

# How Long is a Piece of Time? Phenomenal Time and Quantum Coherence. Toward a Solution

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## ABSTRACT

Time is intimately embedded in the way that we experience the world around us. Indeed, our subjective temporal experiences seem so natural that we assume that this aspect of our conscious lives conveys something of the true nature of the world that we observe - that the events around us really do unfold in a temporally ordered and continuous way. However, deeper reflection combined with our understanding of the physics of the universe reveals a problem of subtle complexity that seems to confound any classical approach to a solution.

Time can be addressed by its following aspects: (i) Physical time: this is usually clock time; for example, time in attosecond unit can now be measured. (ii) Biological time: although all brain areas can be considered as biological clocks, the suprachiasmatic nucleus is the master molecular clock; it can be measured in msec units. (iii) Perceptual rate of time: this can be measured in cycles per second (Hz) using critical flicker frequency (CFF) psychophysical method. It varies from 300 Hz for the honeybee to 80 Hz for Buddhist monks during meditation and 60 Hz in bright light and 24 Hz in dim light for normal humans. Color fusion frequencies are lower. Time can be integrated up to 160 msec for stimuli with luminance contrast, whereas color channels have longer integration time. (iv) Subjective passage of time can be longer (in crisis) or shorter (with age) than physical time depending on the state of mind. (v) Relative positions in time: these can be distinguished in two ways: (a) each position can be 'earlier than' or 'later than' positions. This distinction is permanent. (b) Each position is either Past, Present,

or Future. This distinction varies continuously. (vi) Time can be linear (future  $\rightarrow$  present  $\rightarrow$  past) or cyclic (day  $\leftrightarrow$  night).

There are two hypotheses for *phenomenal time*: (i) classical psychophysical approach, which leads to temporal frequency tuned mechanisms that are not sensitive at temporal frequencies equal to or greater than CFF and (ii) quantum approach, where we argue that the problem of the subjective experience of time (*phenomenal time*) can be addressed using quantum coherence – specifically, a solitonic (traveling wave) coherent state similar to a Bose-Einstein condensate. In our view, both hypotheses are complementary to each other. The neural correlate of the linear nature of time includes frontal cortex and that of cyclic nature includes suprachiasmatic nucleus.

**Key words:** Physical time; Biological time; Perceptual rate of time; Critical flicker frequency (CFF); Color fusion frequency; Temporal integration; Luminance and color channels; Subjective passage of time; Past, Present, or Future; Linear and cyclic nature of time; Subjective experience of time; Phenomenal time; Quantum coherence; Solitonic (traveling wave); Bose-Einstein condensate.

## 1. Introduction

Bergson argued that time could only be understood from the contemplation of the consciousness moment, i.e., time is “grasped by, and belongs only to, inner consciousness” (Bergson 1889/1960). He used the term ‘duration’ to refer to what he understood to be the essence or ‘*Elan Vital*’ of our beings and that this ‘duration’ could not be quantified conceptually. For Bergson, time formed a sub-conceptual, but intrinsic aspect of consciousness. Following Bergson’s lead, we shall use thought experiments to show that no classical analysis rooted in cause and effect can provide tangible insight into why we experience time (referred to as ‘phenomenal time’) as flowing. However, unlike Bergson, we shall argue that a physical determinant for the apparent ‘rate’ at which we experience time may be identified. We shall argue that quantum coherence<sup>1</sup> offers a context that may root Bergson’s ‘*Elan Vital*’ in the physical.

According to Vimal (2008c), “In subjective experiences (SEs) of space and time, space includes the subject and objects. The SE of subject, *I-ness*, is called ‘Self’; this is partly elaborated in Bruzzo and Vimal (2007). The SEs of objects, subject’s external body, and subject’s internal states such as feelings, thoughts, and so on can be investigated using the PE-SE framework (Vimal 2008a,b).<sup>2</sup> An overview of consciousness and the structure of matter, based on PE-SE framework, is given in MacGregor and Vimal (2008). We can have SEs or first person experiences (1Es) of time, external space (subject and objects), and

internal entities (emotions and thoughts). The SE of time is called *phenomenal time* (which includes *past*, *present* and *future*) and the SE of space *phenomenal space*.” Thus, *phenomenal time*<sup>3</sup> can be defined as the subjective, personal, or first person experience of time.

### 1.1. The Problem of Phenomenal Time

According to James (1890/1981), in the context of phenomenal time, (i) Clay’s ‘the obvious past’, ‘the specious present’, ‘the real present’, and ‘the future’ play important role in the stream of consciousness, (ii) the ‘sensible present’ and ‘spacious present’ have duration (a few seconds to a minute), which is in recent past, i.e., working memory, whereas the ‘the real present’ implies a durationless instant, the latter boundary of ‘specious present’ (Hameroff 2003), (iii) the perception of space and that of time interacts (Vimal 2008c), i.e., “Date in time corresponds to position in space”, (iv) the sensations of duration have a much narrower range (a few seconds) than those of space (miles at a glance), (v) “To be conscious of a time interval at all is one thing; to tell whether it be shorter or longer than another interval is a different thing”, (vi) “an interval sounded shorter if a long one had immediately preceded it, and longer when the opposite was the case”, (vii) “our sense of time is sharpened by practice”, (viii) “Tracks of time filled (with clicks of sound) seem longer than vacant ones of the same duration, when the latter does not exceed a second or two”, (ix) “a loud sound, limiting a short interval of time, makes it appear longer, a slight sound shorter”, (x) ‘we have no sense for empty time’, (xi) “In general, a time filled with varied and interesting experiences seems short in passing, but long as we look back. On the other hand, a tract of time empty of experiences seems long in passing, but in retrospect short”, (xii) “The same space of time seems shorter as we grow older”, (xiii) ‘the feeling of past time is a present feeling’, and (xiv) a succession of feelings (or ideas or thoughts) is not a feeling (or idea or thought) of succession.

Phenomenal time is a long standing problem for cognitive science and the philosophy of mind. For St Augustine, a central enigma was the subjective experience of change. He argued that the experience of change must involve a connection between future events, present events, and past events. However, if each moment comprised an infinitely thin slice of time, then such a connection seemed impossible. One might argue that the experience of change emerges simply as a consequence of the causal relationships that effect transitions, however, as Le Poidevin put it ‘Change in our experience is not the same thing as experience of change.’ (Le Poidevin 2004).

The experience of time is a central qualitative component of conscious experience. If a solution to the problem of phenomenal time could be found this would amount to a significant step forward in our search for the physical basis of

conscious states. In our opinion, deep philosophical problems as is instanced by the problem of phenomenal time should be considered as significant clues that may lead us to the underlying physical processes involved.

Instead of approaching the problem of phenomenal change - an endeavor which has frustrated many philosophers, we shall approach the problem in a different way – by attempting to solve another closely related problem – the problem of the apparent rate at which time is experienced. However, we immediately encounter what seems to be an intractable problem. It would seem reasonable that any explanation of phenomenal time rooted in the physical must necessarily involve temporal quantities (durations). It is difficult to see how an explanation of the rate at which we experience time could not involve time in some way. But, any explanation of phenomenal time which involved durations would appear to lead to vicious circularities (tautologies).

Also, the concept of an absolute and fixed rate of time is wholly absent from our physical description of the universe. From the standpoint of physics, although we may claim (within limits determined by quantum mechanics and relativity) that event A precedes event B, there is no criteria that determines how quickly or how slowly consecutive events should be experienced. According to McCall (1994), “the general view today of scientifically minded philosophers concerning the temporal passage is that it is a subjective illusion”.<sup>4</sup>

This seems counter intuitive. We know, for example, that it takes exactly a minute for the second hand of a watch to make a single revolution. However, we can only verify this by correlating the behavior of the watch hand to other events that exhibit predictable relative sequential behavior. For example, an early pioneer of clock design, John Harrison, used the rotation of the Earth and the movement of the stars to establish a relative fixed datum by which the accuracy of a clock could be verified. In this instance, what is being verified is not the accuracy of the clock in measuring out the constant flow of time but the predictable, sequential behavior of the clock when compared to another sequential and relatively fixed datum – in this case the rotation of the Earth.

The time measured in physics (or objective time) is physical time. The Planck time is the unit of time in the system of natural units known as Planck units, which is the time it would take a photon traveling at the speed of light in a vacuum to cross a distance equal to the Planck length; it is about  $5.39 \times 10^{-16}$  seconds<sup>5</sup>; however, it has not been measured yet. Images of electrons leaving atoms were produced by short pulses of laser light and recorded within 100 attoseconds ( $10^{-16}$  seconds); this is the shortest time measured so far.<sup>6</sup>

Following on from the above, the objection may be raised that there are indeed criteria by which we may determine an absolute rate of time. Extremely accurate clocks used by scientists often depend upon quantum phenomena – oscillatory rates of particles, for example. However, this in no way points to a

constant *rate* of time. Although these techniques involve the fundamental and extremely predictable behavior of quantum phenomena, the temporal ‘quantities’ derived from them are only meaningful to us when compared to temporal quantities of which we already have experience.

The absence of temporal flow in physics is independent of the amount, complexity or content of information. From this we can lay to rest a very common and intuitive assumption which serves as an explanation (or partial explanation) of our experience of temporal flow (phenomenal time): Our experience of temporal flow cannot be explained in terms of the rate at which stimuli impinges upon the senses and the nervous system.

Another seemingly reasonable approach that we may lay to rest is that the apparent rate at which time is experienced depends upon the amount of neural processing done in any particular objective time segment. The idea is that the more neural processing achieved equates to a ‘slower’ rate at which time is experienced. However, this approach fails for the same reason that the idea that our experience of time is determined by the rate at which stimulus impinges upon the nervous system fails. The absence of temporal flow in physics is totally independent of the amount, complexity, or informational content of physical events taking place, whether the physical events being considered are taking place outside or inside our heads. This point should become clearer as the argument progresses.<sup>7</sup> Thus, the fundamental problems that we address are as follows: (i) what are the various aspects of time? (ii) What is the subjective experience (SE) of time or phenomenal time? And (iii) what is the neural correlates of phenomenal time?

### *1.2. Goal*

This paper is solely concerned with our experience of time – in the moment. It will attempt to discover what physical quantity or process associated with neural processing is implicated in determining the apparent ‘rate’ at which events seem to unfold and which thus forms an intrinsic component of our moment by moment experience. We shall be addressing directly that aspect of our consciousness which reveals to us a world of constant flow and change that underpins our sense and intuitions of time.

We shall first argue that phenomenal time poses a vexing problem within the context of the physics of the universe, as we currently understand it.

We shall approach the problem of phenomenal time by examining it within the context of a thought experiment that offers an original and thought-provoking perspective upon the problem.

We shall argue that the problem of phenomenal time cannot be solved within the context of a classical physics. Furthermore, we shall suggest an

approach rooted in quantum coherence – specifically, a solitonic (traveling wave) coherent state similar to a Bose-Einstein condensate (BEC), and demonstrate how a key aspect of the problem of phenomenal time may be resolved and we shall point to a specific physical quantity as the principle factor that determines the apparent rate that we experience time.

Lastly, we shall discuss the physiological correlates of cyclic and linear nature of time underlying temporal consciousness.

Having outlined the problem, we must now address the question of what physical/physiological quantity or process is implicated in determining the apparent rate at which time is experienced.

## 2. Models related to time

The background to the current proposal is a ‘fractal catalytic model’ of consciousness described in Davia (2006), which proposes that living processes are ‘catalytic’ at multiple levels. From the scale of the enzyme up to the scale of the entire organism, a living process exists and persists by mediating transitions in its environment as a catalyst. Within the theory, our perceptions arise as a result of mediating transitions via fixed points (structure) implicit in our bodies, the environment and the interactions between them. Support for the model comes from the extensive evidence of particular types of waves (solitonic traveling waves) that are associated with dissipating energy via fixed structure that are found at all levels of a biological organism.

A compatible analysis is a dissipative quantum model of the brain (Vitiello 2001), in which the brain is constantly entangled with its environment in a way that maintains the unified whole in time. This entanglement causes our perceptions to be imprinted upon memory, and is then processed into the cognitive map of our environment. This map appears to be in relative motion (‘relating the presence of consciousness to the contents consciousness is conscious of’)<sup>8</sup> during the SE of passage of time (Franck 2004; Husserl 1966/96).

The soliton-catalytic model of Davia (2006) does not contradict the quantum-dissipative model of Pessa and Vitiello (2003), rather they are equivalent to each other; they try to connect discrete neural activities to classical field to quantum field.<sup>9</sup> Within the catalytic model, it is noted, that solitons are a classical analogue of quantum particles suggesting the possibility that solitons may ‘induce’ macroscopic quantum states. Although solitons are often defined as non-dissipative, this is not true for similar phenomena that occur within dissipative media. Within the soliton-catalytic model the brain is considered to be an excitable media and therefore a dissipative media. In the soliton-catalytic model (Davia 2006), energy is dissipated via structure (fixed points that do not change under transformation).

According to Vimal (2008c), the wriggles in Humphrey's framework (Humphrey 2000) of sensation from the internalization of action during evolution can be considered equivalent to the traveling wave in soliton-catalytic model (Davia 2006).<sup>10</sup>

Heidegger (1927/1962) bridged western and eastern thought relating to relative motion and phenomenal time. A western view is that consciousness ('Being') is distinct from the content of consciousness ('being-there of things and events'). An eastern view for consciousness is 'empty Being' or 'filled Nothing' (Franck 2004). Both views may be related.

Time is the dimension of change that has two meanings: (i) As in physics, the 'real change' means that 'world states differing in 'date' (or time) also differ in structure or function', and (ii) in 'temporal change' future becomes present and then past; both changes are unified in the subjective experience of time (Franck 2003). According to Franck (2004), "we have to look for the symmetry that needs to be broken for conceiving time as a process instead of as a dimension only [...] The 'paradox' of a Now that lasts 30 milliseconds<sup>11</sup> and forever at the same time is resolved by breaking the symmetry between presence and distance in time. The symmetry broken is that between the lifetime and the diameter of the Now. The Now is allowed to last 30 ms and forever at the same time by being put into motion relative to the eigentimes adding up to time [t]". Thus, the symmetry breaking will lead to both continuous Self<sup>12</sup> and the change of the content of consciousness at a certain rate, such as critical flicker frequency. In addition, one could argue that the 'present' (the content of consciousness) travels forward into 'future' and backward into 'past', but at what rate?

One might argue that the apparent rate at which time is experienced (phenomenal time) depends on the spatio-temporal characteristics of visual mechanisms. For example, human visual system has one luminance and two color (Red-Green and Yellow-Blue) psychophysical channels (Kaiser & Boynton 1996), each has spatial, temporal, and spectral frequency tuned mechanisms. There are six bandpass spatial frequency tuned luminance mechanisms (Wilson et al. 1983) and six spatial frequency tuned Red-Green color mechanisms (one lowpass and five bandpass) (Vimal 1998a, 2002a). There are four temporal frequency tuned luminance mechanisms: one low-pass with a corner frequency of 8 Hz, and three bandpass with bandwidth of 2-2.5 octaves peaking between 4-8 Hz (Lehky 1985). There are two temporal frequency tuned color mechanisms: one low-pass and other bandpass (Metha & Mullen 1996). The above are threshold mechanisms, which have flattening effect and show color-contrast constancy at suprathreshold level (Vimal 2000; Vimal et al. 1995).

The luminance channel showed no temporal integration beyond 160 msec, whereas color channels had longer integration time (Smith et al. 1984). Our goal is to investigate a general unifying principle underlying these tuned

mechanisms and to relate them to phenomenal time.

In chaos theory, the balance between linear and nonlinear time involves (a) the changing demands as one approaches and departs bifurcation points, and (b) time dilation and contraction as a control parameter (Abraham 1995). For example, meditators self-organize time perception differently compared to non-meditators: critical flicker fusion frequency progressively increase by 11-15% following yoga training (Vani et al. 1997). “Meditating Tibetan Buddhist monks show highly coherent, high amplitude gamma synchrony EEG in the range of 80 per second” (Lepine 2007). “Buddhists commonly assert that the continuum of awareness is composed of successive moments, or ‘pulses’, of cognition each lasting for about ten milliseconds” (Wallace 1999).

