The Journal of Mind and Behavior
Summer 2008, Volume 29, Number 3
Pages 239–254
ISSN 0271–0137

Neurophysics of the Flow of Time

Ronald Gruber

Stanford University

Three physical theories explaining the flow of time are examined. One theory suggests that "flow" is associated with the manner of information transfer between registers (modules) within the brain. Different robotic systems are predicted to experience different types of flow. Here, human examples (savants and amnesics) are found to support the theory and the model is modified suggesting that flow is a cognitive illusion. A second theory suggests that time is non-existent, that the universe is a complex quantum state which, upon observation, the brain acquires "stills" and converts them to an illusion of motion and flow. Accordingly the brain should be able to generate a physiological illusion of temporality (the experiential phenomenon of before/after) from stills. Experimental evidence is given that the temporality illusion so generated is not physiological; it is cognitive, lending no support to that theory. A third theory suggesting that the flow of time is really a myth is briefly reviewed.

Keywords: flow of time, temporality, now, present

On a daily basis we divide time into the past, present and future. Thoughts of the future enter the fleeting present (some say 2–3 seconds) only to be relegated to the fixed past in the form of memory. This description of the flow of time is at odds with modern physics (Davies, 2002). Einstein expressed this point to a friend, stating the past, present and future are only illusions, even if stubborn ones (see Davies, 2002). Smart (1980) claimed that if the flow of time is literally supposed to be a motion, whether of time or of events in spacetime, there is an objection to the idea. Motion is the rate of change of spatial position with respect to temporal position. What sense would one make of the motion of time itself or of motion through time? These issues forced Smart to conclude that there is no river of time and that the flow of time is merely an illusion. Others have argued similarly (Brown, 1990; Euler,

Requests for reprints should be sent to Ronald Gruber, M.D., 3318 Elm Street, Oakland, California 94609. Email: rgrubermd@hotmail.com

1997) and Elitzur (1996) concluded that time's passage and consciousness are two parts of the same mystery. It should be emphasized, however, that the flow of time is only one aspect of the perception of time. Poppel (1978) suggested a taxonomy of elementary time experiences which includes: experience of duration, simultaneity/successiveness, sequence, present ("now") and anticipation.

The purpose of this paper is to examine three very different physical theories regarding the flow of time. The first is that of Hartle (2005) which basically views the human brain as an information gathering and utilizing system (IGUS) in which the flow of time is associated with the manner of information transfer between modules. Theoretical robotic IGUSs would thus demonstrate different flows of time. The second is a theory of Barbour (1997, 2000) based upon ideas from quantum gravitation stating that time does not exist. He suggests that the universe is a complex quantum state that upon observation, the brain acquires in the form of stills. Barbour posits that the human brain experiences motion from the processing of a small group of such stills, but the motion itself (including time) is an illusion. The third is Park's (1971) theory which states that the flow ("passage of time" as he refers to it) is a myth. He suggests that it is something by which to measure events, is analogous to length which measures matter, and therefore can never be tested, i.e., length is not a physical entity per se, but rather a means of measuring physical entities. "Flow" in Park's view is in the same category as length.

Analyzing the Flow of Time Theories

The IGUS Theory

Hartle (2005) rightfully argues that questions concerning past, present and future cannot be ignored by physics. He describes the origin of the division of physical time into the subjective time of past, present, and future with the aid of robotic models (not to be confused with, although conceivably similar to Koch's [2004] zombies). These robots are considered to be information gathering and utilizing systems. Information is gathered by the robot as follows (see Figure 1): it has n + 1 memory locations P_0, P_1 . . . P_n which are called registers (neurological modules). The image in register P_n is erased and replaced by the image in P_{n-1} and replaced by the image in P_{n-2}, etc. The registers $P_1 - P_n$ therefore constitute the brain's memory of the past. The most recent image is in P_0 (the robot's present, according to Hartle); the oldest is in P_n which is subsequently erased (goes to the "trash can"). Information is utilized by the robot by employing the information in registers P_0, P_1 . . . P_n to compute predictions about its environment. The robot's memory stores a simplified model of its environment containing not all the information in P_0, P_1 . . . P_n but only

