the study of Herzog and his colleagues (2016). They postulated a two-stage information processing model to explain the discrete perception and also consciousness. They implied that like other features, temporal features (such as duration) are coded as quantitative labels. When unconscious processing is accomplished, all features are simultaneously rendered conscious at discrete moments in time, sometimes even hundreds of milliseconds after stimuli were accessible. Their model defies prominent theories on the philosophy of mind, which believes that consciousness is a continuous stream. They also propose that the phenomenal experience of events has the appearance of continuity.

7. An underrepresented concept: the temporal problem of continuity of consciousness

Theoretically speaking, we can solve the problem of continuity if we consider these two problems seriously: The binding problem of consciousness (in philosophical jargon) or multisensory integration/spatial binding (in psychological and neuroscientific jargon) and what I call the gluing problem of consciousness (temporal binding). In other words, I believe that it would be necessary to study these two problems in order to decipher this unified, smooth, and continuous experience of our existence.

So, what is the binding problem? The binding problem or what is known among cognitive scientists, psychologists, and neuroscientists as multisensory integration is the study of how information from the different sensory modalities (such as sight, sound, touch, smell, self-motion, and taste) which have been activated in different regions of the brain are integrated by the

nervous system. To put it much precisely, phenomenologically speaking, we see ourselves as a unified 'self' in the center of the world which moves smoothly in time. However, it should be noted that the mechanism behind creating this existential unity is not integrated spatially. Different regions of the brain are distributed in building the edifice of 'conscious experience' or a special 'conscious perception' like seeing. In other words, the binding problem of consciousness pursues this question that how different brain regions are connected to create a unified 'self'.

Another puzzling issue which seems much more thought-provoking is temporal binding of consciousness. Consider this situation: when we are conscious, we have a sense of presence, and we can feel our own body spatially and temporally in the center of this world. We have the unity of this subjective reality by a phenomenological experience that I am 'one' person in 'one' world (Metzinger, 1995). Aside from how the brain constructs such an outstanding unity from spatial and mechanical means (the binding problem), lots of evidence approves that conscious perception occurs in discrete temporal frames (previously explained). So, another problem arises which I call the gluing problem. The gluing problem pursues this question that what happens in the brain that these discrete temporal frames of conscious perception are connected together in time and we feel like a continuous form of consciousness in a smooth form.

In other words, conscious perception is discrete and temporally scattered both in our inside world (different neuronal oscillations and also diverse transduction time) and the world outside (different speed of light and sound), nevertheless, we perceive that we are moving in a sleek, continuous, and smooth tunnel of life and its events. How does the nervous system deal with these temporally scattered situations? In a much fine-grained analysis, for me, the answer lies in considering two important concepts which ultimately influence on the integrity of brain organization and our flow of consciousness in time: criticality of time and its relation to our brain and sensory information processing by the brain from the outside and inside world.

Turning back to the puzzle of continuity, in my opinion, the fact lies in the relation of the brain with time and time with the outside world. Let me clarify what I mean by these relationships. There is "interior time" inside our skull which concern the duration of neuronal activity with specific frequency ranges. In other words, I mean temporal ranges or circle durations of neural oscillations which occur according to different activities in the cortical levels of the brain. This includes different frequencies ranging from infraslow (0.0001–0.1 Hz) over slow (0.1–1 Hz), delta (1–4 Hz), and theta (5–8 Hz) to faster frequencies like alpha (8–12 Hz), beta (13–30HZ), and broadband gamma (30–240HZ) (Buzsáki, 2006; Buzsáki et al., 2013; Buzsáki, 2019). These different oscillations demonstrate different functions and, most likely, related to different underlying neurophysiological mechanisms that give rise a wide range of behavioral and functional activities (Buzsáki, 2006). Thus, these different frequencies with their particular cycle durations provides "windows of opportunity" (Schroeder and Lakatos, 2009; Lakatos et al., 2013) or "islands of nowness" (Pöppel, 1996) to provide a stage in order to an action is implemented rightly.