Two views of time that initially appear relevant, but in fact, are not relevant because they do not support the concept of a rate of temporal flow are the following. Positions in time can be distinguished in two ways (McTaggart 1908)<sup>13</sup>: In series A, ‘each position is either Past, Present, or Future’. In series B, ‘each position is Earlier than some, and Later than some, of the other positions’. Since time involves change (as in series A) and since the relations of earlier and later are permanent (as in series B) and since objective present could be different from the SE of time, both series should be considered to address the problem of subjective experience of time or phenomenal time. However one could also argue as follows:

The difference between series A and B is that the view of time of series B is similar to that of Einstein in that time is understood to be a static structure in which no ontological significance is attributed to any particular moment - all moments have equal ontological status. A problem with this view is – ‘Why now?’

The view in series A is that there is only a now - a single moment of becoming. This view of time is a sort of folk or intuitive perspective that most people believe. Neither of these views really impinges upon the arguments in the paper because neither support the idea of a rate of time.

### **3. A Thought Experiment and the Apparent rate of phenomenal time**

#### *3.1 Thought Experiment*

In order to analyze the problem of phenomenal time, consider the following thought experiment. Let us suppose that we have obtained a film of an experiment being conducted by an alien scientist. We have sufficient information derived from the physical events depicted in the film to be able to play the film at the same rate as it was recorded. So we know that should a human being have been present at the scene, he would have experienced events as they would be depicted

if the film was shown at that speed. However, what we are really interested in doing is showing the film at a rate that would depict events to us as the alien scientist experienced them. It so happens that our alien scientist has a transparent head (a peculiarity of the race that this alien scientist belongs to) and we are afforded a view of his neural activity. The alien scientist of our thought experiment is conducting an experiment in order to verify empirically the mathematical model that describes an aspect of the physical universe. We, on the other hand, are more interested in what is going on in his head. There is a rotating fan in the room and the scientist happens to be listening to some music. There is a point in the music characterized by a sustained single note – a sine wave.

The use of an alien scientist is not critical to the thought experiment. Given the proposition that a physical quantity is implicated in determining the apparent rate that we experience time, then, the probability that that physical quantity is precisely the same for any two human beings is vanishingly small. So, for the purposes of the thought experiment we may assume that the alien scientist's brain works in the same way as a human brain.

It is important to stress that the use of the film in this thought experiment is simply a device that is helpful in enabling us to appreciate that the same temporally structured event may, potentially, be experienced in different ways. Also, it enables us to manipulate a familiar technology in a way that simulates what it might be like to experience time in different ways in an intuitive way. Instead of a film we might simply imagine that we experience the depicted event at different subjective temporal rates. This point is being made so that the fact that we are using a film and that there would necessarily be physical facts associated with the circumstances in which such a film was recorded, these facts should not distract us from the point of the thought experiment.

Now, given what may be described as 'the brute fact' of phenomenal time – that the various stimuli in the scientist's lab gives rise to a subjective experience of time such that there is a particular rate that we may play the film to represent events as the scientist experiences them, then we might be able to perform some sort of analysis of the stimuli and the resulting neural activity that will provide us with information that will help us to determine precisely what that rate is.

As we run the film at different rates, the frequency at which the fan in the scientist's lab rotates appears to increase or decrease as does the sympathetic neural response. Each time frame gives us a completely consistent physical view of the events depicted in the film. From a purely physical perspective there is absolutely nothing that favors one temporal reference frame above another. Whether we are considering physical events as they are occurring in the lab or the physical events taking place in the scientist's head, there exists a fundamental symmetry such that any rate at which the film is shown represents an equivalent perspective of the physical events taking place.

So, the scientist in the film does his experiment, performs his calculations and is satisfied that his model accurately describes the universe around him (and, implicitly, also accurately describes the physical processes going on in his own head). Although the film may ‘look’ very odd from our perspective when run at different speeds, this does not alter the fact that all these relative time frames are completely equivalent perspectives on the physical events. Time quantities that appear in his equations conform to the time frame as it is displayed upon clock on the wall in his lab and his calculations appear to be completely consistent when observed from any subjective time frame. But, it seems, there emerges from this symmetry an asymmetry that requires an explanation. For there is one particular rate at which the film may be played that affords us a consistent relationship between physical and mental events.

It may seem that an initial difficulty arises as a consequence of the fact that we are embedded in the thought experiment. Our own subjective experience of time forms an intrinsic part of the way in which we evaluate it. Also, given the claim that there is no absolute rate of time, we can never make truly meaningful statements about temporal flow – only, potentially, relative subjective temporal flow. We might agree with McCall that temporal flow is simply illusory. However, the thought experiment reveals that differences in temporal perception (illusory or not) may be precisely quantified (if only in relative terms). Thus, if one wanted to know what it would be like if we were to experience time at twice the rate that we actually do, then we may simply film an event and play the film at twice the rate it was recorded. Playing the film at the correct rate to depict events as the scientist in the film experiences them may only provide information about the relative difference of subjective temporal experiences – but this information is precisely quantifiable, and suggests the strong possibility that the neural correlate that determines the relative rates at which time is experienced should be clearly identifiable. Furthermore, if we were to conclude that subjective experience cannot be used to form a basis of our logical enquiry into the mind then this is tantamount to the abandonment of our quest to find the neural correlate of conscious states.

To develop the thought experiment further: let us suppose that we have obtained film of two alien scientists who are arguing about the physical basis for phenomenal time. At one point in the film, one of the scientists offers an elaborate and, at first sight, convincing argument that is supposed to amount to a solution to the problem. He claims to have thought of a solution that shows why we must experience time as flowing at a particular rate. Again, we may run this film at any rate that we wish and we may claim with confidence that each rate at which we run the film represents an equally valid and consistent perspective on the physical events taking place. Any claim being made by the scientist pertaining to the physical properties, quantities or events that he is describing and using to support

his argument will necessarily be consistent with the physical properties and events as they are depicted in the film. Whatever argument the scientist may have thought of, in as far as that argument involves true statements about the physical world (inside or outside of his head), it will always (and necessarily) be consistent within the time frame context of the film – at whatever rate it is shown. From this it would seem to follow that, the fact that the scientist’s arguments will be completely consistent in any time frame then, any such argument cannot be used by observers such as ourselves to understand why we (or the alien scientists) experience time as flowing at a particular rate. We must ask ourselves what sort of explanation could be meaningful and useful from any temporal reference frame and which could also be used to adjust the rate of the film to correctly depict events as experienced by the alien scientist?

All this seems to lead to a contradiction. If the scientist is claiming that he has found the physical basis for phenomenal time that demonstrates why we should experience time at a particular and fixed rate, then this seems to be fundamentally at odds with the claim being made here – namely that his arguments will be true given *any* time rate reference frame. Let us consider what we are looking for when we are trying to discover the physical basis for phenomenal time by analyzing the film of the alien scientist at different rates. We naively hope that there is an analysis that can be performed within the context of any time frame that will yield a result that is totally independent of the speed at which the film is shown and which somehow ‘points’ to a particular time frame as being the one corresponding to the scientist’s subjective experience. But, of course, this is impossible, not only because each time rate reference frame is equally valid, but also, because we cannot even make objective claims about the time reference frame of the film, that we, as observers, are experiencing. This is because physics does not support the idea of time as flowing.

But, let us test this claim further. Are there not instances where we may concede that, although there may be a physical consistency between the use of language and corresponding physical events that are their referents, the claim that there might also be a potentially consistent phenomenology (and semantics) is untenable? Let us suppose that a linguist correctly interprets a sentence the gist of which may be understood as: ‘I can just about see the clock hand moving.’ At the speed at which the film is being shown we humans have no difficulty in seeing the clock hand move and may (and perhaps correctly) adjust the speed of the film so that we too can just about see the clock hand moving. From this, one could hypothesize that the primary factor that determines the apparent rate at which time is experienced is the lower limit of a conscious entity’s sensitivity to change.

### 3.2 *Apparent rate of phenomenal time*

This hypothesis is based upon our own subjective experience of what it is like to ‘just about be able to see something move’ and relies upon our inability to conceive of what it might be like if our experience of change was not characterized by a continuum of experiential states – i.e. from almost stationary to moving very fast as we experience them. But, our inability to conceive of what it might be like to experience change in a radically different way is not sufficient evidence that a very different relationship between changing stimuli and corresponding phenomenological states is not possible.

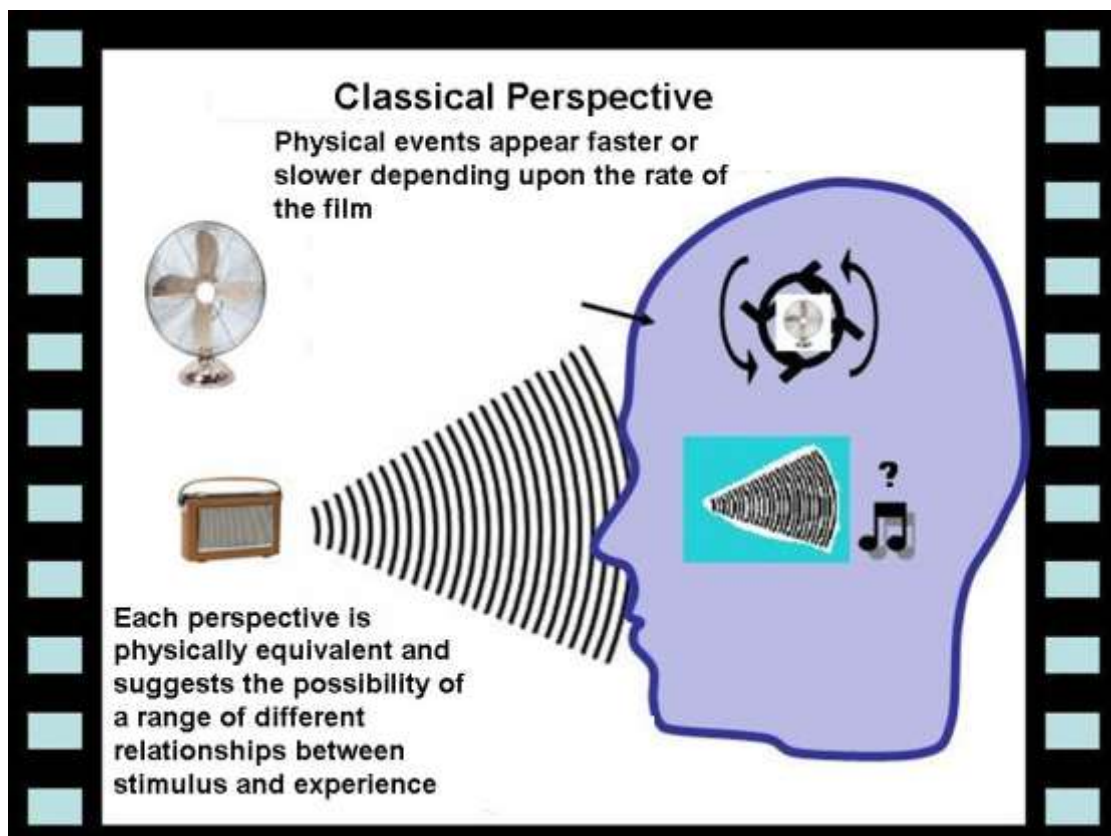
This analysis would seem to be significant with respect to a commonly held assumption in linguistics and advocates of strong AI – specifically: ‘If you take care of the syntax, the semantics will take care of itself’ (Haugeland 1985). It would seem that the above analysis would allow for the possibility that for any given syntax (in as far as it may refer to temporally structured stimuli) there may be a potentially infinite set of corresponding and consistent experiences and thus a potentially infinite set of meanings (see Figs. 1 and 2).

Although we may concede that the limits of a conscious entity’s sensitivity to change is an important consideration for our understanding of time perception and may indeed be a critical factor (as we believe it is), it cannot be used as an explanation for phenomenal time. This is because phenomenal time is precisely that which we are attempting to explain; thus, any explanation of phenomenal time rooted in our experience of change (even at a threshold) is ultimately question begging.

But, perhaps the above point may be strengthened in a different way. Let us suppose that we have developed a technology such that we are able to alter certain aspects of neural processing in real time. Our subject is a conscious entity who is watching a clock hand move. He can see the clock hand moving quite easily and he has not reached the lower limit of his sensitivity to change. We use our technology to increase his sensitivity to change by implanting additional highly sensitive neurons (and associated sensors) that only come into play when the subject’s original lower level of sensitivity is reached. These additional neurons are completely inactive above this threshold. Given that there is no difference in the neural activity of the subject whilst he observes a changing stimulus above the original threshold, it is difficult to see why his experience of the watch hand (and thus his experience of time) should be any different to what it was before the change was made.

If thresholds of sensitivity to change are the ultimate determinant of time experience it would seem to follow that these thresholds must play a role in all experiences. If a particular brain state embodied no information about the threshold of sensitivity to change then, following on from the previous analysis,

we are left with the puzzle of why one particular phenomenal state associated with temporal flow should be favored from a potentially infinite set of possible states. Also, there would seem to be a question arising from the consideration how and why such a complex system evolved. It can be strongly argued that it is the physical behavior of an organism that determines its survival potential. From a classical perspective, physical changes in the brain related to behavior are all that is required to achieve successful survival strategies. In this respect, no consideration of mental states need apply. If thresholds of sensitivity to change necessarily play a role in all mental states this seems to suggest that the process of evolution of the brain involves consideration and selection of phenomenal states – a problematical position!



**Fig. 1** The Classical Perspective

The problem with the classical approach (Fig. 1 and 2) is that any rate that we show the film offers us a completely consistent perspective on the physical events taking place (both outside and inside scientists head). Why should one rate that we show the film offer us a consistent relation between physical and mental events and no other?

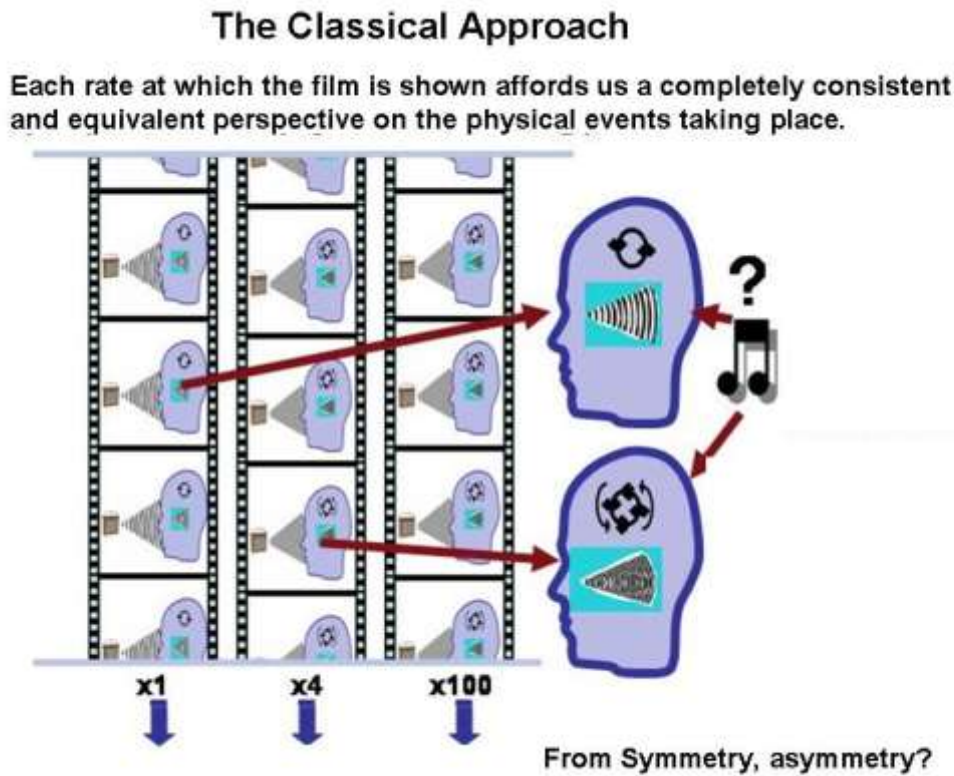


Fig. 2 – The Classical Approach

#### 4. Continuous Experiences and Invariance

Given the analysis in the previous section, it would seem that there can be no explanation for phenomenal time rooted in cause and effect. However, part of the problem may lie in certain assumptions are making. It seems quite natural (if not inevitable) that we should begin to address this problem within the context of a causal relationship between external stimuli and consequent brain states (including causal relationships within the brain itself) such that temporarily structured events that are observed lead to correspondingly temporally structured neural events. Such an approach assumes that the answer to the question of phenomenal may be found within the context of these classical and causal relationships.