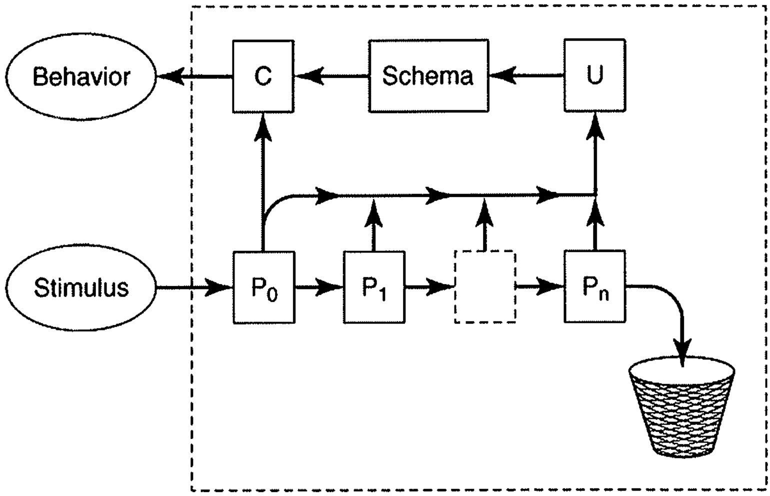

Figure 1: The Hartle IGUS model. Information is gathered by the robot as follows: it has n + 1 memory locations P_0, P_1 . . . P_n which are called registers. The image in register P_n is erased and replaced by the image in P_{n-1} and replaced by the image in P_{n-2} etc. The registers $P_1 - P_n$ therefore constitute the brain's memory of the past. The most recent image is in P_0 (the robot's "present"); the oldest is in P_n which is subsequently erased. The robot uses the images in $P_0 - P_n$ in two process of computation: C ("conscious") and U ("unconscious"). The process U uses the data from all registers to update a simplified model of the external environment. That is used by C together with the most recently acquired data in P_0 to make predictions about its environment. Reprinted from J.B. Hartle, The physics of now. *American Journal of Physics*, *73*, pp. 101–109. ©2005, The American Association of Physics Teachers.

those parts important for the robot's functioning. This model involves a schema. The robot updates its schema by utilizing new information in P_0 along with the old information from P_1, P_2 . . . P_n through a computation process denoted by U (U because it is similar to a human's unconscious processing). The robot has another process of computation, C (similar to a human's conscious processing). The U computation provides input to decision-making C computation. In the normal situation there is direct input into C computation only from the most recently acquired images in the register P_0. No attempt is made to associate C computation to the current theories of consciousness (Dennett, 1997; Hameroff and Woolf, 2003; Penrose, 1989) or to a homunculus function which could easily be criticized (Barba, 2001).

The robot is said to experience the present and remember the past. "The experiential phenomenon of the flow of time is said to be associated with the movement of information into the area of C computation and out again. The flow of time of an IGUS is consistent with the laws of physics and can be described in conventional four-dimensional spacetime. There is no conflict between physics and the subjective past, present and future of an IGUS. In fact, the IGUS is a four-dimensional notion. The past, present and future are not properties of spacetime but of the history of a particular IGUS.

Hartle attempts to convince his reader that the notion of past, present, and future does not follow from the laws of physics by asking the reader to imagine constructing robot IGUSs that process information differently from that of the human IGUS. One of the theoretical robots he suggests is a no schema (NS) robot. It has input from all registers P_0, $P_1 \ldots P_n$ equally. It employs no U computation, constructs no schema, and makes decisions by C ("conscious") computation only from all the data it acquired. Construction of a NS robot in this way does not violate the laws of physics but it would process information differently and exhibit a different flow of time. The NS robot would have only one category of recorded information. It would recall every detail it recorded from the past as vividly and immediately as the present and be an impressive conversationalist.

Testing the IGUS Theory

What is helpful about the IGUS theory is its falsifiability and accessibility to observational testing. Hartle speculates that one could construct a "virtual reality suit" in which the incoming data could be delayed in such a way so as to reproduce alternative versions of the flow of time by these differing IGUS. He speculates, however, that we should not expect to find such IGUS on Earth because it would not be adaptive for a human IGUS to not focus on most recently acquired data to make immediate decisions. However, it is quite possible that some of his predicted IGUSs do exist in humans to a limited extent. Savants process almost every piece of incoming information and recall it as immediately and as vividly as the present. Luria's (2003) famous mnemonist patient, Sherashevsky, could memorize page after page of a telephone book. However, the patient was so overwhelmed with information (couldn't erase information from register [module] P_n) that he led a very depressed and unproductive life. Conversations with Sherashevsky were impressive because he recalled every detail he had recorded about the past immediately and as vividly as the present. For all practical purposes everything he took in was kept in the present. Ironically, everything was new to him at every moment (Draaisma, 2004): he was just like someone without a memory and without a past — only a very large present. It would appear that he was the human analogue of the NS robot who has input to C computation from all registers $P_0 - P_n$ equally (but sequentially). He appeared to employ no or little U computation, and made decisions by C (conscious) computation only (or predominantly) from all the data he acquired. Another famous savant, Ireneo Funes (Borges, 1962; Hartle, 2005, ref. 43) behaved in a very similar manner.