One also needs to consider the "exterior time" encompassing our body and the world. What do I mean by the "exterior time"? The Speed of sound is ~330 m/s and the speed of light is ~300,000,000 m/s. Our nervous system is bombarded constantly by these two signals which cause different transduction time in the brain. Transduction occurs when a sensory receptor switches a type of stimulus energy (e.g. photon, sound wave) into an electrical impulse (language of the brain) that can be understood by the brain. Therefore, due to difference in speed of light and sound, the brain encounters to the challenge of different transduction time. This biophysical fact primes to a logistic difficulty for the brain because information from different sensory channels should to be integrated. For instance, when you have a face-to-face talk with someone, the movements of the speaker's lips and what you hear occur simultaneously.

According to the physical laws, this should not be happened. You should see first the movements of lips, then the voice. Nonetheless, the brain makes it simultaneous. However, there is a limit in synchronization of sound and light for the brain which is called the horizon of simultaneity (Pöppel, 1989; Pöppel et al., 1990). At a distance of approximately 10 meters, synchronization becomes problematic. The visual stimuli will be prior to that of auditory stimuli, consequently, we see first, then hearing happens. We have all experienced the lack of central availability of our conscious perception beyond the horizon of simultaneity in a rainy spring day by a marvelous thunderstorm.

Thus, in my opinion, the brain's "interior time" has to align to the "exterior time" in order to constitute "world-brain relation". Such a temporal alignment— timing on the ongoing activity is aligned to the timing of the stimulus— leads to a "world-brain relation", and it allows any organism to enjoy a smooth, uninterrupted, and well-balanced conscious experience in the world. Any imbalance of precise timing between "interior time" and "exterior time" leads to weird experiences. But, how does this function?

Time and space are, to recap, the building blocks of nature. Although time and space in physics have been widely studied, their relevance for the neuronal function of the brain and, more importantly, consciousness remains largely unknown. If time and space are the most essential attributes of nature and the brain itself is part of nature, consciousness can also be understood as a temporo-spatial phenomenon of the neural operation of the brain in this context. Therefore, we should solve two problems: The binding problem (spatial binding) and the gluing problem (temporal binding). I believe that overlooking one of these concepts will lag us behind understanding the conundrum of such a unique phenomenon of smooth continuity. In a more fine-grained explanation, we should answer four questions:

1. How many brain regions are tangled in each distinct mental act?
2. How are these regions bound together?
3. Having understood how these regions are connected in a coherent form and which areas are involved, we should know how these distributed regions are glued to each other temporally?
4. How does the brain's "interior time" align to the "exterior time" in order to constitute "world-brain relation"?

Having said the importance of considering this theoretical frame, I know that we are far from reaching any straightforward answer or any rash result. However, in this article, I do not intend to present any answer, but revitalizing a profound question. As Nikola Tesla (1934) reminds us that "The scientific man does not aim at an immediate result. He does not expect that his advanced ideas will be readily taken up. His work is like that of the planter—for the future. His duty is to lay the foundation for those who are to come, and point the way."

I should also add here that our temptation in opening new horizons by our scientific tools and the different modes of thinking do not guarantee that every phenomenon is comprehensible to our brains. We should not forget who we are, indeed. We are a bunch of cells/neurons and a product of the evolutionary process who got out of hunter-gatherer communities— thanks to the phenomenon of surplus neurons and many other lucky causes— entered to an agriculture-based civilization and created philosophy, science and technology. We should be modest and know the limits of our knowledge, sensations, and understanding of our world. But these limitations should not stop us from conquering the mysteries of ourselves and the world we live in.

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References

Abbott, L. F., DePasquale, B., & Memmesheimer, R. M. (2016). Building functional networks of spiking model neurons. Nature neuroscience, 19(3), 350.

Augustine, S. (1876). The confessions. Clark.

Barbour, J. (2001). The end of time: The next revolution in physics. Oxford University Press.