However, given the above arguments it would seem that a dilemma arises because different temporal perspectives afford us completely consistent views upon the physical events taking place. As we speed up the film in the thought experiment (Section 3) we imagine that we would see the neural activity associated with a cognitive state change accordingly. Nevertheless, there is just one

perspective (or temporal rate that we may show the film) that affords us a view of neural activity that actually corresponds to a mental state.

Up until now we have been examining the problem of phenomenal time within the context of changing temporally structured experiences. However, there are a class of experiences that are completely invariant with respect to time. When we listen to a sine wave above the critical frequency, the associated experience is completely invariant. Can progress be made by considering the problem within the context of temporally invariant experiences?

It might seem obvious that change forms an intrinsic component of our experience of time. Actually, this assumption may be questioned. Imagine that you are listening to the music in the film in the thought experiment. At the moment in the music where the sustained pure tone occurs, you close your eyes and do nothing except listen to it. Listening to a pure tone is an experience that is interesting when considering the phenomena of consciousness and our experience of time because it is characterized as an *unchanging* and continuous experience. If the experience were to change in any significant respect then it would not be the experience of listening to a pure tone.

The important question to address is, given that you can rid your mind of all distractions and simply listen to a sine wave, then can that experience be rightfully described as a temporal experience? Of course, the commonly described phenomenon of 'losing track of time,' often occurs when concentrating on (or being distracted by) a stimulus such as a pure tone. However, what is being examined is not our ability to successfully locate events (or ourselves) within the context of an objective and extra-experiential temporal reference frame (such as a clock), but phenomenal time as it forms an intrinsic component of consciousness – in the moment.

There are good reasons to suppose that an auditory experience such as described above has an intrinsic temporal component. Firstly, it would seem obvious that for there to be any conscious experience at all it should have some degree of phenomenal temporal extension. Secondly, if simply closing ones eyes and listening to a sine wave could fundamentally alter the temporality of our consciousness then we should expect that alteration to be reflected in the phenomenal quality of the sound that we experience. This follows from the fact that there is a strong correlation between the temporal structure of sound stimuli and the consequent phenomena of experience (i.e. the tones that we hear).

Having identified a relatively simple phenomenal state that may be defined as both temporal and unchanging may afford us an opportunity to gain insight into the underlying physical processes involved. Having argued that change is not essential for an experience to involve phenomenal temporal flow, we may simplify the problem we are addressing by eliminating the need to consider change or 'phenomenal change' as a first order aspect of the problem. We suggest that the

underlying ‘mechanism(s)’ necessary for phenomenal temporal flow may exist without phenomenal change but phenomenal change cannot exist without the underlying ‘mechanism(s)’ necessary for phenomenal flow. This gives us the opportunity of examining the simplest phenomenal state in order to discover its physical basis and, hopefully, lead to an understanding of the critical factor(s) that determine the way that we experience time (see Figs. 3-5). Of course, phenomenal change is certainly in need of an explanation, but, we would argue, phenomenal flow and its underlying physical basis is the more fundamental problem to be addressed.

One reason why we may consider invariant experiences as being important to our making progress with respect to phenomenal time relates to our insights gleaned by considering the problem within the context of the thought experiment (Section 3). By playing the film of the alien scientist at different rates (within the context of causal and temporally structured stimuli and corresponding neural events) we are faced with a potentially infinite set of equivalent perspectives on those physical events and a correspondingly infinite set of potential phenomenal states. If temporally structured stimuli may give rise to temporally invariant states in the brain then no matter what rate we show the film, although the stimulus may change accordingly, the brain state may remain identical.

A key question arises as to the relationship between invariant experiences and the underlying physical/physiological correlates. If we adopt a computationalist position, then it would seem to follow that the invariant experiential states must correlate with invariant computational states. That is to say that although a different set of neurons and neuronal interrelationships may be affected at any one point in time, nevertheless, the overall computational state may remain the same. This type of invariance may be termed ‘trivial invariance’.

To see if this type of invariance may help us we may again subject this approach to the acid test of our thought experiment. Although this approach offers a way by which we may claim that for a particular type of temporal stimulus there may be only one possible computational neural correlate and corresponding phenomenal state, nevertheless there remains the difficulty of determining why there should be a particular fixed rate at which time is experienced.

It would seem that there must necessarily be either a ‘real’ or symbolic temporal quantity that forms an intrinsic component of the invariant computational state. However, as stated at the beginning of this paper, real temporal quantities (durations) cannot serve as a component of any explanation for phenomenal time for reasons of circularity. But, what of symbolic temporal quantities? Unfortunately, this approach seems to fail also – for two reasons. Any symbolic representation of a temporal quantity must, at some stage, be ‘grounded’ in actual durations – i.e. the temporal structure of the stimulus. It follows, then

that although symbols may be employed as an aspect of computation, nevertheless, a full explanation must necessarily involve ‘real’ durations and so, again, leads to circularity. Also, as stated previously, the informational content of the film of the alien scientist remains the same no matter at what rate it is played. It follows that what might be termed the ‘computational content’ of the film must also be the same at whatever rate the film is played. This being the case, are still left with the vexing problem of why one particular rate at which we show the film gives us a consistent relationship between physical and phenomenal states and no other.

## 5. Fields and non-trivial invariance

An example of what may be termed non-trivial invariance may occur within the context of theories of mind that implicate fields as the neural correlate of consciousness. The electro/chemical activity of a neuron is known to give rise to a small electromagnetic field. A large scale encompassing electromagnetic field may emerge as a consequence of the superposition of the electromagnetic fields generated by collective behavior of individual neurons (McFadden 2006). Given the possibility that the overall statistical behavior of neurons exhibits invariance, then it is possible that the large scale electromagnetic field may exhibit invariance also. To illustrate what is meant by non-trivial invariance in this instance, let us suppose that a particular type of simple invariant experience (or phenomenal state) is correlated with field. If we were able to film this field and then show the film of this field at different speeds, then, although the stimulus would appear to increase or decrease in frequency accordingly, the associated brain state would nevertheless appear to be completely unchanged.

Unfortunately, just as in the case of computational trivial invariance discussed above, although we may agree that for a single stimulus there may be only one possible field state, there appears to be no more information available that can meaningfully be applied to address the question of phenomenal time – or how fast time is being experienced for someone with that brain state.

## 6. Quantum Coherence – Toward a Solution

There are two hypotheses to address *phenomenal time*: (i) classical psychophysical approach, which leads to temporal frequency tuned mechanisms that have zero sensitivity at CFF or higher temporal frequencies and (ii) quantum approach, which entails neural Bose-Einstein condensate (BEC) soliton. The first approach suggests that the inability to detect change beyond critical flicker fusion (CFF) frequency may be because our visual system is not sensitive to frequencies greater than CFF. In other words, visual system needs time to integrate information, which we have defined as *phenomenal time* and is about 16.7 msec for CFF = 60

Hz.

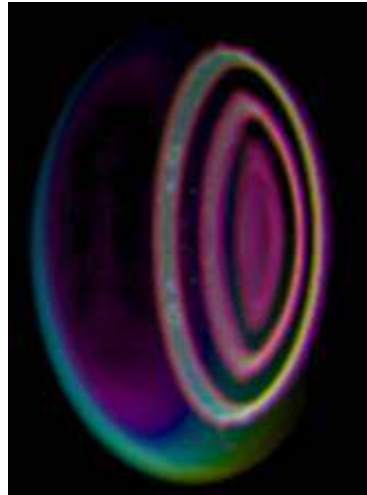
Alternatively, in the second approach, one can argue that rather than focus on the ability to detect change, insight into phenomenal time may come by focusing on the inability to detect change. One operationalization of the inability to detect change is the CFF rate. CFF may be correlated with a neural BEC soliton, the properties of which include temporal uncertainty. This alternative hypothesis is detailed below.

There is a growing group of researchers who are pointing to the possibility that quantum states may be implicated in the phenomenon of consciousness (Ho 1995; Hameroff & Penrose 1995; Koch & Hepp 2006). Particularly relevant to the current argument is research that points to the possibility that dynamic systems may give rise macroscopic states that resemble a phenomenon termed a Bose-Einstein condensate (a field that may exhibit invariance in time).<sup>14</sup> A Bose-Einstein condensate is a condensed phase of matter in which the individual identity of the comprising atoms is lost and forms a coherent unity – a single wave function. This phase change is extremely difficult to bring about and usually requires temperatures very close to absolute zero. However, there is a growing body of research that suggest that similar states may be brought about as a consequence of the behavior of nonlinear dynamic systems. Studies into the behavior of complex networks like the World Wide Web, suggest that, under certain conditions, a change in the overall dynamic behavior of the network may occur that is a classical analogue of a Bose-Einstein condensate (BEC) and is mathematically modeled in the same way (Bianconi & Barabasi 2001; Barabasi 2002, pp 99-107). Also, pioneering work examining the complex interaction of neurons suggests the possibility that macroscopic quantum states similar to a BEC may also occur in the brain (Amoroso 1996; Frohlich 1968; Freeman & Vitiello 2006; Georgiev 2004).

Related research argues that if such macroscopic states do indeed form the neural correlate of consciousness then these states may be in the form of solitons (Davia 2006). A soliton is an extremely robust non-linear dynamic that preserves its structure as a consequence of a fine balance between linear dissipative and nonlinear compressive forces.

According to the fractal catalytic model, consciousness correlates with the evolution of a robust traveling wave (a soliton) that mediates energy dissipation as a macro-level process of catalysis (Davia 2006); Fig. 3. illustrates a Bose-Einstein Condensate soliton, which is a type of coherent soliton (Cornell & Wieman 2002a).

The fractal catalytic model argues that non-linear interactions in the brain give rise to solitons (or robust traveling waves; they were observed in visual area V1 and are essential for the organization of retina to lateral geniculate nuclei connectivity prior to birth<sup>15</sup>) that mediate energy dissipation as a macroscopic



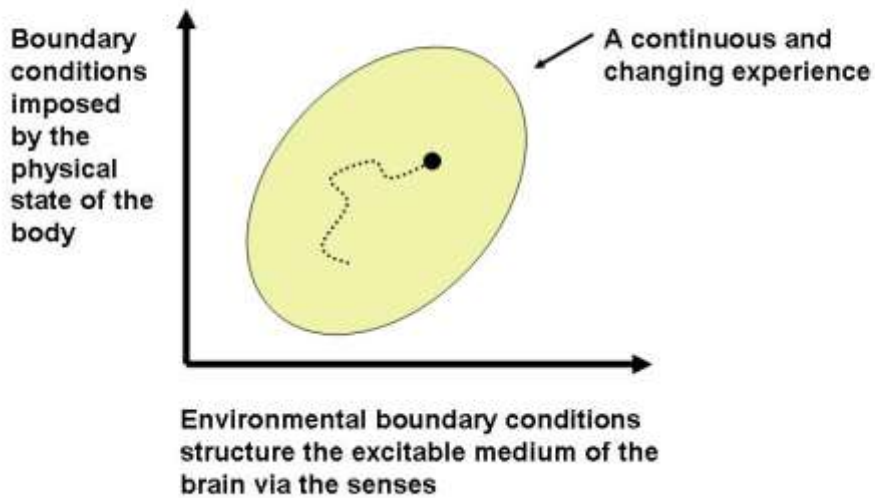
**Fig. 3** – BEC soliton

process of catalysis. Solitons require structure in the boundary conditions of their environments for the possibility of their emergence. For example, the regular structure of a canal is ideal for soliton formation and a soliton was first observed as a unique type of wave in a canal by John Scott-Russell. The fractal catalytic model argues that the brain (which is considered to be an excitable medium) is structured in real time by the body and the environment (both immediately via the senses and historically via past experience) and that any spatio/temporal symmetries (invariance) implicit in the body, the senses and dynamics of interaction between body/senses and the environment may support soliton formation in the brain (Davia 2006) (Fig. 4). Within the context of this theory, consciousness is correlated with the spatio/temporal evolution of a coherent soliton.

Fig. 4 shows a continuous trajectory associated with a continuous and changing experience. Such a brain state may correspond to the experience of listening to a sine wave changing in pitch. Within the context of the classical approach we may expect the answer to the question of phenomenal temporal flow to be addressed within the context of the changing stimulus and the corresponding neural state. However, this presupposes that what might be described as ‘phenomenal change’ forms the basis of the way that we experience time as flowing; or, in other words, that we must understand what is meant by ‘phenomenal change’ and its physical basis before we can understand phenomenal temporal flow. An alternative position (and one that we hold), is that phenomenal temporal flow and its physical/physiological correlate precedes phenomenal change. Fig. 5 shows the simplest cognitive state permitted by the fractal catalytic model.

### Conscious States and the Fractal Catalytic Model

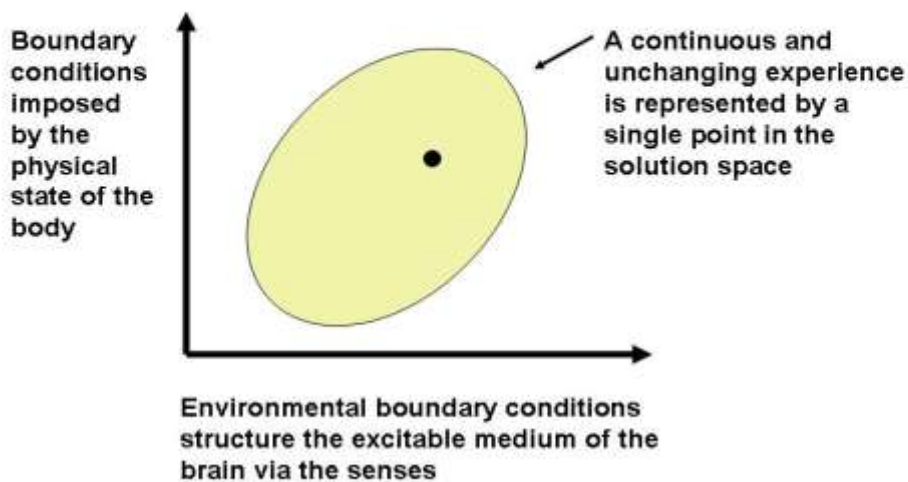
Conscious states are thought to be coherent solitonic solutions to the boundary conditions imposed by past experiences, the body and the senses.



**Fig. 4** Solitons in the brain are proposed to arise as solutions to the boundary conditions imposed by the body and environment, via the senses.

### Conscious States and the Fractal Catalytic Model

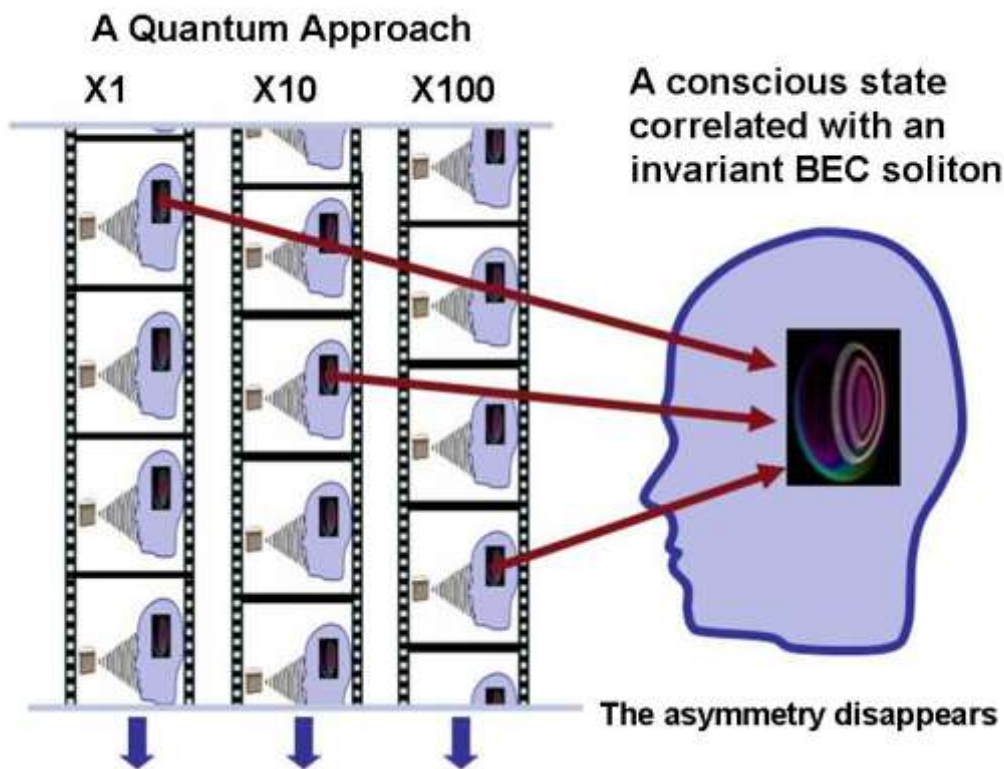
The most simple conscious states permitted by the model



**Fig. 5** – The most simple cognitive state permitted by the fractal catalytic

model is a continuous but unchanging experience, such as the experience of flickering light that is flickering at a rate faster than the critical flicker-fusion threshold; we propose that this phenomenon may be associated with a neural state corresponding to a BEC soliton.