One other IGUS variant would appear to be Scoville's (1968) patient, H.M., who suffered from anterograde amnesia following temporal lobe resection involving the hippocampus. The substance of a conversation at 1:00 pm was no longer remembered at 1:15 pm. He had memory for some events occurring prior to the surgery. However, he was unable to acquire memory for events that occurred in the present. Consequently, his flow of time was from the future to the present with no past (except for very old memories from prior to the surgery). It is as if he had very few registers (P_n = a small number) or as if information from his memory registers (modules) was sent to the "trash can" early. The net result is that he lived in a continual present, the year 1953 when the operation was performed (Poppel, 1988).

Some who meditate, particularly those practicing Zen Buddhism, have noticed that time is suspended (Ornstein, 1977). In particular, a peculiar alteration in the temporal experience of advanced meditators occurs in the state of Samadhi. This and similar phenomena have been reviewed by Block (1979) and described as a feeling of void in which there is a paradoxical awareness without thoughts. In this mode, all action occurs in an infinite present. There is no construction of sequence. Events occur simultaneously. In effect, no flow of time is experienced. Also, there is no experience of motion or temporality (the experiential phenomenon of before/after). Ornstein hypothesized that large doses of certain psychedelic drugs can overwhelm the linear construction [of time] and also allow an infinite present to exist. Thus, it would appear that meditation and some drug states can result in an altered flow of time when information from $P_0 - P_n$ is sent simultaneously (not sequentially as for Sherashevsky) to C processing.

Minor Modification of the IGUS Model

Some terminology and details of Hartle's IGUS theory need clarification. In that theory, the present of a human IGUS is said to be confined to the P_0 register (module) with a time interval of 0.1 sec., the approximate shortest interval that a human can distinguish between two visual stimuli. However, the short interval Hartle refers to is commonly associated with temporality. Temporality is the earlier/later (before/after) experience (Ruhnau, 1997), is unlike duration (Block, 1996; Gruber and Block, 2005; Gruber, Wagner and Block, 2004), and is not to be confused with Fraser's (1978) "temporalities" (levels of time perception from ultra short moments to the arrow of time). Poppel (1988) refers to temporality as sequentiality. If subjects are asked to indicate the sequence of two sensory stimuli they will not be able to indicate the temporal order correctly if the interval is less than approximately 30 msec.

Temporality is the smallest component of the IGUS and the P_0 register is most likely required for it to occur. Lastly, it should be emphasized that temporality is a subjective phenomenon of non-simultaneity and not to be confused with the non-simultaneity which is a physical, not subjective, time interval measurement commonly used in relativity theory (Gruber and Price, 1997; Taylor and Wheeler, 1992).

The present (in a normal brain) involves a physically longer interval of time than temporality. That moment requires sufficient physical time to experience a state of consciousness or "nowness" (Poppel, 1997). It is a 2–3 sec. interval when the closed mind opens up for new information from the environment — an interval when the brain can differentiate future from past. It has been referred to as the "subjective present" (Poppel, 1988), the "experienced present" (Ruhnau, 1997), and the "extended present" (Kinsbourne and Hicks, 1990). Thus, the first several registers, e.g., $P_0 - P_{25}$ are more likely to be the registers required for the present. Moreover, this same group of registers (not just P_0) would have to have direct input to C computation for the present to be an experiential phenomenon. Therefore, the Hartle model is modified as indicated in Figure 2.

Illusion in General

Before arguing whether or not the flow of time in the IGUS theory is an illusion it is best to actually define or at least categorize what is meant by an illusion. In general, an illusion is the perception by an observer that is discrepant with what physics and its apparatuses measure. Gregory (1991) defines it well

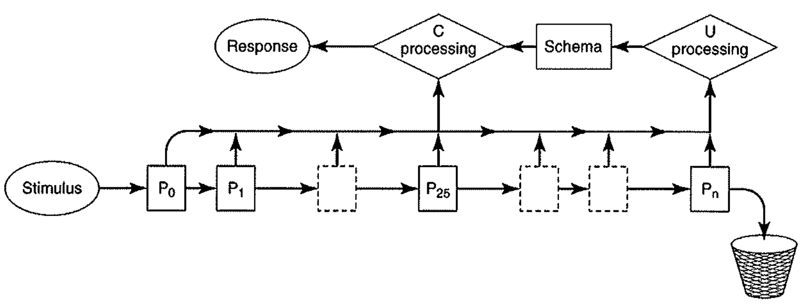

Figure 2: Modifications of the Hartle IGUS model: the first register, P_0 (Hartle's "present" register) is likely to be the register required for temporality (the before/after experience). The present is a physically longer interval of time, one that is required for the brain to experience a state of consciousness. It is a 2–3 sec. interval when the closed mind opens up for new information from the environment. Thus, the first several registers, e.g., $P_0 - P_{25}$ (which span a 2–3 sec. interval), are more likely to be the registers required for the "present."

by classifying illusions into three basic types: physical, physiological, and cognitive. A physical illusion is an altered perception due to the physics of the manner in which it is perceived and fully explained by the physics of the situation. For example, the apparent bend of a spoon in a glass of water due to diffraction is an example of a physical illusion.