Basu, S. (1997). The conservatism principle and the asymmetric timeliness of earnings. Journal of accounting and economics, 24(1), 3-37.

Bergson, H. (1889/2001). Time and Free Will. An Essay on the Immediate Data of Consciousness. 1889. Trans. FL Pogson, MA Mineola, New York: Dover.

Beth, T., & Ekroll, V. (2015). The curious influence of timing on the magical experience evoked by conjuring tricks involving false transfer: Decay of amodal object permanence?. Psychological research, 79(4), 513-522.

Blackmore, J. T. (1972). Ernst Mach; his work, life, and influence. University of California Press.

Blackmore, S. (2002). There Is No Stream of Consciousness. What is all this? What is all this stuff around me; this stream of experiences that I seem to be having all the time?. Journal of Consciousness Studies, 9(5-6), 17-28.

Buzsaki, G. (2006). Rhythms of the Brain. Oxford University Press.

Buzsáki, G., (2019). The brain from inside out. Oxford University Press.

Buzsáki, G., Logothetis, N., & Singer, W. (2013). Scaling brain size, keeping timing: evolutionary preservation of brain rhythms. Neuron, 80(3), 751-764

Chaudhuri, R., & Fiete, I. (2016). Computational principles of memory. Nature neuroscience, 19(3), 394.

Crick, F., & Koch, C. (1990). Some reflections on visual awareness. In Cold Spring Harbor symposia on quantitative biology (Vol. 55, pp. 953-962). Cold Spring Harbor Laboratory Press.

Crick, F., & Koch, C. (2003). A framework for consciousness. Nature neuroscience, 6(2), 119-126.

Dassonville, P., Bridgeman, B., Bala, J. K., Thiem, P., & Sampanes, A. (2004). The induced Roelofs effect: two visual systems or the shift of a single reference frame?. Vision research, 44(6), 603-611.

Dimmick, F. L. (1920). An experimental study of visual movement and the phi phenomenon. The American Journal of Psychology, 31(4), 317-332.

Fink, A., & Neubauer, A. C. (2005). Individual differences in time estimation related to cognitive ability, speed of information processing and working memory. Intelligence, 33(1), 5-26.

Fuchs, A. F. (1967). Saccadic and smooth pursuit eye movements in the monkey. The Journal of Physiology, 191(3), 609.

Galambos, R., Makeig, S., & Talmachoff, P. J. (1981). A 40-Hz auditory potential recorded from the human scalp. Proceedings of the national academy of sciences, 78(4), 2643-2647.

Gibson, J. J. (1975). Events are perceivable but time is not. In The study of time II (pp. 295-301). Springer, Berlin, Heidelberg.

Gray, C. M., König, P., Engel, A. K., & Singer, W. (1989). Oscillatory responses in cat visual cortex exhibit inter-columnar synchronization which reflects global stimulus properties. Nature, 338(6213), 334-337.

Gruber, R. P., & Block, R. A. (2013). The flow of time as a perceptual illusion. The Journal of Mind and Behavior, 91-100.

Hafed, Z. M., & Clark, J. J. (2002). Microsaccades as an overt measure of covert attention shifts. Vision research, 42(22), 2533-2545.

Hameroff, S. (2003). Time, consciousness and quantum events in fundamental spacetime geometry. In The nature of time: Geometry, physics and perception (pp. 77-89). Springer, Dordrecht.

Heine, S. (1994). Dogen and the koan tradition: A tale of two Shobogenzo texts. SUNY Press.

Henderson, J. M., Brockmole, J. R., Castelhano, M. S., & Mack, M. (2007). Visual saliency does not account for eye movements during visual search in real-world scenes. In Eye movements (pp. 537-III). Elsevier.

Herzog, M. H., Kammer, T., & Scharnowski, F. (2016). Time slices: what is the duration of a percept?. PLoS Biology, 14(4), e1002433.