As discussed previously, from a classical perspective, we expect that for each different temporal reference frame, neural states would appear to occur faster or slower depending upon the rate at which the film is shown (see Fig. 2). Alternatively, if an invariant conscious state is to be correlated with a soliton in the form of a BEC, then, just as it is possible for a simple electromagnetic field to exhibit non-trivial invariance, so it is possible for non-trivial invariant states to occur such that no matter at what rate we run the film the physical correlate of consciousness (the BEC soliton) may always appear exactly the same (Fig. 6), as long as the flicker rate is greater than CFF frequency (see below).



**Fig. 6.** If the brain state corresponds to a coherent soliton in the form of a Bose-Einstein Condensate, then this state would appear invariant no matter the rate at which we run the film in the thought experiment described in section 3.

A BEC soliton is an interesting phenomenon when considered in the light of the problem we are addressing. Unlike a classical soliton (e.g. a tsunami), a coherent soliton in the form of BEC (Cornell & Wieman 2002a) exhibits properties quite different from a classical soliton:

“The uncertainty principle puts limits on what is knowable about anything, including atoms. The more precisely you know an atom's location, the less well you can know its velocity, and vice versa. That is why the condensate peak is not infinitely narrow. If it were, we would know that the atoms were in the exact centre of the trap and had exactly zero energy. According to the uncertainty principle, we cannot know both these things simultaneously.” (Cornell & Wieman 2002b)

Although complex, a BEC soliton is a probability wave function. As such it embodies characteristics of any quantum probability wave function. In addition to the uncertainty between position and momentum, the wave function also describes the uncertainty between energy and time. So, a soliton in the form of a BEC is a four dimensional phenomena with extension in time as well as space. The degree of this extension is determined by the Uncertainty Principle.

Correlating consciousness with a coherent BEC soliton does not immediately solve our problems. Although, the uncertainty in time of the wave function may be significant with respect to the problem we are addressing, within the context of the potentially infinite number and variety of cognitive and behavioral states and the potentially infinite number of associated wave functions, it is difficult to see why our experience of temporal flow should exhibit such consistency

However, progress may be made by considering research that provides evidence that there may be an underlying ‘carrier wave’ that supports other neurological processes – a carrier wave for consciousness?

### *6.1. The sensation transition-zone for fusion*

"Lalanne (1876) [...] pointed out that the frequency of stimulus fusion in the tactile, auditory, and visual modality equals 18 Hz. Lalanne conjectured a common, yet unknown, mechanism behind this. "Measuring tactile stimulus fusion" (Kompass 2004).

“Brecher (1932), [...] using an ascending method of limits, found in 14 subjects that the fusion thresholds in vibration perception occur, on the average, at a critical period of 55.3 ms or, in terms of frequency, 18Hz” (Geissler & Kompass 2001).

Von Békésy (1960) provides the information related to continuous auditory threshold.

### 6.2. *A Fly in the Ointment?*

Although there is considerable research that points to 18 Hz as the frequency that demarks a boundary between structured and continuous experience, recent work implicates 16 Hz as the threshold:

“Professor Helmer, Frank (Nørretranders 1991) [...] Viewing consciousness as having a fixed capacity, then the rate at which its contents could be changed becomes all important. Beginning with pulses of sound, Frank discovered that the smallest perceptible time frame (subjektives Zeitquant - psychological moment abbreviated to SZQ) approximates to 1/16 of a second. If pulses occur with a frequency greater than 16Hz then humans lose the perception of individual pulses and perceive instead a continuous tone. He found that the same was true for images.” (Benson et al. 1999).

These findings are consistent with the generally accepted figure of 16 Hz associated with the ‘flicker-fusion’ threshold of movie frame images (but see Section 7.2 for variation in CFF). If film is shown at a frame-rate less than 16 Hz then ‘flicker’ becomes more pronounced.

Although there may be disagreement as to whether 16 Hz or 18 Hz is the significant frequency, and color flicker-fusion frequency is lower than luminance flicker-fusion frequency (Kaiser et al. 1986; Kaiser & Boynton 1996; Kaiser et al. 1989), there is sufficient evidence pointing to a critical threshold that demarcates the boundary between continuous and discontinuous experience across sensory modes. We suggest that evidence of fusion across sensory modes is very significant. But, what are these observations pointing to? There seems little doubt that that these finding will be important for our understanding of temporal experience. This is because the flicker-fusion threshold demarcates the boundary between temporally modulated stimuli that can and cannot be sensed, it marks the limit above which change cannot be experienced. Also, the evidence seems to suggest some fundamental neural process that underpins or supports other neural processes, indeed, these findings have been used to support the idea that there may be an important cycle rate or minimum unit of consciousness. For the argument that follows we shall assume that these findings point to an underlying coherent carrier wave<sup>16</sup> for consciousness.

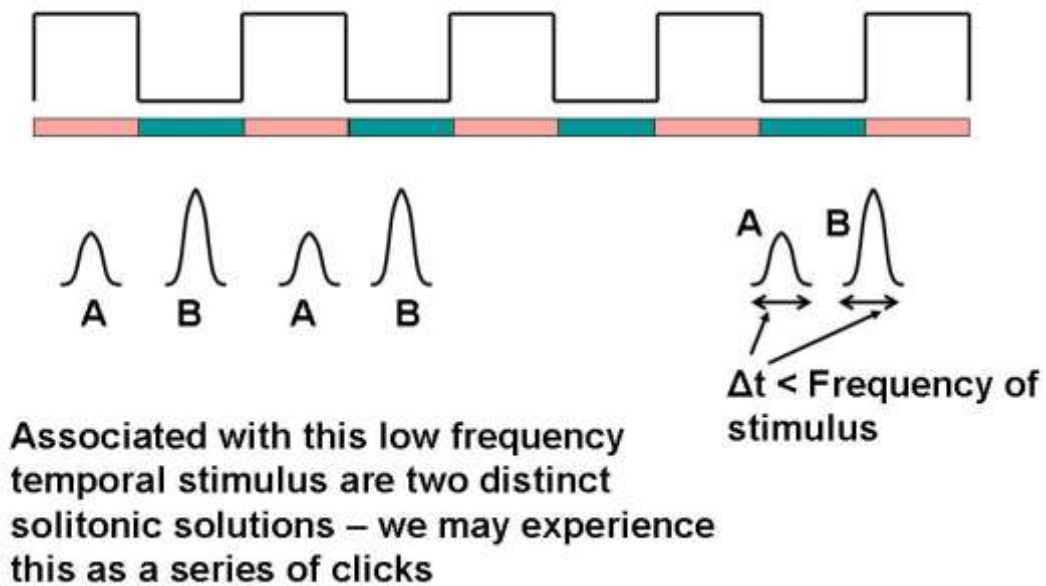
### 6.3. *Catalytic-soliton model for phenomenal time*

As discussed above, the fractal catalytic model of consciousness correlates mental states with the spatio-temporal evolution of a coherent soliton. We suggest the possibility that, in a similar way that a tsunami, may ‘adapt’ to variations in the depth of the ocean and change its organization to a new robust state, so the underlying coherent soliton associated with consciousness may be continually

adapting and changing its organization as a consequence of variations in the boundary conditions imposed upon it by the body and the senses (see Figs. 4 and 5).

As discussed previously temporal variations in experience are to be correlated with changes in the overall structure of the wave function. These changes may be consequent upon changes in the boundary conditions that comprise the environment of the soliton – i.e. stimulus. If the temporal structure of the stimulus exhibits modulations that are greater than the uncertainty of the probability wave function of the BEC soliton then, it is suggested, a varying experience will be the result (Fig. 7).

### Varying Experiences



**Fig. 7** - A stimulus giving rise to a varying experience.

But, what of stimuli that exhibit temporal variations ( $\Delta T_s$ ) that are smaller than the uncertainty of the wave function ( $\Delta T$ )? If temporal awareness/consciousness is to be correlated with a BEC soliton then surely there arise problems associated with the suggested interaction with the environment. Can we not consider such interactions as measurements resulting in an exchange of information between the BEC soliton and the environment and vice-versa? If so, then any interaction with the environment which effectively fell below the threshold of the temporal uncertainty ( $\Delta T$ ) of the wave function would cause it to

collapse (when  $\Delta T_s < \Delta T$ ). However, this depends upon the type of interaction. In lasers, for example, this problem does not occur because energy is supplied to the laser via a two stage process. Energy is first ‘pumped’ into the system which excites electrons. The subsequent release of this energy is stimulated by the coherent light itself in such a way such that exchange of information below the threshold of temporal or spatial uncertainty does not occur. Frohlich proposed that a similar process may be operating in the brain (Frohlich 1968).

What is being suggested is that stimuli with temporal intervals smaller than the temporal uncertainty of the carrier wave function (i.e., when  $\Delta T_s < \Delta T$ ) may nevertheless give rise to unique and unvarying solitonic solutions (see Fig. 5).

To support the ideas of Frohlich, we may point to evidence that suggests that we do not passively sense the world around us. The brain is not ‘hard wired’ to the structures in the environment and the body via the senses. Dynamic feedback processes of the nervous system and the senses may determine if a potential stimulus is ‘sensed’ or not. This loose coupling is a fundamental characteristic of neuronal interactions. This being said, interactions between the environment and the proposed BEC soliton cannot violate the Uncertainty Principle. In as far as there are limitations regarding what information may be obtained about a quantum coherent phenomenon, it necessarily follows that there are limitations about what information the quantum coherent phenomenon may contain about its environmental boundary conditions that it is a solution to.

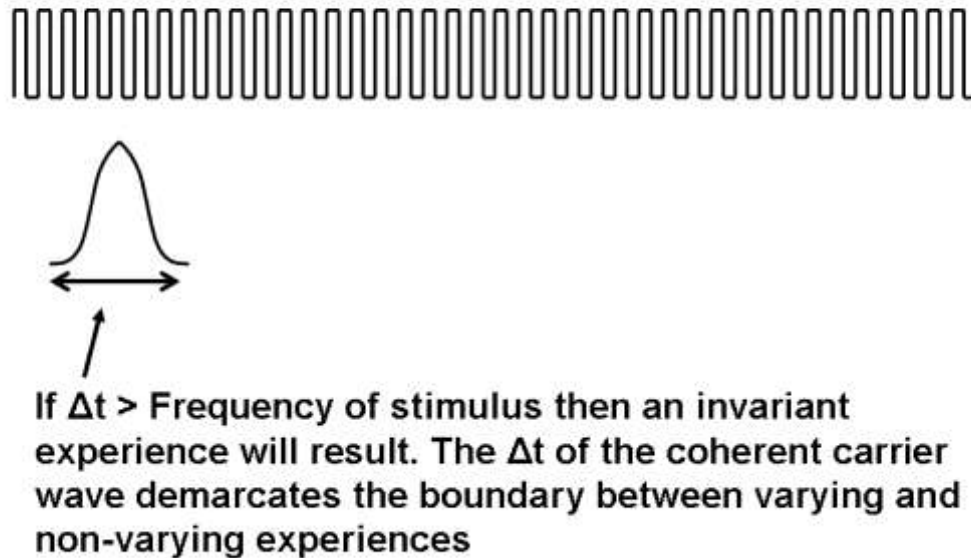
So, given the possibility that the neural correlate of temporal consciousness is a BEC soliton, and given the possibility that there may be unique solitonic solutions determined by temporal structures which fall below the uncertainty in time associated with its wave function (i.e., when  $\Delta T_s < \Delta T$ ), then those solutions cannot embody information that could be used to distinguish individual temporal components of the stimulus within the BEC’s soliton’s temporal uncertainty. This accords well with the phenomenology of experience. Although we may be able to experience a high frequency stimulus, we are unable to distinguish its small scale structure (see Fig. 8).

Given that the flicker fusion frequency or CFF is a crucial quantity that represents the limit above which we cannot experience change (i.e., when stimulus flicker frequency  $FF_s > CFF$ ), then it would seem reasonable to conclude that the primary factor that determines the apparent ‘rate’ at which we experience time is the uncertainty in time associated with the carrier wave function of the BEC soliton. The flicker-fusion frequency may be giving us very precise information about the way in which we (and other species) experience time.

It must be pointed out that a threat to this hypothesis exists as a consequence of a large body of research that seems to show that the flicker-fusion frequency depends upon factors such as intensity and wavelength of stimuli,

adaptation condition, background condition and so on (Kaiser et al. 1986; Kaiser & Boynton 1996; Kaiser et al. 1989). For example, in one recent study, it was shown that the flicker fusion frequency may change as a consequence of a decrease in the intensity of a stimulus (Geissler & Kompass 2001).

### Non-Varying Experiences – A Conjecture



**Fig. 8** – A stimulus giving rise to a non-varying experience

However, we could argue that uncertainty in time associated with the carrier wave function of the BEC soliton also similarly depends on the above factors. Therefore, the catalytic-soliton model cannot be rejected. For example, a critical consideration is how the stimulus is being ‘interpreted’ by the brain. One could argue the possibility that with a decrease in the intensity then, as a consequence of the poverty of stimulus, the resulting brain state may correspond to a lower frequency stimulus. This being the case it would account for the apparent change in the flicker fusion frequency because although the frequency of the stimulus may be greater than the flicker fusion frequency, the ‘interpreted’ frequency may be lower. In other words, we suggest that the same results can be accounted for as a consequence of changes in how the stimulus is being interpreted by the brain rather than a change in the flicker fusion frequency.

Alternatively, one could also argue that some of the temporal frequency tuned mechanisms that were sensitive at high suprathreshold luminance becomes less sensitive to the extent that they are non-functional at lower luminance. This is

in analogy to the number of luminance spatial frequency (SF) tuned mechanisms dropped down from 6 at photopic to 4 at mesopic level to 2 at scotopic level, where higher SF tuned mechanisms were first to drop (Vimal & Wilson 1986, 1987). It would be interesting to extract temporal frequency tuned mechanisms at mesopic and scotopic luminance levels.

If the first argument (uncertainty in time associated with the carrier wave function of the BEC soliton depends on the above factors) made above proves to be correct then one might also expect that the interpreted frequency bear a simple harmonic relation to the frequency of the actual stimulus. It would be difficult to explain why the ‘interpreted’ frequency could arise and be supported by a harmonically unrelated stimulus. We should expect that with a gradual decrease in the intensity of the stimulus the ‘interpreted’ frequency should ‘jump’ successively to lower frequencies that bear a harmonic relation to the stimulus. Such ‘jumps’ would give rise to an apparent ‘quantization’ of changes to the flicker fusion frequency. Just such a ‘quantized’ succession of jumps are known to occur (Geissler & Kompass 2001).

Our attempts to resolve the problem of phenomenal time have each failed when tested within the context of our thought experiment. However, the thought experiment assumes that successive physical states of the brain as may be recorded by the film capture the neural correlate of consciousness. In other words, when we watch a film of successive brain states we are also watching the physical states that may be correlated with successive phenomenal states. However, if the neural correlate of consciousness is a coherent wave function with extension in time as well as space then it follows that no frame of the film can ever capture the physical correlate of a phenomenal state. Running the film at various rates becomes a meaningless act in terms of the problem that we are addressing – phenomenal time.

Also, at the beginning of this discussion we argued that the apparent rate at which time is experienced must be consequent upon a temporal quantity. We also argued that the temporal quantity could not be a duration as is commonly understood because this would give rise to a vicious circularity – we would be attempting to understand duration in terms of duration – a tautology. An important consideration when attempting to resolve this problem is the question of what exactly do we mean by duration. From the perspective of the experiencer, for something to have duration there must be a sense in which a discrimination can be made such that different ‘parts’ of the experience can be related to each other with respect to time. Thus: part A of the experience can be judged to occur before or after part B of the experience. Defining duration in this way may be significant within the context of coherent states with temporal uncertainty.