A physiological illusion is due to the physiological status at the time of the illusion that causes the subject's experience to be different than what the physics of the situation suggests. One common experience is the oculogyric illusion. When a person turns around several times quickly and then stops suddenly, the room appears to move in the direction opposite to that of the spin. Davies (2002) has considered this particular illusion to be analogous to the illusion of the flow of time. The most common physiological illusion is the phi (technically beta) phenomenon (Steinman, Pizlo, and Pizlo, 2000). If two closely, spatially separated visual stimuli are separated by a duration of 30–200 msec. the first stimulus appears to move towards the second. This apparent movement is the basis of modern cinematography.

A cognitive illusion (not to be confused with non-optical cognitive illusions of thinking, judgment, and memory [Pohl, 2004]) is not totally contradicted by physics but is also not a completely accurate description of what is being observed. It is a perception that results from an altered or faulty cognition or interpretation of what the brain senses. For example, Rubin's vase looks like a woman at times; at other times it looks like a vase. Another example is the Muller–Lyer illusion which involves two lines of equal length with arrowheads at their ends. The line with the arrowheads pointing outward appears considerably shorter than the line with arrowheads pointing inward (Koch and Hayworth, 2003). To some extent all perception derived from sketchy information is potentially a cognitive illusion. Several examples come from studies in vision (Shepard, 2001). Under different lighting conditions color appears to remain constant as the information that falls on the retina depends on the light spectrum and reflectivity. So doing allows biologic organisms to see the same intrinsic color regardless of variations in illumination. Categorizing illusions, e.g., cognitive vs. physiological, is important to the verification of the various physical theories claiming to explain the flow of time. If a theory asserts that the flow of time is a physiological illusion when, in fact, the flow is a cognitive illusion, that theory is weakened.

Illusion in the IGUS Theory

The IGUS neurophysics theory is a description of the manner in which the human brain and other IGUSs process information in order to account for the flow. Information is transformed from one register (module) to another. The nature of the IGUS is dependent upon the quality and quantity of information transferred to the C module. As Park (1971) would suggest, it is simply not necessary and is perhaps incorrect to presuppose that time (or information) actually flows. Furthermore, the flow of time that an IGUS experiences is not necessarily descriptive of the physical world outside himself (itself). Therefore, whereas the transformation of information between modules is real, the flow of time itself is an illusion. Because different IGUSs give different interpretations of the physical environment and because an individual human IGUS can give different interpretations (different flow of time experiences) of the physical environment, the illusion is cognitive rather than physiological. Since the flow of time contains a temporality component (in the first register), the IGUS theory implies that temporality, too, is a cognitive illusion. However, it does not imply that time, motion or non-simultaneity are illusions.

Behavior vs. "Experience" of the Flow of Time

Robots will exhibit different flow of time behaviors, but to experience them they will require quite sophisticated minds, with self-concept, attentional mechanisms and the ability to form the idea of new complex concepts. Therefore testing them will be rather difficult; the flow of time IGUSs exhibit through virtual reality may get mixed with subjectively perceived flow of time. The experiential phenomenon (subjective perception) of the flow of time is in all likelihood similar to how the nervous system constructs consciousness. Poppel (1994) suggests that the brain organizes a response to stimuli requiring multimodal integration only at intervals that are multiples of 30 msec. (discrete processing epochs or snapshots according to Koch, 2004) and then integrates the perception of these events into a coherent conscious scene spanning at most 3 sec., but not more. The resultant temporal window of "now" (see Barbour, 1997) is the primary consciousness from which the brain reconstructs past and future (Poppel, 1994). Being concerned primarily with the various behavioral expressions of the flow of time, the IGUS theory does not address the experiential phenomenon per se. Thus, one has to ask if Hartle's robots can possess the experience of flow and if the savants and anterograde amnesic victims are really more like Koch's zombies.

Duch's (2005) study would suggest that there exists potential for experiential phenomena in robots: he argues that artificial systems based on brain-like computing principles must claim to experience qualia or states of experiential phenomenon — referred to as articons (from arti-ficial con-sciousness). Unlike the Turing machine which involves "dead" abstract binary entities without spatio-temporal structure, articons are not only data flow machines, but have specific architecture that due to the non-linear character of interactions among modules creates working memory states that cannot be decomposed into separate independent components. However, because artificial systems will never be identical with biological systems, providing only a rough functional approximation to brain-like organization, their qualia will be different than that of humans.