Hirsh, I. J., & Sherrick Jr, C. E. (1961). Perceived order in different sense modalities. Journal of experimental psychology, 62(5), 423.

Hume, D. (1739/2003). A treatise of human nature. Courier Corporation.

Husserl, E. (1928). Lectures on the Phenomenology of Inner Time-Consciousness.

James, W. (1890/1998). The principles of psychology. 2(1998). Thoemmes Press.

Kant, I. (1908). Critique of pure reason. 1781. Modern Classical Philosophers, Cambridge, MA: Houghton Mifflin, 370-456.

Koch, C. (2004). The Quest for Consciousness: A Neurobiological Approach. Roberts & Company Publishers.

Kovaćs, I., & Julesz, B. (1992). Depth, motion, and static-flow perception at metaisoluminant color contrast. Proceedings of the National Academy of Sciences, 89(21), 10390-10394.

Krauzlis, R. J., Bogadhi, A. R., Herman, J. P., & Bollimunta, A. (2018). Selective attention without a neocortex. Cortex, 102, 161-175.

Lakatos, P., Musacchia, G., O'Connel, M. N., Falchier, A. Y., Javitt, D. C., & Schroeder, C. E. (2013). The spectrotemporal filter mechanism of auditory selective attention. Neuron, 77(4), 750-761.

Leibniz, G. W. (1687/1989). The metaphysical foundations of mathematics. In Philosophical papers and letters (pp. 666-674). Springer, Dordrecht.

Logothetis, N. K. (1999). Vision: a window on consciousness. Scientific American, 281(5), 68-75.
Metzinger, T. (1995). The problem of consciousness. Conscious experience, 3-37.

Murthy, V. N., & Fetz, E. E. (1992). Coherent 25-to 35-Hz oscillations in the sensorimotor cortex of awake behaving monkeys. Proceedings of the National Academy of Sciences, 89(12), 5670-5674.

Noë, A. (2002). Is the visual world a grand illusion?. Journal of consciousness studies, 9(5-6), 1-12.

Oppenheimer, J. M. (1990). Science and Nationality: The Case of Karl Ernst von Baer (1792-1876). Proceedings of the American Philosophical Society, 134(2), 75-82.

Podvigin, N. D., & Pöppel, E. (1994). Characteristics and functional meaning of oscillatory processes in the retina and lateral geniculate body. Sensory Systems, 8, 97-103.

Pöppel, E. (1985). Grenzen des Bewußtseins. Deutsche Verlags-Anstal.(Translated as Mindworks: Time and conscious experience. Harcourt Brace Jovanovich, 1988).

Pöppel, E. (1989). The measurement of music and the cerebral clock: a new theory. Leonardo, 83-89.

Pöppel, E. (1996). Reconstruction of subjective time on the basis of hierarchically organized processing system. In Advances in psychology (Vol. 115, pp. 165-185). North-Holland.

Pöppel, E. (1997). A hierarchical model of temporal perception. Trends in cognitive sciences, 1(2), 56-61.

Pöppel, E., & Logothetis, N. (1986). Neuronal oscillations in the human brain. Discontinuous initiations of pursuit eye movements indicate a 30-Hz temporal framework for visual information processing. Die Naturwissenschaften, 73(5), 267-268.

Pöppel, E., Schill, K., & von Steinbüchel, N. (1990). Sensory integration within temporally neutral systems states: a hypothesis. Naturwissenschaften, 77(2), 89-91.

Radilova, J., Pöppel, E., & Ilmberger, J. (1990). Auditory reversal timing. Activitas nervosa superior.

Ramachandran, V. S., Rogers-Ramachandran, D., Stewart, M., & Pons, T. P. (1992). Perceptual correlates of massive cortical reorganization. science-new york then washington-, 258, 1159-1159.

Robinson, T. M. (Ed.) (1987). Heraclitus: Fragments. Toronto, ON: University of Toronto Press.

Ronkin N. Abhidharma. The Stanford Encyclopedia of Philosophy. Stanford, CA: Stanford University. 2014.