Any attempt to interact with a coherent state that resulted in information being obtained that fell below the temporal uncertainty of the wave function (i.e.,

when  $\Delta T_s < \Delta T$ ) must cause it to collapse. It follows, that should a type of coherent state exist that embodied information about its' environmental boundary conditions, then, that coherent state could not embody information that could be used to make a discrimination in time that fell below the temporal uncertainty of the wave function. We suggest that the temporal uncertainty of the wave function demarks the boundary below which discriminations in time cannot be made. We suggest that for this reason, time as it forms part of the wave function cannot be considered as a 'duration' as is normally conceived. Of course, this begs the metaphysical question as to the ontological status of time and space as they form integral aspects of the wave function – a topic for another paper perhaps.

## 7. Neural Correlates and Temporal Information Processing

According to (James 1890/1981), “to state it in neural terms, there is at every moment an accumulation of brain-processes overlapping each other, of which the fainter ones are the dying phases of processes which but shortly previous were active in a maximal degree. The amount of the overlapping determines the feeling of the duration occupied. What events shall appear to occupy the duration depends on just what processes the overlapping processes are” (his emphasis deleted).

### 7.1. *Cyclic and linear form of temporal information processing*

The brain itself can be considered as a clock or 'organ of time sense' (Dawson 2004; Fraser 1975; Melges 1989). The biological circadian clock has an intrinsic period of about 24 hours, which synchronizes to the daily day-night (light–dark) cycle (Herzog 2007).<sup>17</sup> For example, suprachiasmatic nucleus (SCN) tracks the cyclic form of time such as sleep-wake rhythms and regulates the biological need for sleep, food, and reproduction. Activation of SCN and primary visual cortex depends upon time of day (Vimal et al. 2006; 2008). Whereas hippocampus and frontal cortex tag a linear cause-and-effect form of temporal information about the memories of the past and the expectancies for the future, respectively, and regulate neural nets that together form memories, consciousness, and the perception of past, present and future (Dawson 2004; Melges 1989). Both forms of biological time or clocks are critical in temporal consciousness; when one is turned on, other is turned off. When these clocks are out of synchrony, both physical and mental disorder can occur. Temporal disorganization of the brain is a characteristic of the aging process, such as a disruption of the sleep–wake cycle, 'an increase in the subjective rate of time passage'<sup>18</sup>, and a decline in future expectancies (Dawson 2004). Time seems to speed up as we grow older and time appears to slow down in crisis, for example time seems 36% longer in free fall.<sup>19</sup> Phenomenal time (subjective experience of time) slowing towards stopping, in

some cases, such as at death, in near-death experience, meditation, and psychedelic drug use (Osis & Haraldsson 1997; Smith & Tart 1998). A player who has higher rate of conscious moments may win the game (Hameroff 2003). The temporal disorganization observed in schizophrenia, autism, and bipolar disorders may be partially due to genetic mutations in the human clock gene (Saleem et al. 2001; Wimpory et al. 2002). The brain is temporally organized via ‘temporal tagging’ and ‘re-entry’, which bind the wide range of spatiotemporal stimulus-features to a unified subjective experience that is held in synchrony with the external world (Dawson 2004; Edelman & Tononi 2000). Time and its neuroendocrine correlate melatonin are involved in binding the spatiotemporal stimulus features for subjective experience (Dawson 2004). Melatonin decreases the desynchronization between internal circadian rhythms and the external environment, which occur in jet-lag, shift-work, blindness, and delayed sleep phase insomnia (Skene et al. 1996).

From the fMRI data for the phenomenological concepts of temporality i.e. phenomenal time, (Northoff & Heinzl 2006) wrote, “Lloyd (Lloyd 2002) observed that the multivariate distance and changes between brain images is approximately linearly related to their temporal distance. The more closer acquired in time the more similar the images. Thus, the changes between the different images occur gradually over time. Lloyd argues that these results are consistent with Husserl's description of time consciousness in that they reflect the inexorable temporal flux of the conscious state. Analogous to the way that each moment of our phenomenological experience of time builds on foundation of the previous moment, the series of fMRI images appears to form a continuously evolving temporal pattern of global activity.” One could also argue that if a subject's CFF = 60 Hz, then the subject has an *occasion of experience* (Whitehead 1978) at every 16.7 msec.

To sum up, from the point of view of consciousness the past, although a causal influence and qualifier of the present conscious state, is nevertheless past and no longer exists even though it was but a second ago, and the future, although but a second away, is yet to be, and therefore beyond our scope (Dawson 2004). We are each but slender moments of becoming. Unlike Aristotle who believed this moment to be infinitely slender, we suggest that actually this moment may be precisely quantified and we also suggest a value of between 1/16 and 1/18 of a second (but the variation in flicker fusion frequency should be carefully taken in to account as discussed before). Although we have focused our attention upon the problem of the rate at which time is experienced we perceive the possibility that progress may now be made with respect to the problem of phenomenal change. Aristotle defined the problem within the context of a temporal structure that was infinitely divisible. From this perspective, it seems inevitable that phenomenal change must result from the causal relationship of successive brain states – a

philosophically problematic position. However if conscious states are to be correlated with macroscopic coherent states then the problem of phenomenal change must be considered within a very different physical context – a context that allows for complex non-linear temporal relations within the smallest unit of consciousness.

### 7.2. *Variation in CFF*

The critical flicker fusion frequency (CFF) is ‘the frequency at which a flickering light is indistinguishable from a steady, non-flickering light’ (Wells et al. 2001). CFF depends on species, luminance level, color, and other conditions. (Frank 2000) reported, ‘nocturnal insects tend to have lower CFFs [and lower temporal resolution] than diurnal insects’, and ‘there is a trend towards lower CFFs with increasing habitat depth’. Some of luminance CFFs are as follows<sup>20</sup>: (i) 60 Hz in bright light and 24 Hz in dim light for humans, (ii) 58 Hz for cat (Loop & Frey 1982), (iii) 70 Hz for octopus in bright light, and (iv) 180-300 Hz for honeybee, dragon fly and blowfly flies (Autrum & Gallwitz 1951). If we consider the dizzy behavior and the dazzlingly rapid changes in the song of the nightingale (and we also assume that there is a universal and fixed rate of temporal flow), we might reasonably conclude that, should there be a set of phenomenal states associated with such behavior, then they must be radically different from our own. It is difficult to conceive of what it might be like to be able to consciously control the body and make decisions so quickly. Notwithstanding the arguments previously offered to the effect that consistency of phenomenal states cannot be used to underpin a theory of why we experience time the way that we do, having subsequently argued that the subjective rate of temporal flow is potentially variable and may be associated with a specific physical/physiological quantity, the proposition that there be interspecies similarities and consistencies of phenomenal experience associated with temporally structured behavior and stimuli becomes tenable.

It is possible that the tone experienced by a conscious entity consequent upon an auditory stimulus may be directly related to the ratio of the frequency of the stimulus to the flicker fusion frequency (or the uncertainty in time of the carrier wave function). In this way we hope to have closed the gap slightly, not only between the qualitative and the quantitative, but also, between ourselves and other species.

Time is one small part of a broader philosophical enquiry that addresses the questions how we, and what does it mean to, represent and experience an ‘external’ space and time. The answers to these questions may reside in the fact that we do not represent space and time at all. Experience may be essentially spatial and temporal because the underlying correlate of consciousness is a spatial

and temporal interaction phenomenon – a coherent wave function – perhaps a BEC soliton.

## 8. Critique

This section provides the questions and our responses to three issues raised by a reviewer.

(1) Invoking solitons in the context of brain dynamics begs the question of their physical properties. What is the speed of their propagation? More fundamentally still: where do they propagate? Knowing the distances and propagation velocities will give us the time scales involved if they are supposed to elucidate issues related to phenomenal time.

One estimate of about 40 ms for a soliton-like wave from V1-V5 comes from the observations of traveling waves in the visual area (Xu et al. 2007). According to Xu et al. (2007), “The compression of the primary wave started as an abrupt slowing of the wave leading edge. [...] the primary wave was initiated by the visual stimulus and quickly expanded into the entire V1 area [...] at a propagation velocity of 50-70 mm/s. When reaching the V1/V2 border, the leading edge of the wavefront had an abrupt slowing (the velocity around the V1/V2 border was about 5 mm/s). Meanwhile, the trailing edge of the wave was still in V1 and maintained a higher speed (50–70 mm/s). As a result, a thin band of compressed activity formed along the V1/V2 border [...] The compression and the resulting thin band sustained for a relatively long time compared with the time taken for the initial propagation within V1. [...] Wave compression can be clearly seen as a thin horizontal stripe at the V1/V2 border [...], indicating a nearly zero propagating velocity for about 35 ms during the course of the wave compression. [...] Since the evoked waves underwent compression at the V1/V2 border, their overall propagating velocity might be slower than that of spontaneous waves. [...]

As a common feature, sensory-evoked waves robustly initiated from the location of cortical afferents and propagated over a large area. Due to the propagation, a time delay is spatially distributed over the cortical area as determined by the propagating velocity. On a population scale, such delayed activation is different from the synchrony on a millisecond scale between active neurons. Wave compression/reflection observed in this report suggests an even larger time delay, in that the depolarization in V2 is  $\sim 30$  ms after V1 is activated [...] The reflected wave, in contrast, would allow V1 and V2 to be depolarized together within 10 ms following the compression. [...] Feedback waves traveling from areas 21 and 19 toward area 18 and 17 were recently reported by VSD imaging in ferrets (Roland et al. 2006). [...] Propagating waves are known to change velocity, direction, or both due to dynamic interactions with other waves.”

Time involved in  $V1 \leftrightarrow V5$  is about similar to that in  $V1 \leftrightarrow V2$ . Thus, one could assume that solitons might take  $\sim 30$  ms from  $V1$  to  $V5$  and  $\sim 10$  ms from  $V5$  to  $V1$ , total of about 40 ms for round-trip travel of solitons in the  $V1$ - $V5$  neural-net. This leads to  $1/40$  ms = 25 Hz, which is within the range of CFF of 24-80 Hz.

A similar estimate is yielded by studies of conduction velocity in visual area ( $V1$ ,  $V2$ , and  $V5$ ); the estimate is between 3-10 m/s = 3-10 mm/ms (Girard et al. 2001; Movshon & Newsome 1996). Antidromic latencies are between 1 and 3 ms when stimulating  $MT/V5$  and recording in  $V1$  (Movshon & Newsome 1996). This yields a distance of about 10 mm between  $V1$  and  $V5$ . Phenomenal time is subjective experience (SE) of time in our framework. The essential ingredients of the subjective experience of phenomenal time includes re-entry (Vimal 2008d). If we arbitrarily assume re-entry of 5 times in the neural-circuit of  $10 \times 2 = 20$  mm, the time needed for the emergence of the subjective experience of time is about  $(5 \times 20 \text{ mm}) / (3-10 \text{ m/s}) \sim 10-33 \text{ msec} \sim 30-100 \text{ Hz}$ . This first order rough calculation is of the same order as of the range 24-80 Hz for CFF. For CFF = 60 Hz in bright light, the number of re-entry would be in the range of 2-9 times.

Thus, two mechanisms (soliton-propagation velocity vs. conduction velocity) yield similar conclusions. It would be interesting to investigate if these two mechanisms are complementary or one of them could be rejected.

(2) The discussion of the frequencies in Section 6.2 is quite interesting. However, both 16 and 18 Hz are incredibly small if there is supposed to be any relation to quantum effects. A simple check by multiplying these values by the Planck constant will tell us right away that only at frequencies exceeding the GHz range can there be any quantum effects.

One needs to be careful in above calculations. In the fractal catalytic model, classical phenomena may transit to quantum phenomena; the catalysis at the molecular level is thought to operate as a quantum phenomena involving wave-based facilitation (Sataric et al. 1991, Knapp & Klinman 2002; Sutcliffe & Scrutton 2000; Sutcliffe & Scutton 2002). A different but possibly related argument, for quantum effects, has been made in the Penrose-Hameroff model, which proposes orchestrated objective reduction (OR Orch) of quantum coherence in brain microtubules (Hameroff 1994; Hameroff & Penrose 1995; Hameroff 2003). The problems related to quantum effects in this model are addressed to some extent (Hameroff 2007).

According to (Hameroff 2003), "At very small scales, space is not smooth, but quantized. [...] as we go down in scale from the size of atoms ( $10^{-8}$  centimeters) empty space seems smooth until eventually we find granularity at the incredibly small "Planck scale" ( $10^{-33}$  centimeters,  $10^{-43}$  seconds). There are several types of descriptions of the Planck scale: string theory, "quantum foam", and loop

quantum gravity. In the context of loop quantum gravity, Penrose [...] portrayed the Planck scale as a dynamical spider-web of spin. Taking spin as an irreducible, fundamental entity, spin networks define spectra of discrete Planck scale volumes and configurations which dynamically evolve and define spacetime geometry [...]. The amount of potential information in Planck scale spin networks is vast; each Planck scale volume, or “pixel of reality” may be shaped by huge variability and nonlocal interactions. Plus their sheer number is enormous—there are roughly  $10^{107}$  Planck volumes in the volume of a human brain, far greater than the number of particles in the universe. [...] In the Penrose formulation, objective reduction due to the quantum gravity properties of fundamental spacetime geometry occurs at a time  $T$  given by the Heisenberg indeterminacy principle  $E=h/T$ , in which  $E$  is the magnitude of superposition/separation,  $h$  is Planck's constant over  $2\pi$ , and  $T$  is the time until reduction. The magnitude  $E$  is related to the gravitational self-energy of the superposition and may be calculated from the amount of mass "separated from itself" and distance of separation. Since  $E$  is inversely related to  $T$ , small separations/superpositions (if isolated) will reduce at a long time  $T$ , and large separations/superpositions (if isolated) will reduce quickly. For example an isolated superpositioned electron would reduce by OR only after 10 million years. A large isolated superpositioned object (such as Schrödinger's mythical one kilogram cat) would reduce by OR after only  $10^{-37}$  seconds (too quickly for anyone to notice). [...] When enough entangled tubulins are superpositioned long enough to reach Penrose's OR threshold by  $E=h/T$ , an objective reduction (OR) "conscious event" occurs. Each Orch OR event chooses a particular set of classical tubulin states which may proceed to regulate classical neural activities, e.g. trigger axonal firings, adjust synaptic strengths and rearrange the cytoskeleton, thus exerting causal efficacy, learning and memory. Feedback provides “orchestration” of the quantum computation, hence “orchestrated objective reduction: Orch OR”. In the context of pan-protopsyndist/pan-experiential philosophy, each Orch OR event is "conscious" because a particular configuration of proto-conscious qualia embedded in fundamental spacetime geometry is selected. Brain processes occur in time scales on the order of tens to hundreds of milliseconds. For example sensory responses are on the order of 500 milliseconds (1/2 second), alpha EEG is roughly 100 milliseconds (1/10 second), and "coherent 40 Hz", the brain-wide synchrony which seems to correlate with conscious activity, is on the order of 25 msec (1/40 second). For Orch OR events in the brain to correspond with known neural events we can use  $E=h/T$ . For  $T=25$  msec (coherent 40 Hz),  $E$  in terms of number of tubulins may be calculated, and estimating for percentage of tubulins/neuron involved in consciousness, we find that 10,000 to 100,000 neurons are involved in each Orch OR conscious event. Each OR event is instantaneous, so the 25 milliseconds/conscious events are in the pre-conscious quantum superposition phase of multiple possibilities of

perceptions or choices.”

Thus, 16-80 Hz is of the same order as 40 Hz in above calculation involving quantum effects.

(3) Bose condensation is a very attractive and rather exotic phenomenon in quantum physics. For it occur, there must be elementary excitations that occupy some phase space which, below a certain temperature, becomes too small, so they have to condense into the ground state. What are these excitations in the brain dynamics case? What is the phase space? What is the equivalent of temperature?

In the case of the brain, our hypothesis is that the ‘elementary excitations’ may correspond to the modulation of neural activities in various cortical areas, such as V5 for visual motion and flicker. When the flicker frequency is less than the CFF, we perceive motion. But when the frequency is above the CFF, such as 60 Hz in a bright light, we don’t perceive the flicker. The spatiotemporal neural activity corresponds to a ‘phase space’ organized for this area by time (rather than ‘temperature,’ as it is frequently exemplified). If the time is less than  $1/\text{CFF} = 1/60 \sim 16.7$  ms, we do not perceive flicker and our theoretical interpretation proposes that the system has gone through Bose condensation.

Objections have been raised that heat acts as noise to have a detrimental effect on the formation of coherent solitons. However, in the fractal catalytic model (Davia 2006), all energy is dissipated via structural invariants that arise from the organism’s interaction with its environment. Consequently, the simple understanding concerning the amount of heat may need to be modified; the theory suggests that the heat (noise) may be organized and dissipated via structure. So only the heat at the formation of the soliton will apply and the real heat may be small.