The Non-existent Time Theory

A compelling theory involving the flow of time comes from the more recent quantum theory by Barbour (1997, 2000) — not to be confused with other quantum consciousness theories (Hameroff and Wolf, 2003; Kuttner and Rosenblum, 2006; Penrose, 1989; Wolf, 1985; Zaman, 2002). Classically, the universe is thought of in terms of a spacetime block which includes three space dimensions and one time dimension. However, Barbour's theory provides a completely timeless description of the universe based on the notion of possible relative configurations of the universe. According to Barbour we never see space itself, nor do we see time. The universe in its history simply passes through a succession of such relative configurations. These relative configurations are identified with instants of time (or nows as he defines the term). According to Barbour, the brain observes these configurations in the form of stills within the brain: it converts a group of 6 or 7 such stills over a "fraction of a second" to motion.

Loosely speaking, the universe of Barbour's theory can be thought of as a block of overlapping quantum states. When a person makes an observation the brain acquires a small group of stills representing a short period of time from the corresponding spacetime block. Then, if one were to freeze the brain when watching a gymnast tumble, for example, there would be many represented positions of the gymnast. According to that theory the brain at any instant contains a collection of stills and "plays the movie for us." This is how it is possible to see motion when none is there. The net result is that the motion that is perceived is a physiological illusion. By stating that time and motion are illusions, his non-existent-time theory also implies that the flow of time, temporality and non-simultaneity are all physiological illusions.

Barbour's suggested mechanism of motion perception is different than that of Koch (2004) who argues that the perception of motion is "painted" onto each perceptual frame or "snapshot" — that motion is not experienced simply because of a change in position between two consecutive snapshots as in the movies. One of the most compelling pieces of evidence for the painting-on concept, even though not everyone agrees as to the mechanism of action (Kline, Holcombe, and Eagleman, 2004), is the astounding motion illusion, in which regularly spaced objects are on occasion seen to move opposite to the actual direction of motion (Andrews and Purves, 2005).

Since it has been argued that neural processing may involve transmission of data backwards and forwards in time (Libet, 2004), despite opinions to the contrary (Dennett, 1992), it is easy to see how one might hypothesize that motion is generated from stills by the brain. Moreover, some pathologic states suggest that the brain can create motion from stills. A few patients have been described who have cinematographic vision during a visual migraine (Sacks, 1992). They do not see movement as continuous but rather as a succession of stills, a succession of different configurations and positions more like the flickering of a film run too slowly. In the rare condition of akinetopsia (Rizzo, Nawrot, and Zihl, 1995), the patient suffers from a selective loss of motion perception. Such an individual might have difficulty pouring coffee into a cup because the fluid would appear frozen like a glacier. People in the street might suddenly appear here and then there but the patient may not actually see them moving from here to there. Finally, the fact that motion perception occurs in snapshots <100 msec. in duration (VanRullen, Reddy, and Koch, 2006) causes one to reconsider the origin of motion.

Need for Falsifiability

Some neuroscientists consider the quantum world to be irrelevant to their field. However, theories involving quantum mechanics should not be dismissed outright (Koch and Hepp, 2006). For the non-existent time theory (or any theory for that matter) to be believable it is essential to be falsifiable (Popper, 1959), i.e., it must be logically possible to make an observation or do a physical experiment that would show the assertion to be false. No empirical hypothesis, proposition or theory can be considered scientific if it does not admit the possibility of a contrary case. Unlike other important criteria regarding the validity of a theory such as parsimony and generalizability (Sternberg, 2006), falsifiability is indispensable (La Fave, 1971). Even Einstein admitted no amount of experimentation can ever prove one right; but a single experiment can prove one wrong (see Calaprice, 2005). The IGUS theory satisfies those criteria.

Barbour (2005) agrees to the need for falsifiability and admits that currently there are no physical tests for the theory.[1] However, there appears to be a falsifiable aspect of the theory in the realm of experimental psychology. Because the theory suggests that the human brain creates the physiological illusion of motion from stills it implies that the observation of stills under other circumstances should also result in an illusion of motion or at least temporality. However, a physiological illusion of motion or temporality from stills has never been described before. Finding such an example would lend a small degree of support to the non-existent time theory. Arguably, it would be the first time that a theory of quantum gravitation is being challenged (subjected to falsifiability) by a theory of psychology.

[1]Personal communication, March 12, 2005.