Rose Addis, D., & Tippett, L. J. (2008). The contributions of autobiographical memory to the content and continuity of identity a social-cognitive neuroscience approach. Self-Continuity Individual and Collective Perspectives.

Ruhnau, E., & Haase, V. G. (1993). Parallel distributed processing and integration by oscillations. Behavioral and Brain Sciences, 16(3), 587-588.

Sartre, J. P. (1943/2015). Being and nothingness. Central Works of Philosophy: Twentieth Century, Moore to Popper, 4, 155.

Schleidt, M., Eibl-Eibesfeldt, I., & Pöppel, E. (1987). A universal constant in temporal segmentation of human short-term behavior. Naturwissenschaften, 74(6), 289-290.

Schroeder, C. E., & Lakatos, P. (2009). Low-frequency neuronal oscillations as instruments of sensory selection. Trends in neurosciences, 32(1), 9-18.

Schwender, D., Klasing, S., Daunderer, M., Madler, C., Pöppel, E., & Peter, K. (1995). Awareness during general anesthesia. Definition, incidence, clinical relevance, causes, avoidance and medicolegal aspects. Der Anaesthesist, 44(11), 743-754.

Shannon, C. E. (1948). A mathematical theory of communication. Bell system technical journal, 27(3), 379-423.

Steinman, R. M. (2001). Coordinating Actions in Nearby 3-D Space. Maryland university college park.

Sternberg, S. (1966). High-speed scanning in human memory. Science, 153(3736), 652-654.

Tanaka, J. W., & Sengco, J. A. (1997). Features and their configuration in face recognition. Memory & cognition, 25(5), 583-592.

Tesla, N. (1934). Radio power will revolutionize the world. Modern Mechanix and Inventions.

Treisman, A. M., & Gelade, G. (1980). A feature-integration theory of attention. Cognitive psychology, 12(1), 97-136.

Treisman, A., & Gormican, S. (1988). Feature analysis in early vision: evidence from search asymmetries. Psychological review, 95(1), 15.

Treisman, A., & Sato, S. (1990). Conjunction search revisited. Journal of experimental psychology: human perception and performance, 16(3), 459.

Van Lommel, P. (2006). Near-death experience, consciousness, and the brain: A new concept about the continuity of our consciousness based on recent scientific research on near-death experience in survivors of cardiac arrest. World Futures, 62(1-2), 134-151.

VanRullen, R., & Koch, C. (2003). Is perception discrete or continuous?. Trends in cognitive sciences, 7(5), 207-213.

VanRullen, R., Carlson, T., & Cavanagh, P. (2007). The blinking spotlight of attention. Proceedings of the National Academy of Sciences, 104(49), 19204-19209.

Varshney, L. R., Sjöström, P. J., & Chklovskii, D. B. (2006). Optimal information storage in noisy synapses under resource constraints. Neuron, 52(3), 409-423.

Vierordt, K., 1868. Der zeitsinn nach versuchen. H. Laupp.

von Baer, K. E. (1828). Über Entwickelungsgeschichte der Thiere: Beobachtung und Reflexion (Vol. 1). Bornträger.

von Helmholtz, H. (1825/1924). Helmholtz's treatise on physiological optics (Vol. 2). Optical Society of America.

von Steinbüchel, N. (1995). Temporal system states in speech processing. Supercomputing in brain research: from tomography to neural networks (Eds. HJ Herrmann, DE Wolf and E. Pöppel). World Scientific, Singapore, 75-81.

Whitehead, A. N. (1968/1938). Modes of thought (Vol. 93521). Simon and Schuster.

Wittmann, M., & Szelag, E. (2003). Sex differences in perception of temporal order. Perceptual and motor skills, 96(1), 105-112.

Zihl, J., Von Cramon, D., & Mai, N. (1983). Selective disturbance of movement vision after bilateral brain damage. Brain, 106(2), 313-340.