## 9. Conclusion

We summarize<sup>21</sup> our proposal as follows:

(I) Rather than focus on the ability to detect change, insight into phenomenal time may come by focusing on the inability to detect change. This is consistent with the ‘psychological present’: ‘there is always an experienced duration in which experience does not change’ (Stroud 1967; van Leeuwen 2007).

(II) One operationalization of the inability to detect change is the critical flicker fusion (CFF) rate.

(III) CFF may be correlated with a neural Bose-Einstein condensation (BEC) soliton (traveling wave), the properties of which include temporal

uncertainty.

(IV) A single CFF (16 Hz to 18 Hz) would be associated with an 'underlying coherent carrier wave' for consciousness; however, CFF may depend on many factors.

(V) The subjective experience of time is *phenomenal time*; in terms of measurable physical time it is  $1/\text{CFF}$ .

(VI) There are two hypotheses to address *phenomenal time*: (i) temporal frequency tuned mechanisms that have zero sensitivity at CFF or higher temporal frequencies and (ii) neural Bose-Einstein condensate (BEC) soliton, which is summarized above in (II) and (III). Further research is needed to find out which one can be rejected or whether they are complementary to each other. Our current view is that both hypotheses are complementary to each other.

(VII) After every *phenomenal time*; there may be an 'occasion of experience' or subjective experience (SE), i.e., Buddhist Monk who has CFF of 80 Hz may have SE every 12.5 msec whereas a subject who has CFF of 60 Hz may have SE every 16.7 msec.

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### Competing interests statement

The authors declare that they have no competing financial interests.

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## Endnotes

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<sup>1</sup> Quantum coherence ((Penrose 1994), <http://www.nonlocal.com/hbar/coherence.html>) refers to (a) ‘circumstances when large numbers of particles can collectively cooperate in a single quantum state’, (b) the superposition of all of the alternative possibilities open to the system in pure state (‘the process which converts a pure to a mixed state is known as decoherence’) , and (c) non-local connection (Hameroff 1994).

<sup>2</sup> PE-SE framework postulates that all types of irreducible fundamental SEs (quality of sensations) and/or proto-experiences (PEs) are superimposed in strings or elementary entities (fermions and bosons). These elementary entities are therefore non-specific to a specific SE and behave as non-experiential material entities. If this type of superposition is correct, then co-evolution and co-development can produce neural-nets where SEs can emerge. Thus, the PE-SE framework is complementary to all reductive models. Further details are given in (Vimal 2008a).

<sup>3</sup> In our view, the subjective experience of time (phenomenal time) that is reportable is *access* awareness of time, which requires attention; whereas, the SE of time that is non-reportable and does not require attention is *phenomenal* awareness of time. The *access* awareness of time emerges during the interaction of stimulus dependent feed-forward signals and fronto-parietal feedback attentional signals. The *phenomenal* awareness of time is mainly because of the interactions of stimulus dependent feed-forward signals. However, in this article, we will use the term *phenomenal time* for both, unless otherwise stated.

<sup>4</sup> According to Albert Einstein, “past, present and future are only illusions, however persistent” (<http://www.iwaynet.net/~wdc/time.htm>).

<sup>5</sup> Adapted from [http://en.wikipedia.org/wiki/Planck\\_time](http://en.wikipedia.org/wiki/Planck_time).

<sup>6</sup> Adapted from <http://news.bbc.co.uk/2/hi/science/nature/3486160.stm>.

<sup>7</sup> To cast this idea in a slightly different light it might be helpful to contemplate, for a moment, the progress of western science. Newtonian mechanics assume (implicitly) that time and space form a constant and immutable substrate upon which laws of motion play themselves out. In a sense then, within the context of Newtonian mechanics, time and space are ‘outside’ of physics; they form an a-priori bedrock for physics.

In this light, the achievement of Einstein is all the more remarkable. Einstein effectively made space and time intrinsic quantities of physics and the universe itself – we now understand that the universe was not born *into* a space and time that already existed – the birth of the universe was also the birth of space/time.

Does this mean that space/time is a tangible substance? Surprisingly, this may not be the case. Most physicists believe that space/time is a structure that is implicit in the interactions between physical phenomena. In other words, it is the fundamental laws of relativity and quantum mechanics that limit the possibilities of physical interactions and thus determine the structure of space/time.

Making space and time intrinsic aspects of the physical Universe means that their properties are not absolute and/or not ‘pre-determined’ but must ultimately be consistent with and derivable from other known physical laws. The concept of a ‘Universe’ that includes

everything that exists must be a self-supporting and ‘internally’ consistent phenomenon that requires no external ‘constants’ to support it. Indeed, the current state of physics involves about 20 constants that have been discovered empirically. These constants represent the incompleteness of our current understanding of the universe. For example the unit charge of the electron is not a derived quantity. M-Theory and its antecedents the variants of String Theory ([http://en.wikipedia.org/wiki/String\\_theory](http://en.wikipedia.org/wiki/String_theory)) represent attempts to formulate a complete physical description of the universe such that these constants may be derived theoretically within a unified framework.

It may not be obvious from what has been said previously that there is a fundamental problem to be addressed. In order to illustrate the difficulty it is useful to consider time within the context of a thought experiment.

Let us suppose that we film a physical event. The physical event takes place in a room with a clock on the wall. Let us imagine that a reaction takes place in a glass beaker that results in a small explosion. Now, we may subsequently run the film at any rate that we wish. For example, we may slow the film down so that we see the glass beaker slowly crack followed by a slow motion explosion with pieces of glass sailing, in a seemingly surreal way, across the room. Surprisingly, it turns out that the slow motion film is an equally valid and physically consistent perspective on this event.

But, it seems quite obvious that explosions never occur this way. Fragments of glass never move so slowly through the air. However, we must try to avoid evaluating this event from our own subjective point of view. If we wished to analyze the event objectively, then, in order to determine if it is consistent with our understanding of the physics of the universe, we must carry out our analysis given the relative time frame as it is presented in the film. Thus, the duration of a second as it is depicted by the clock on the wall in the film may seem like a very long time for us, however, if we analyze the physics of the event mathematically using the clock on the wall as the time frame, then, it turns out, that no inconsistencies emerge. The event conforms precisely to predictions based upon the same equations that might be applied if the film was run at the normal rate, In fact, this is true no matter what at what rate the film is shown.

To strengthen this point in a slightly different way, let us suppose that a species evolved to experience time in a way similar to that depicted by the slow motion film. Then, if that species also evolved to develop a complex set of laws to describe the physical events that they witnessed around them, there would be absolutely no reason why those physical laws would not be identical to our own. This may not be such a strange idea - many of us have witnessed the dizzying motion of tiny insects and wondered if they might not experience time in a different way than we humans do. And indeed, if we believe that it is possible to experience time at various rates, then we must conclude, with St Augustine, that time (in as far as we are referring to our experience as a constant and flowing unfolding of events) is a purely mental phenomenon.

To qualify the preceding claims slightly: The absence of any physical correlate of temporal rate (or flow) is not inconsistent with what might be termed ‘an objective temporal reference frame’. Although relativity allows for the structure of space/time to vary depending upon one’s relative inertial reference frame, from equivalent inertial reference frames the structure of space/time is always the same. Thus, the oscillatory rate of the cesium atom will always be the same when compared to a fixed datum that shares the same inertial reference frame and will always ‘appear’ (subjectively) the same if observed from the same inertial reference frame and by the same observer. So, although there is no absolute rate of

time, nevertheless space/time embodies symmetries and structure such that we may make objective claims about *relative* temporal relationships. For example, if we obtained a film of an alien scientist looking at a strange clock on the wall of his lab, then, given that we could somehow also witness the behavior of cesium atoms in his lab, we would be able to play the film at the rate at which it was originally recorded – or, more precisely, we would be able to adjust the behavior of the projector such that it afforded us a perspective of events in the alien scientist’s lab from an equivalent inertial reference frame. Thus, we would be able to witness events at the same subjective rate as we would have experienced them if we were actually present when the film was made. What we would not be able to do so easily, would be to play the film to represent events to us as the alien scientist experiences them.

The number of times a cesium atom oscillates whilst the hand of a clock makes a single rotation will always be the same if the cesium atoms and the clock share the same inertial reference frame. However, whether the motion of the clock-hand is seen to crawl round the dial or is gone in the blink of an eye depends solely upon the ‘eye’ of the observer. Indeed, if we are to take reports of ‘time-dilation’ during periods of extreme stress seriously, then we must conclude that the rate at which we experience time is variable. If this is the case then there must be some physical quantity associated with brain function that changes with differences in temporal perception. Indeed, if we also take the artificial consciousness project seriously, then there would seem to be no logical or physical reason why we should not be able to build a conscious machine to experience time differently to ourselves. For example, we may wish to build a conscious machine that can make decisions depending upon very small temporal changes. In this case it might be a serious shortcoming for such a machine to experience time as ‘slowly’ as we do. If we accept the possibility that we may someday build such a machine then we have already committed ourselves to the idea that the rate of time experienced by a conscious entity is determined by some sort physical/physiological process or quantity. The argument in this paper represents a search for what this process or quantity might be.

<sup>8</sup> The relative motion between consciousness and the content of consciousness is simply the relative motion of the Now (= mental presence) relative to the moments of time ordered in the fourth dimension (= the events presenting themselves in the present). This is consistent with ‘phenomenal time’ in our framework. (Email communication with Franck on September 21, 2007). According to (Robbins 2007), “the problem of qualia is an offspring of abstract space and its correlate, abstract time. ... Semantics rests in the realm of mind, mind embedded in the concrete, indivisible, time-evolution of the matter-field.”

<sup>9</sup> According to (Vimal 2008c), “The quantum-dissipation model connects the discrete neural signals (**DNS**) to classical electromagnetic field (**EMF**) using quantum field theory (**QFT**) and chaos theory, for example  $DNS \leftrightarrow EMF \leftrightarrow QFT$  model for memory (Del Guidice et al. 1988; Pessa & Vitiello 1999; 2003; Vitiello 1995; Vitiello 2001; Vitiello 2002). This is useful in the investigation of Self and phenomenal time [...] In this model, “Water and other biochemical molecules entering brain activity are, indeed, all characterized by a specific electric dipole which strongly constrains their chemical and physical behavior” (Pessa & Vitiello, 2003). The electric dipole field can be considered as the fundamental units of the brain rather than neurons (Stuart, Takahashi, & Umezawa, 1978). However, in our view, both are related via neuronal-firing and other electrochemical activities of neurons and astroglia. In other words, classical electromagnetic field (EMF) arises from the electrochemical activity of discrete neural signals (DNS). The coupling between the classical electrochemical level and the quantum

dynamical level (QFT) is analogous to the coupling between classical acoustic waves and phonons in crystals. Intrinsic features of the dissipative quantum model are (i) brain processes are intrinsically and inextricably dependent on the quantum noise in the fluctuating random force in the brain-environment coupling, (ii) the chaotic behavior of the trajectories in the space of memory states. In the dissipative model, the 'brain (ground) state' may be represented as the superposition of the full set of memory states; therefore, previously recorded/'printed' information is not destroyed during current recording. In the non-dissipative model the number of freedom is missing and consecutive information 'printing' produces 'overprinting' (Pessa & Vitiello 2003). Dipole-rotation- and time-reversal symmetry breaking is equivalent to the recording of information in memory in (Pessa & Vitiello 2003) model; this meaning of symmetry is different from the shape-symmetry in terms of uniform diameter and structure of microtubules for generating soliton/traveling-wave (Davia 2006). Dissipative system for avoiding overprinting of new information for new memory in terms of superposition in (Pessa & Vitiello 2003) model is different from the traveling wave being non-dissipative for robust recording in microtubules (Davia 2006)."

<sup>10</sup> The following is adapted from (Vimal 2008c): We need to distinguish perception from sensation. According to (Humphrey 1992; 2000), (i) when we see a red rose, we *perceive* the external presence of a rose of red color (perception) and we also have *subjective experience* of redness (sensation); (ii) sensation helps keeping perception honest: 'Sensation lends a here-ness and a now-ness and a me-ness to the experience of the world, of which pure perception in the absence of sensation is bereft'; (iii) sensory quality is largely internal, covert and private; it appeared only after natural selection shaped it; (iv) "In the past my ancestors evolved to feel red this way because feeling it this way gave them a real biological advantage"; (v) 'self-representations arise through action, and that the "feeling self" may actually be created by those very sensory activities that make up its experience.'; and (vi) the quality of sensations (or SEs), though private today, has been shaped by natural selection in the past as a result of evolution: the primitive activity of sensing slowly became *privatized* from the overt public behavior and transformed into internal mental activity. The soliton-catalytic model of (Davia 2006) may be consistent with idea that sensation is the result of internalization of action via evolution and natural selection using the traveling wave. For example, when red light fell on the skin of primitive amoeba-like animal (floating in the ancient sea), it detected it and made a characteristic wriggle of activity (it wriggled 'redly') (Humphrey 2000). This wriggle can be considered as due to traveling wave of soliton-catalytic model, which when got internalized during evolution might have led to SE *redness* in humans. However, the explanatory gap remains in Humphrey's framework unless the PE-SE framework is invoked in the process of privatization. [...] The above models (Davia 2006; Del Giudice et al. 1988; Humphrey 1992; 2000; Pessa & Vitiello 1999; 2003; Vitiello 1995; 2001; 2002) can be called 'non-experiential materialistic' model because SEs are assumed to be the emergent property of network or field, and hence has explanatory gap. Perception may be explained to some extent by DNS $\leftrightarrow$ EMF $\leftrightarrow$ QFT model and soliton-catalytic model; Humphrey's model can address how sensation evolved from action. However, to address the explanatory gap, we need PE-SE framework (Vimal 2008a,b), which is a complementary to all non-experiential materialistic models because it allows experiential entities such as SEs of subject, objects, time, and so on into 'non-experiential materialistic' models. [...]

Once the of electrical-dipole-rotational-symmetry and time-reversal symmetry are broken by recording new information (represented by a coherent condensation

of the NG bosons), (a) 'NOW you know' occurs, (b) 'arrow of time', a partition in time evolution, and the distinction between the *past* and the *future* are introduced in brain dynamics, and (c) one moves forward in time (Pessa & Vitiello 2003).

The spatial invariance of the phenomenal time requires assigning a conserved entity over space. This space-invariant entity could be long-range spatial correlations, which is wave-like collective modes, such as QFT-NG boson modes. They can be generated dynamically, which can explain memory (past) (Pessa & Vitiello 2003). They can propagate over whole brain spatiotemporally. They are the carriers of the order in terms of long-range (a) spatial correction for the present phenomenal time, (b) temporal correlation for past phenomenal time, and (c) spatiotemporal correlations to maintain continuity of Self until disintegration during death. The past in terms of memory could also be recoded in microtubule-network (Woolf 2004; 1998; Woolf & Hameroff 2001; Woolf et al. 1999). In soliton-model of (Davia 2006), the emergent of the *phenomenal time* may also include extra-neural interaction of the soliton/traveling-wave (generated during neuronal-firing) carrying time-related information with motion or flicker related structures, such as motion area V5, for CFF.

<sup>11</sup> The 'specious present' spans in clock time on at least two levels: lower-threshold eigentimes in the range of 10-30 msec and higher threshold in the range of 1-3 seconds (Atmanspacher & Filk 2003).

<sup>12</sup> The temporal continuity of Self or the continuous temporal synchronization of SE can be explained by temporal long-range correlation or entanglement (Franck 200x).

<sup>13</sup> According to (McTaggart 1908), "Positions in time, as time appears to us *prima facie*, are distinguished in two ways. Each position is Earlier than some, and Later than some, of the other positions. And each position is either Past, Present, or Future. The distinctions of the former class are permanent, while those of the latter are not. [...] For the sake of brevity I shall speak of the series of positions running from the far past through the near past to the present, and then from the present to the near future and the far future, as the A series. The series of positions which runs from earlier to later I shall call the B series. The contents of a position in time [moment] are called events. [...] It may be the case that the distinction introduced among positions in time by the A series -- the distinction of past, present and future -- is simply a constant illusion of our minds, and that the real nature of time only contains the distinction of the B series --the distinction of earlier and later. [...] it seems to me that the A series is essential to the nature of time, and that any difficulty in the way of regarding the A series as real is equally a difficulty in the way of regarding time as real. [...] 'Now', the 'specious present' varies in length according to circumstances, and may be different for two people at the same period. [...] This duration [of objective present] cannot be the same as the duration of all specious presents [...] The duration of the objective present may be the thousandth part of a second. Or it may be a century [...] The objective time has only two durations, separated by a present which [...] is not a duration but a point. [...] The specious present of our observations - - varying as it does from you to me -- cannot correspond to the [objective] present of the events observed. [...] Our conclusion, then, is that neither time as a whole, nor the A series and B series, really exist. [...] the realities which we perceive as events in a time-series do really form a non-temporal series. [...] they are in reality no more a series than they are temporal."