An Experiment Resembling Inverse Cinematography

The experiment to test that prediction was as follows (Gruber, Vincent, and Gruber, 2004). The principle of the apparatus resembles the inverse of cinematography whereby a film is stationary and the subject moves (see Figure 3). The subject sits in the center of a four-foot diameter stationary ring that is at eye level. The inside of the ring contains a film strip: 140 one-inch frames (stills), each frame containing one number: the first 20 frames each with the number one, followed by 20 frames each with the number two . . . followed finally by 20 frames each with the number seven.[2] The subject controls her own rotation rate on a motor-driven platform and can see one of the frames by looking through a two-inch LCD (liquid crystal display) unit that acts as a

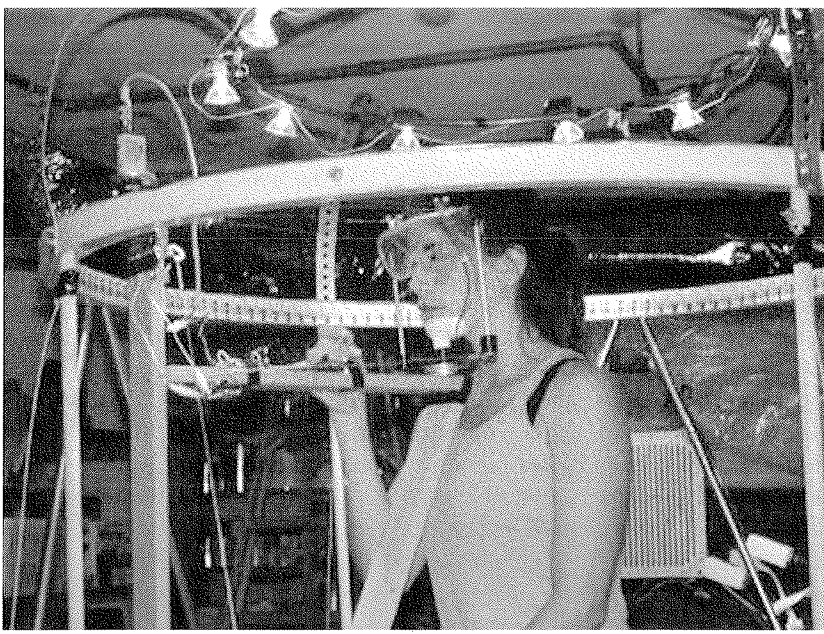

Figure 3: A film of numbers (the first 20 frames each with the number one, followed by 20 frames each with the number two, etc. . .) is located inside a large stationary ring and the subject (in the center) rotates. At low speeds the subject only experiences that the numbers are spatially separated. At high speeds the subject experiences that the numbers are spatially superimposed and that one number appears after another. The subject experiences a cognitive (not physiological) illusion of temporality, and not the phi phenomenon of cinematography.

[2]Numbers were used instead of pictures in order to avoid the phi phenomenon (the cinematographic illusion) and prevent it from complicating the experiment.

shutter, the shutter speed of which is under the control of the subject. As the subject passes by each frame (still), she makes a brief observation of a number.

At low platform rotation rates (and at low or high shutter speeds) the subject moves from one frame to the next. She experiences that the numbers on the ring are stationary and spatially separated. She experiences that she simply moves past them one by one. She does not experience temporality for the numbers i.e., she does not experience that one number appears "after" another. However, at relatively high rotation rates short of producing nausea (one revolution in 6–8 sec.) and fast shutter speeds (7 msec. to avoid a blur), she experiences that the numbers one through seven appear and then disappear in numerical order. The subject does not pay attention to the fact that she is moving by them one by one. She does not experience that the numbers on the ring are stationary and spatially separated. The numbers do not appear to exist simultaneously. She experiences only temporality for the numbers i.e., one number appears "after" another. The experiment was performed on seven subjects all of whom experienced the same phenomenon.

The phenomenon they experienced is an illusion of temporality; occurring at the high speed it appears to be an illusion of spatial superposition (not to be confused with quantum superposition). As the images of the numbers are seen through the shutter opening (LCD unit) they are spatially superpositioned upon one another (located within the shutter). Then, because the numbers are viewed chronologically the experiential result is temporality. The phenomenon is the result of observe/no-observe behavior. In principle, but not practicality, the subject could do this by opening and closing her eyes rapidly (an eyelid flicker rate of 8 per sec. is not uncommon) while viewing the frames on the ring. It is a cognitive illusion because depending upon the subject's chosen rate of observation she can experience temporality or not. Because it is a cognitive, and not a physiological illusion, one of the implications of the non-existent time theory is not supported. When the experiment was designed it was expected to support the non-existent time theory but much to the author's surprise it simply did not do so.