<sup>14</sup> A Bose-Einstein condensate is a field and may exhibit invariance in time. However, does it make sense to think of an unchanging brain state as a temporal experience? In order to address these questions we must examine in a little more detail the nature of the BEC soliton (Fig. 3) and the theoretical context in which it is thought to occur as a central aspect of neural processing and the neural correlate of consciousness (NCC). The ‘explanatory gap’ implicit in NCC is addressed in (Vimal 2007; Vimal 2008a;b) elemental proto-experiences (PEs) are introduced without extending physics. Elemental PEs are evolved into neural-net PEs embedded in a neural net. A specific subjective experience is selected out of many neural-net PEs when a specific stimulus is presented to a subject (by the process of objective reduction of these neural-net PEs, i.e., collapse of wavefunctions)

<sup>15</sup> Traveling waves in the brain are observed (Xu et al. 2007) reported that (i) visually evoked primary wave originated in V1 and was ‘compressed’ (via GABA inhibition) when propagating to V2, which then reflected and propagated backward into V1, (ii) the compression/reflection pattern appears to be organized by an internal mechanism associated with visual processing. Furthermore, (Kole et al. 2007) reported digital to analog transformations in living systems: action potentials are the primary binary (digital) signal used by neurons for communication within the central nervous system. They showed that the site of action potential initiation in neurons, the axon initial segment, serves as a critical locus where these binary signals can be modified in a graded (analog) manner. In the retina, spontaneous activity takes the form of traveling waves, which are essential for the organization of retina to lateral geniculate nuclei pre-birth connectivity (Penn et al. 1998).

<sup>16</sup> Adapted from [http://en.wikipedia.org/wiki/Carrier\\_wave](http://en.wikipedia.org/wiki/Carrier_wave): A carrier wave is “a waveform (usually sinusoidal) that is modulated (modified) with an input signal for the purpose of conveying information, for example voice or data, to be transmitted. This carrier wave is usually of much higher frequency than the baseband modulating signal (the signal which contains the information). Carrier waves are used when transmitting radio signals to a radio receiver. Frequency modulation (FM) and amplitude modulation (AM) are common methods of sending information over carrier waves. [...] The frequency for a given radio station is actually the carrier wave's center frequency.”

<sup>17</sup> “Circadian clocks may be crucial for widespread changes in brain activity and plasticity. These daily changes can modify the amount or activity of available genes, transcripts, proteins, ions and other biologically active molecules, ultimately determining cellular properties such as excitability and connectivity” (Herzog 2007).

<sup>18</sup> The subjective experience of time (phenomenal time) is related to real physical clock time via biological clock but the former allows the duration of an hour to be longer or shorter; we are aware of the present but cannot experience the passage of time without a memory (Franck 2003). The phenomenal time (awareness of how ‘mental presence’ changes) depends on the effort needed to control the presence of phenomena, which varies with sleep-wake cycle and may depend on the environment and drugs; SE of time starts fading away with sleep-onset and reappears when we wake up; however, the temporal present and the physical clock time are independent of sleep-wake (daily circle of wakefulness, fatigue, dreaming sleep and dreamless sleep) cycle (Franck 200x). According to (Franck 200x), “The mode that mental phenomena exist in is called presence. The mode matter and radiation exist in is called reality

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[physical clock time]. Physical theory disregards presence in both the form of mental presence [phenomenal time: first person perspective] and the form of the temporal present. In contrast to mental presence, the temporal present is objective in the perspective of the third person. [...] The temporal present, when conceived as the actual time slice of spacetime, is what cuts three-dimensional objects out of four-dimensional trajectories. [...]. The temporal present, rather, is presence below the level of self-knowledge.”

The recurrent network in the granular layer and NMDA channels in granule and Golgi cells of cerebellum represents the passage of time (over a range of tens to hundreds of milliseconds), which is essential for organizing movements of different body parts into a coordinated action; the glomerulus is involved in a robust representation of time (Ivry & Spencer 2004; Yamazaki & Tanaka 2007).

<sup>19</sup> Adapted from “Does time slow in crisis?": <http://www.physorg.com/news116655680.html>

<sup>20</sup> See also [http://www.indianchild.com/what\\_do\\_animals\\_see.htm](http://www.indianchild.com/what_do_animals_see.htm)

<sup>21</sup> We are thankful to Prof. Patricia Carpenter for a part of summary. She commented (email correspondence on 26 November, 2007), “This proposal seems related to Stroud’s ‘psychological moment’ proposal (Stroud 1967) -- that there was a central pacemaker (in his view, uninfluenced by external stimuli) that psychologically 'packaged' events? Events within a moment were not discriminable in terms of sequence. Research yielded different estimates of the duration of these moments, and there were arguments concerning whether the moments were fixed or traveling. In the 1960’s, a type of ‘carrier wave’ was hypothesized to be the alpha wave. An alternative proposal was the persistence of various peripheral neural events. More generally, others argued that there are multiple correlates of these perceptual phenomena, rather than only a central neural phenomena. CFF may not be the only operationalization of the inability to detect change”. This can be the topic of further research.

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## Phenomenal Time and its Biological Correlates

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**Abstract:** - Our goal is to investigate the biological correlates of the first-person experience of time or phenomenal time. 'Time' differs in various domains, such as (i) physical time (e.g., clock time), (ii) biological time, such as the suprachiasmatic nucleus, and (iii) the perceptual rate of time. One psychophysical-measure of the perceptual rate is the critical flicker frequency (CFF), in which a flashing light is perceived as unchanging. Focusing on the inability to detect change, as in CFF, may give us insight into phenomenal time. CFF varies from 24 Hz for dim light and 60 Hz in bright light and is lower for colored lights. We propose that problem of the phenomenal time can be addressed using two contrasting but complementary approaches (inability to detect changes vs. ability to detect changes): (1) The soliton-catalytic model that entails invariant quantum coherent state for temporal frequencies (TFs)  $\geq$  CFF, similar to a Bose-Einstein condensate (BEC). (2) Temporal frequency tune mechanisms model, which starts with ability to detect changes for TFs  $<$  CFF and then their sensitivities decreases to zero at CFF. Phenomenal time may be quantized into 'subjective occasions of experience' (SE), which arise out of the interaction of the individual and situation. The SEs for a subject who has CFF of 60 Hz are approximately 16.7 ms in duration. Pioneering work examining the complex interaction of neurons suggests the possibility that macroscopic quantum states similar to a BEC may also occur in the brain (Davia, 2006; Freeman & Vitiello, 2006; Georgiev, 2004; Vimal & Davia, 2008).

**Key-Words:** - Phenomenal time; Quantum coherence; Soliton; Bose-Einstein condensate; Critical flicker frequency (CFF); Color fusion frequency; Temporal integration; Temporal frequency tuned mechanisms; Luminance and color channels; Subjective passage of time; Past, present, or future; Linear and cyclic nature of time

### 1 Introduction

Bergson argued that time could only be understood from the contemplation of the consciousness moment, i.e., time is "grasped by, and belongs only to, inner consciousness" (Bergson, 1889/1960). According to James (James, 1890/1981), in the context of phenomenal time, (i) Clay's the obvious past, the specious present, the real present, and the future play important role in the stream of consciousness, (ii) the 'sensible present' and 'spacious present' have duration (a few seconds to a minute), which is in recent past, i.e., working memory, whereas the 'the real present' implies a durationless instant, the latter boundary of 'specious present', (iii) the perception of space and that of time interacts, i.e., "Date in time

corresponds to position in space”, and (iv) a succession of thoughts is not a thought of successions. According to Vimal (Vimal, 2008a), phenomenal time can be defined as the subjective, personal, or first person experience of time.

## 2 Problem Formulation

Phenomenal time is a long standing problem for cognitive science and the philosophy of mind. St Augustine argued that the experience of change must involve a connection between future events, present events, and past events. However, if each moment comprised an infinitely thin slice of time, then such a connection seemed impossible. One might argue that the experience of change emerges simply as a consequence of the causal relationships that effect transitions; however, “Change in our experience is not the same thing as experience of change” (Le Poidevin, 2004). In physics, there is no absolute rate of time, i.e., although we may claim (within limits determined by relativity) that event A precedes event B, there is no criteria that determines how quickly or how slowly consecutive events should be experienced. The concept of an absolute and fixed rate of time is wholly absent from our physical description of the universe. The temporal passage has been considered a subjective illusion (McCall, 1994). We shall argue that the problem of phenomenal time cannot be solved within the context of a classical physics. An approach rooted in quantum coherence, such as a solitonic (traveling wave) coherent state similar to a Bose-Einstein condensate (BEC) or an approach based on temporal frequency tune mechanisms, may resolve the problem. We shall point to a specific physical quantity as the principle factor, which determines the apparent rate that we experience time. We shall discuss the physiological correlates of cyclic and linear nature of time underlying temporal consciousness. The fundamental problem is formulated as follows: what are various aspects of time, what is phenomenal time and what are its neural correlates?

## 3 Problem Solution

### 3.1 Aspects or forms of time and phenomenal time

The various forms of time are as follows: (A) Physical time: This is physical clock time. The Planck time is the unit of time in the system of natural units known as Planck units, which is the time it would take a photon traveling at the speed of light in a vacuum to cross a distance equal to the Planck length; it is about  $5.39 \times 10^{-16}$  seconds; however, it has not been measured yet. Images of electrons leaving atoms were produced by short pulses of laser light and recorded within 100 attoseconds ( $10^{-16}$  seconds); this is the shortest time measured so far. (B) Biological time: although all brain areas can be considered as biological clocks, the suprachiasmatic nucleus is the master molecular clock; it is measured in msec. (C) Perceptual rate of time: this is psychophysically measured in cycles per second (Hz) using luminance critical flicker frequency (CFF). It varies from 24 Hz in dim light and 60 Hz in bright light for normal humans to 80 Hz for Buddhist monks during meditation to 300 Hz for the honeybee. Color fusion frequencies are lower than CFF. Time can be integrated up to 160 msec for luminance stimuli, whereas integration time is longer for color stimuli.<sup>1</sup> When we view a sinusoidally flickering light with temporal frequency (TF) above CFF, the associated experience is invariant in a sense that we do not perceive any flicker and light appears like steady light. In other words, if we start from TF = 0 Hz to CFF, (i) we perceive first steady light at 0 Hz, (ii) then flicker-perception increases with increase of TF to maximum value at peak-TF and (iii) then flicker-perception decrease as we increase TF and (iv) eventually reaches

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<sup>1</sup> One should be careful with flickering light because epileptic seizures may develop in photosensitive subjects under certain conditions. “Photosensitivity is sensitivity to flickering or intermittent light stimulation but includes sensitivity to visual patterns. Photosensitive epilepsy therefore can be defined as recurrent convulsions precipitated by visual stimuli, particularly flickering light” (Harding & Jeavons, 1994). For epileptic seizures, it is essential that stimulation must be binocular (viewed through both eyes) in addition to central presentation of flickering lights or patterns (Harding & Jeavons, 1994). Therefore, care must be taken by asking subjects to use an eye-patch on one of the eyes for viewing the stimuli monocularly to eliminate seizures or photosensitive subjects should be excluded.

flicker-perception of zero at CFF. However, CFF depends on internal and external context, i.e., it would be possible to alter the predictions of the values of peak-TF and CFF, but the above 4 steps will occur. It would be interesting to experiments on time-estimation at above 4 crucial points. Our prediction is that phenomenal time (SE of time) will be different (possibly faster) at peak-TF than that at  $TF > CFF$ ; note that we perceive maximum flicker at peak-TF and no flicker at CFF. (D) Relative positions in time: these can be distinguished in two ways: (i) Each position is either Past, Present, or Future. This distinction varies continuously. (ii) Each position can be *earlier* or *later* than positions. This distinction is permanent. (E) Cyclic and linear nature of time: Time can be cyclic (day  $\leftrightarrow$  night) or linear (future  $\rightarrow$  present  $\rightarrow$  past). (F) Subjective passage of time can be shorter or longer than physical time depending on the state of mind. Phenomenal time is subjective experience of time. It seems to speed up as we grow older, slow down in crisis, and slowing towards stopping, in some cases, such as at death, in near-death experience, meditation, and psychedelic drug use (Vimal & Davia, 2008). Furthermore, rather than focusing on the ability to detect change, insight into phenomenal time may come by focusing on the inability to detect change such as in CFF. After every phenomenal time, there may be an ‘occasion of experience’ or SE, for example, Buddhist Monk who has CFF of 80 Hz may have SE every 12.5 msec whereas a subject who has CFF of 60 Hz may have SE every 16.7 msec.

### 3.2 Models and experiments related to time

We would like to discuss a few models that may address phenomenal time. (i) In the **dissipative quantum model** of the brain, “Water and other biochemical molecules entering brain activity are, indeed, all characterized by a specific electric dipole which strongly constrains their chemical and physical behavior” (Pessa & Vitiello, 2003). The electric dipole field can be considered as the fundamental units of the brain rather than neurons (Stuart, Takahashi, & Umezawa, 1978). In this model (Vitiello, 2001), the brain is constantly entangled with its environment in a way that maintains the unified whole in time. This entanglement causes our perceptions to be imprinted upon memory, which are then processed into the cognitive map of our environment. This map appears to be in relative motion (‘relating the presence of consciousness to the contents consciousness is conscious of’) during the SE of passage of time (Franck, 2004; Husserl, 1966/96). (ii) The **soliton-catalytic model** (Davia, 2006) argues that non-linear interactions in the brain give rise to solitons, which mediate energy dissipation as a macroscopic process of catalysis. It does not contradict the quantum-dissipative model (Pessa & Vitiello, 2003), rather they are equivalent to each other; they try to connect discrete neural activities to classical field to quantum field (Vimal & Davia, 2008). Within the catalytic model (Davia, 2006), it is noted, that solitons are a classical analogue of quantum particles suggesting the possibility that solitons may ‘induce’ macroscopic quantum states. Although solitons are often defined as non-dissipative, this is not true for similar phenomena that occur within dissipative media. Within the soliton-catalytic model the brain is considered to be an excitable media and therefore a dissipative media. In the soliton-catalytic model (Davia, 2006), energy is dissipated via structure (fixed points that do not change under transformation). (iii) According to Vimal (Vimal, 2008a), the wriggles in **Humphrey’s framework** (Humphrey, 2000) of sensation from the internalization of action during evolution can be considered equivalent to the traveling wave in soliton-catalytic model (Davia, 2006). (iv) One could argue that the apparent rate at which time is experienced (phenomenal time) depends on the **spatio-temporal characteristics of visual mechanisms**. For example, human visual system has one luminance and two color (Red-Green and Yellow-Blue) psychophysical channels, each has spatial, temporal, and spectral frequency tuned mechanisms. There are six bandpass spatial frequency tuned luminance mechanisms and six spatial frequency tuned Red-Green color mechanisms (one lowpass and five bandpass) (Vimal, 1998a, 2002a). There are four temporal frequency tuned luminance mechanisms: one low-pass with a corner frequency of 8 Hz, and three bandpass with bandwidth of 2-2.5 octaves peaking between 4-8 Hz (Lehky, 1985). There are two temporal frequency tuned color mechanisms: one low-pass and other bandpass (Metha & Mullen, 1996). The above are threshold mechanisms, which have flattening effect and show color-contrast constancy at suprathreshold level (Vimal, 2000; Vimal, Pandey, & McCagg, 1995). The luminance channel showed no temporal integration beyond 160 msec, whereas color channels had longer integration time (Smith, Bowen, &

Pokorny, 1984). Our goal is to investigate a general unifying principle underlying these tuned mechanisms and to relate them to phenomenal time. (v) In **chaos theory**, the balance between linear and nonlinear time involves (a) the changing demands as one approaches and departs bifurcation points, and (b) time dilation and contraction as a control parameter. For example, meditators **self-organize** time perception differently compared to non-meditators: critical flicker fusion frequency progressively increase by 11-15% following yoga training (Vani, Nagarathna, Nagendra, & Telles, 1997). Buddhist monks show highly coherent, high amplitude gamma synchrony EEG about 80 Hz (Lepine, 2007). To sum up, there are two major approaches to address CFF based phenomenal time: (I) An approach based on inability to detect changes, such as for TFs  $\geq$  CFF. Here, the soliton-catalytic model can be used, which entails invariant quantum coherent state with respect to change in TF, similar to a Bose-Einstein condensate (BEC). (II) An approach based on temporal frequency tune mechanisms, which starts with ability to detect changes for TFs  $<$  CFF and then their sensitivities decreases to zero at CFF. These two contrasting approaches (inability to detect changes vs. ability to detect changes) may indeed be complementary.

### 3.3 Continuous experiences and invariance related to time

One could hypothesize that the apparent rate at which time is experienced is dependant upon the lower limit of a subject's sensitivity to change. This hypothesis is based upon our own subjective experience of what it is like to 'just about be able to see something move' and relies upon our inability to conceive of what it might be like if our experience of change was not characterized by a continuum of experiential states – i.e. from almost stationary to moving very fast as we experience them. But, our inability to conceive of what it might be like to experience change in a radically different way is not sufficient evidence that a very different relationship between changing stimuli and corresponding phenomenological states is not possible. Up until now we have been examining the problem of phenomenal time within the context of changing temporally structured experiences. However, there is a class of experiences that are completely invariant with respect to time. When we listen to a sine wave above the critical frequency, the associated experience is completely invariant. Can progress be made by considering the problem within the context of temporally invariant experiences? Having argued that change is not essential for an experience to involve phenomenal temporal flow, we may simplify the problem we are addressing by eliminating the need to consider change or 'phenomenal change' as a first order aspect of the problem. We suggest that phenomenal temporal flow may exist without phenomenal change but phenomenal change cannot exist without phenomenal flow. Invariant experience with respect to phenomenal time is related to perceiving steady light for all stimulus-flicker rates that are greater than critical flicker fusion frequency. Thus, for a particular temporally structured stimulus there may be only one possible phenomenal state.

### 3.4 Quantum coherence and solitons in visual area – toward a solution

The inability to detect change beyond critical flicker fusion (CFF) frequency may be because our visual system is not sensitive to frequencies greater than CFF. In other words, visual system needs time to integrate information, which we have defined as *phenomenal time* and is about 16.7 msec for CFF = 60 Hz.

Alternatively, one can argue that rather than focus on the ability to detect change, insight into phenomenal time may come by focusing on the inability to detect change. One operationalization of the inability to detect change is the CFF rate. CFF may be correlated with a neural Bose-Einstein condensate (BEC) soliton, the properties of which include temporal uncertainty. Quantum states are implicated in the phenomenon of consciousness (Hameroff, 2003). Dynamic systems may give rise macroscopic states that resemble a phenomenon termed a Bose-Einstein condensate (a field that may exhibit invariance in time). A Bose-Einstein condensate is a condensed phase of matter in which the individual identity of the comprising atoms is lost and forms a coherent unity – a single wave function. This phase change is extremely difficult to bring about and usually requires temperatures very close to absolute zero. However, there is a growing body of research that suggest that similar states may be brought about as a consequence

of the behavior of nonlinear dynamic systems. Studies into the behavior of complex networks like the World Wide Web, suggest that, under certain conditions, a change in the overall dynamic behavior of the network may occur that is a classical analogue of a Bose-Einstein condensate (BEC) and is mathematically modeled in the same way (Bianconi & Barabasi, 2001). Pioneering work examining the complex interaction of neurons suggests the possibility that Macroscopic quantum states similar to a BEC may also occur in the brain (Davia, 2006; Freeman & Vitiello, 2006; Georgiev, 2004; Vimal & Davia, 2008). If such macroscopic states do indeed form the neural correlate of consciousness then these states may be in the form of solitons (Davia, 2006). A soliton is an extremely robust non-linear dynamic that preserves its structure as a consequence of a fine balance between linear dissipative and nonlinear compressive forces.

Solitons (or robust traveling waves) were observed in visual area V1 and are essential for the organization of retina to lateral geniculate nuclei connectivity prior to birth. For example, traveling waves in the brain are observed (Xu, Huang, Takagaki, & Wu, 2007) reported that (i) visually evoked primary wave originated in V1 and was 'compressed' (via GABA inhibition) when propagating to V2, which then reflected and propagated backward into V1, (ii) the compression/reflection pattern appears to be organized by an internal mechanism associated with visual processing. There is an empirical evidence that solitons can be generated in a BEC (Denschlag et al., 2000). Furthermore, (Kole, Letzkus, & Stuart, 2007) reported digital to analog transformations in living systems: action potentials are the primary binary (digital) signal used by neurons for communication within the central nervous system. They showed that the site of action potential initiation in neurons, the axon initial segment, serves as a critical locus where these binary signals can be modified in a graded (analog) manner. In the retina, spontaneous activity takes the form of traveling waves, which are essential for the organization of retina to lateral geniculate nuclei pre-birth connectivity (Penn, Riquelme, Feller, & Shatz, 1998). Solitons require structure in the boundary conditions of their environments for the possibility of their emergence. Furthermore, the fractal catalytic model (Davia, 2006) argues that the brain (which is considered to be an excitable medium) is structured in real time by the body and the environment (both immediately via the senses and historically via past experience) and that any spatio/temporal symmetries (invariance) implicit in the body, the senses and dynamics of interaction between body/senses and the environment may support soliton formation in the brain (Davia, 2006). Within the context of this theory, consciousness is correlated with the spatio/temporal evolution of a coherent soliton. If an invariant conscious state is to be correlated with a soliton in the form of a BEC, then, just as it is possible for a simple electromagnetic field to exhibit non-trivial invariance, so it is possible for non-trivial states to occur such that no matter at what rate we present the flickering stimulus the physical correlate of consciousness (the BEC soliton) may always appear exactly the same, as long as the flicker rate is greater than CFF frequency.

A BEC soliton is an interesting phenomenon when considered in the light of the problem we are addressing. Unlike a classical soliton (e.g. a tsunami), a coherent soliton in the form of BEC exhibits properties quite different from a classical soliton. Although complex – a BEC soliton is a probability wave function. As such it embodies characteristics of any quantum probability wave function. In addition to the uncertainty between position and momentum, the wave function also describes the uncertainty between energy and time. So, a soliton in the form of a BEC is a four dimensional phenomena with extension in time as well as space. The degree of this extension is determined by the Uncertainty Principle. Correlating consciousness with a coherent BEC soliton does not immediately solve our problems. Although, the uncertainty in time of the wave function may be significant with respect to the problem we are addressing, within the context of the potentially infinite number and variety of cognitive and behavioral states and the potentially infinite number of associated wave functions, it is difficult to see why our experience of temporal flow should exhibit such consistency. However, progress may be made by considering research that provides evidence that there may be an underlying 'carrier wave' that supports other neurological processes – a carrier wave for consciousness. The basis of this hypothesis is as follows: The frequency of stimulus fusion in the tactile, auditory, and visual modality equals 18 Hz (Lalanne, 1876). If film is shown at a frame-rate less than 16 Hz then 'flicker' becomes more pronounced. Color flicker-fusion frequency is lower than luminance flicker-fusion frequency (Kaiser, Ayama, &

Vimal, 1986; Kaiser, Vimal, Cowan, & Hibino, 1989). Thus, there is sufficient evidence pointing to a critical threshold that demarcates the boundary between continuous and discontinuous experience across sensory modes. The flicker-fusion threshold demarcates the boundary between temporally modulated stimuli that can and cannot be sensed – it marks the limit above which change cannot be experienced. These findings support the hypothesis that there may be an important cycle rate or minimum unit of consciousness. For the argument that follows we shall assume that these findings point to an underlying coherent carrier wave for consciousness.

### 3.5 Catalytic-soliton and temporal frequency tuned mechanisms models for phenomenal time

As discussed above, the fractal catalytic model of consciousness correlates mental states with the spatio-temporal evolution of a coherent soliton. The underlying coherent soliton associated with consciousness may be continually adapting and changing its organization as a consequence of variations in the boundary conditions imposed upon it by the body and the senses. If the temporal structure of the stimulus exhibits modulations that are greater than the uncertainty of the probability wave function of the BEC soliton then, a varying experience will be the result. But, what of stimuli that exhibit temporal variations ( $\Delta T_s$ ) that are smaller than the uncertainty of the wave function ( $\Delta T$ )? Stimuli with temporal intervals smaller than the temporal uncertainty of the carrier wave function (i.e., when  $\Delta T_s < \Delta T$ ) may nevertheless give rise to unique and unvarying solitonic solutions. Given the possibility that the neural correlate of temporal consciousness is a BEC soliton, and given the possibility that there may be unique solitonic solutions determined by temporal structures which fall below the uncertainty in time associated with its wave function (i.e., when  $\Delta T_s < \Delta T$ ), then those solutions cannot embody information that could be used to distinguish individual temporal components of the stimulus within the BEC's soliton's temporal uncertainty. This hypothesis accords well with the phenomenology of experience. Although we may be able to experience a high frequency stimulus, we are unable to distinguish its small scale structure. Given that the flicker fusion frequency or CFF is a crucial quantity that represents the limit above which we cannot experience change (i.e., when stimulus flicker frequency  $FF_s > CFF$ ), then it would seem reasonable to conclude that the primary factor that determines the apparent 'rate' at which we experience time is the uncertainty in time associated with the carrier wave function of the BEC soliton. The flicker-fusion frequency may be giving us very precise information about the way in which we (and other species) experience time. It must be pointed out that a threat to this hypothesis exists as a consequence of a large body of research that seems to show that the flicker-fusion frequency depends upon factors such as intensity and wavelength of stimuli, adaptation condition, background condition and so on (Kaiser et al., 1986; Kaiser et al., 1989). However, we could argue that uncertainty in time associated with the carrier wave function of the BEC soliton also similarly depends on the above factors. Any attempt to interact with a coherent state that resulted in information being obtained that fell below the temporal uncertainty of the wave function (i.e., when  $\Delta T_s < \Delta T$ ) must cause it to collapse. We suggest that the temporal uncertainty of the wave function demarks the boundary below which discriminations in time cannot be made. We suggest that for this reason, time as it forms part of the wave function cannot be considered as a 'duration' as is normally conceived.

Alternatively, one could also argue that some of the temporal frequency tuned mechanisms that were sensitive at high suprathreshold luminance becomes less sensitive to the extent that they are non-functional at lower luminance. This is in analogy to the number of luminance spatial frequency (SF) tuned mechanisms dropped down from 6 at photopic to 4 at mesopic level to 2 at scotopic level, where higher SF tuned mechanisms were first to drop (Vimal & Wilson, 1986, 1987). It would be interesting to extract temporal frequency tuned mechanisms at mesopic and scotopic luminance levels. One could further argue that if a subject's CFF = 60 Hz, then the subject has Whitehead's *occasion of experience* at every 16.7 msec. The critical flicker fusion frequency (CFF) is the frequency at which a flickering light is indistinguishable from a steady, non-flickering light. CFF depends on species, luminance level, color, and other conditions. Frank (Frank, 2000) reported, "nocturnal insects tend to have lower CFFs [and lower

temporal resolution] than diurnal insects”, and “there is a trend towards lower CFFs with increasing habitat depth”. Some of luminance CFFs are as follows (Vimal & Davia, 2008): (i) 60 Hz in bright light and 24 Hz in dim light for humans, (ii) 58 Hz for cat, (iii) 70 Hz for octopus in bright light, and (iv) 180-300 Hz for honeybee, dragon fly and blowfly flies. These data can also be explained by their temporal frequency tuned mechanisms, which needs further investigation.

### 3.6 Biological correlates of phenomenal time

The brain itself can be considered as a clock or ‘organ of time sense’ (Dawson, 2004). The biological circadian clock has an intrinsic period of about 24 hours, which synchronizes to the daily day-night (light–dark) cycle (Herzog, 2007). According to Herzog, “circadian clocks may be crucial for widespread changes in brain activity and plasticity. These daily changes can modify the amount or activity of available genes, transcripts, proteins, ions and other biologically active molecules, ultimately determining cellular properties such as excitability and connectivity” (Herzog, 2007). For example, suprachiasmatic nucleus (SCN) tracks the cyclic form of time such as sleep-wake rhythms and regulates the biological need for sleep, food, and reproduction. Activation of SCN and primary visual cortex depends upon time of day (Vimal et al., 2006; Vimal et al., 2008). Whereas hippocampus and frontal cortex tag a linear cause-and-effect form of temporal information about the memories of the past and the expectancies for the future, respectively, and regulate neural nets that together form memories, consciousness, and the perception of past, present and future (Dawson, 2004). Both forms of biological time or clocks are critical in temporal consciousness; when one is turned on, other is turned off (Dawson, 2004). When these clocks are out of synchrony, both physical and mental disorder can occur (Dawson, 2004). Temporal disorganization of the brain is a characteristic of the aging process, such as a disruption of the sleep–wake cycle, ‘an increase in the subjective rate of time passage’, and a decline in future expectancies (Dawson, 2004). Time seems to speed up as we grow older and time appears to slow down in crisis (Vimal & Davia, 2008), for example time seems 36% longer in free fall.<sup>2</sup> Phenomenal time (subjective experience of time) slowing towards stopping, in some cases, such as at death, in near-death experience, meditation, and psychedelic drug use (Osiris & Haraldsson, 1997; Smith & Tart, 1998). A player who has higher rate of conscious moments may win the game (Hameroff, 2003). The temporal disorganization observed in schizophrenia, autism, and bipolar disorders may be partially due to genetic mutations in the human clock gene. The brain is temporally organized via ‘temporal tagging’ and ‘re-entry’, which bind the wide range of spatiotemporal stimulus-features to a unified subjective experience that is held in synchrony with the external world (Dawson, 2004; Vimal, 2008b). Time and its neuroendocrine correlate melatonin are involved in binding the spatiotemporal stimulus features for subjective experience (Dawson, 2004; Vimal, 2008b). Melatonin decreases the desynchronization between internal circadian rhythms and the external environment, which occur in jet-lag, shift-work, blindness, and delayed sleep phase insomnia (Vimal et al., 2008). From the fMRI data for the phenomenological concepts of temporality i.e. phenomenal time, (Northoff & Heinzl, 2006) wrote, (Lloyd, 2002) “observed that the multivariate distance and changes between brain images is approximately linearly related to their temporal distance. The more closer acquired in time the more similar the images. Thus, the changes between the different images occur gradually over time. Lloyd argues that these results are consistent with Husserl’s description of time consciousness in that they reflect the inexorable temporal flux of the conscious state. Analogous to the way that each moment of our phenomenological experience of time builds on foundation of the previous moment, the series of fMRI images appears to form a continuously evolving temporal pattern of global activity.”

## 4. Conclusion

We summarize our proposal as follows: (1) Rather than focus on the ability to detect change, insight into phenomenal time may come by focusing on the inability to detect change. This is consistent with the

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<sup>2</sup> Adapted from “Does time slow in crisis?”: <http://www.physorg.com/news116655680.html>

‘psychological present’: ‘there is always an experienced duration in which experience does not change’ (Stroud, 1967; van Leeuwen, 2007). (2) One operationalization of the inability to detect change is the critical flicker fusion (CFF) rate. (3) CFF may be correlated with a neural Bose-Einstein condensation (BEC) soliton (traveling wave), the properties of which include temporal uncertainty. (4) A single CFF (16-18 Hz) would be associated with an ‘underlying coherent carrier wave’ for consciousness; however, CFF may depend on many factors. (5) The subjective experience of time is *phenomenal time*; in terms of measurable physical time it is  $1/\text{CFF}$ ; it can be addressed by temporal frequency tuned mechanisms. (6) After every *phenomenal time*; there may be an ‘occasion of experience’ or subjective experience (SE), i.e., Buddhist Monk who has CFF of 80 Hz may have SE every 12.5 msec whereas a subject who has CFF of 60 Hz may have SE every 16.7 msec. (7) Thus, the CFF based *phenomenal time* can be explained by two models: (i) soliton-BEC model based on the time-interval in which a subject is unable to detect change of stimulus or flicker and (ii) temporal frequency tuned mechanisms model based on the limit to detect change (when mechanism’s sensitivity to flicker is zero). The latter is popular in psychophysics. Further investigation is needed to find out which model is better or if they are complementary to each other.

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### Competing interests statement

The author declares that he has no competing financial interests.

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