IGUS vs. Non-existent Time Theory

Both Hartle's and Barbour's theory suggest or imply that the brain constructs the flow of time from a series of images or stills. However, there is a difference in that the IGUS theory suggests that the brain receives a chronological series of discrete images (stills). The manner in which the information of the incoming stills is processed determines the type of flow that is exhibited. Details of motion perception are not provided by the theory. However, the principles of Koch (2004) are not precluded. In the non-existent time theory, processing does not begin until a group of static stills are impressed upon the brain. In contradistinction to Koch's view that motion is painted onto each frame (still), the Barbour theory suggests that motion results from "playing the movie." Moreover, no mechanism for obtaining qualitatively different flows of time is provided.

The Untestable "Flow" Theory

Park (1971) argues that time is not a thing as such. For Park, time describes the flow of events and nothing more. It is more like length, something by which to measure events, more like an adjective than a noun.[3] As long as events flow, time does not need to flow. Park takes the position that the flow of time (including the present) does not need to be explained by physics. He takes the position that the flow is not so much an illusion as a myth because it involves no deception of the senses. He asserts that one cannot perform any experiment to tell unambiguously whether or not time is passing — the explanation of the flow of time is that at every moment we are in contact with our surroundings. Park's arguments are compelling and his theory has never been seriously challenged. However, because it is not falsifiable, nothing further will be said here.

Conclusions

The IGUS theory is the most comprehensive theory of the flow of time. The flow is associated with the manner of information transfer between registers (neurological modules). The theory implies that the flow and also temporality are cognitive illusions. Different IGUSs are predicted to experience different types of flow. Human examples of IGUSs were found, thereby helping to confirm the theory. The actual model did require modification in keeping with the current principles of time perception. The only reservation is whether or not the robots experience the flow of time, or are merely exhibiting behavior of different types of flows of time. The quantum theory of Barbour is an ingenious but unorthodox theory of time in need of falsifiability. It states that motion is an illusion, and implies that the flow of time and temporality are physiological illusions. Like the IGUS theory it implies that the brain constructs the flow of time from images (stills). However, it does not account for the variety of flows of time that are possible. It also implies that the brain has the capacity under other circumstances to create such a physiological illusion. The experiment reported here demonstrates that temporality from observing stills can be a cognitive illusion but not a physiological illusion — lending no support to the non-existent time theory. The myth theory of time would seem to be logically correct in that time is something by which to meas-

[3]Personal communication, September 9, 2005.

ure events. However, its admission of non-falsifiability makes it impossible to validate. Only the modified IGUS neurophysics theory provides the most detailed and partially-tested theory for the flow of time.

References

Andrews, T., and Purves, D. (2005). The wagon-wheel illusion in continuous light. *Trends in Cognitive Science*, 9, 261–263.

Barba, G.D. (2001). Beyond the memory-trace paradox past the fallacy of homunculus: A hypothesis concerning the relationship between memory, consciousness and temporality. *Journal of Consciousness Studies*, 8, 51–78.

Barbour, J.B. (1997). Nows are all we need. In H. Atmanspacher and E. Ruhnau (Eds.), *Time, temporality, now* (pp. 201–216). Berlin: Springer Verlag.

Barbour, J.B. (2000). *The end of time*. Oxford: Oxford University Press.

Block, R.A. (1979). Time and consciousness. In G. Underwood and R. Stevens (Eds.), *Aspects of consciousness* (Volume 1, pp. 179–218). London: Academic Press.

Block, R.A. (1996). Psychological time and memory systems of the brain. In J.T. Fraser and M.P. Soulsby (Eds.), *Dimensions of time and life* (pp. 61–76). Madison: International Universities Press.

Borges, J.L. (1962). *Ficciones*. New York: Grove Press.

Brown, J.W. (1990). Psychology of time awareness. *Brain and Cognition*, *14*, 144–164.

Calaprice, A. (2005). *The new quotable Einstein*. Princeton: Princeton University Press.

Davies, P. (2002, September). That mysterious flow. *Scientific American*, *287*, 24–29.

Dennett, D.C. (1992). Time and the observer: The where and when of consciousness in the brain. *Behavioral and Brain Sciences*, *15*, 183–247.

Dennett, D.C. (1997). Consciousness in human and robot minds. In M. Ito, Y. Miyashita, and E.T. Rolls (Eds.), *Cognition, computation and consciousness* (pp. 17–29). New York: Oxford University Press.

Draaisma, D. (2004). *Why life speeds up as you get older*. Cambridge: Cambridge University Press.

Duch, W. (2005). Brain-inspired conscious computing architecture. *Journal of Mind and Behavior*, 26, 1–22.

Elitzur, A.C. (1996). Time and consciousness: The uneasy bearing of relativity theory on the mind–body problem. In S.R. Hameroff, W. Alfred, and A.C. Scott (Eds.), *Towards a science of consciousness: The first Tucson discussions and debates* (pp. 543–550). Cambridge: MIT Press.

Euler, M. (1997). Sensations of temporality models and metaphors from acoustic perception. In H. Atmanspacher and E. Ruhnau (Eds), *Time, temporality, now* (pp. 159–178). Berlin: Springer Verlag.

Fraser, J.T. (1978). *Time as conflict*. Basel: Birkhauser.

Gregory R.L. (1991). Putting illusions in their place. *Perception*, *20*, 1–4.

Gruber, R.P., and Block, R.A. (2005). Effects of caffeine on prospective duration judgments of various intervals depend on task difficulty. *Journal of Human Psychopharmacology: Clinical and Experimental*, *20*, 275–285.

Gruber, R.P., and Price, R.H. (1997). Zero time dilation in an accelerating rocket. *American Journal of Physics*, *65*, 979–980.

Gruber, R.P., Vincent, A., and Gruber, A.L. (2004). *Emergence of temporality from a non-temporal, static situation*. Presented at the International Society for the Study of Time. Cambridge University, Cambridge, England.

Gruber, R.P., Wagner, L.F., and Block, R.A. (2004). Relationships between subjective time and information processed (reduction of uncertainty). In P. Harris and M. Crawford (Eds.), *Time and uncertainty* (pp. 188–203). Leiden: Brill Academic Publishers.

Hameroff, S., and Woolf, N.J. (2003). Quantum consciousness: A cortical neural circuit. In N. Osaka (Ed.), *Neural basis of consciousness* (pp. 167–200). Amsterdam: Benjamins Publishing.

Hartle, J.B. (2005). The physics of now. *American Journal of Physics*, *73*, 101–109.

Kinsbourne, M., and Hicks, R.E. (1990). The extended present: Evidence from time estimation by amnesics and normals. In G.Vallar and T. Shallice (Eds.), *Neuropsychological impairments of short-term memory* (pp. 319–330). New York: Cambridge University Press.
Kline, K., Holcombe, A.O., and Eagleman, D.M. (2004). Illusory motion reversal is caused by rivalry, not by perceptual snapshots of the visual field. *Vision Research*, *44*, 2653–2658.
Koch, C. (2004). *The quest for consciousness* (pp. 205–216). Englewood: Roberts and Co.
Koch, C., and Hayworth, E.S. (2003). Examining the relationship between need for cognition and the Muller–Lyer illusion. *North American Journal of Psychology*, *5*, 249–255.
Koch, C., and Hepp, K. (2006). Quantum mechanics in the brain. *Nature*, *440*, 611–612.
Kuttner, F., and Rosenblum, B. (2006). The only objective evidence for consciousness. *Journal of Mind and Behavior*, *27*, 43–56.
La Fave, L. (1971). Psychological methodology: Should it differ from that of natural science? *Canadian Psychologist*, *12*, 513–525.
Libet, B. (2004). *Mind time: The temporal factor in consciousness*. Cambridge: Harvard University Press.
Luria, A.R. (2003). *The mind of a mnemonist*. Cambridge: Harvard University Press.
Ornstein, R.E. (1977). The psychology of consciousness. London: Jonathan Cape.
Park, D. (1971). The myth of the passage of time. *Studium Generale*, *24*, 19–30.
Penrose, R. (1989). *The emperor's new mind*. New York: Oxford University Press.
Pohl, R.F. (2004). *Cognitive illusions*. New York: Psychology Press.
Poppel, E. (1978). Time perception. In R. Held, H.W. Leibowitz, and H.L. Teuber (Eds.), *Handbook of sensory physiology* (pp. 713–729). Heidelberg: Springer Verlag.
Poppel, E. (1988). *Mindworks: Time and conscious experience*. Boston: Harcourt Brace Jovanovich.
Poppel, E. (1994). Temporal mechanisms in perception. *International Review of Neurobiology*, *37*, 185–202.
Poppel, E. (1997). The brain's way to create "nowness." In H. Atmanspacher and E. Ruhnau (Eds.), *Time, temporality, now* (pp. 107–120). Berlin: Springer Verlag.
Popper, K.R. (1959). *The logic of scientific discovery*. London: Hutchinson.
Rizzo, M., Nawrot, M., and Zihl, J. (1995). Motion and shape perception in cerebral akinetopsia. *Brain*, *118*, 1105–1127.
Ruhnau, E. (1997). The deconstruction of time and the emergence of temporality. In H. Atmanspacher and E. Ruhnau (Eds.), *Time, temporality, now* (pp. 53–70). Berlin: Springer Verlag.
Sacks, O.W. (1992). *Migraine*. Berkeley: University of California Press.
Scoville, W.B. (1968). Amnesia after bilateral medial temporal-lobe exicision: Introduction to case H.M. *Neuropsychologia*, *6*, 211–213.
Shepard, R.N. (2001). Perceptual–cognitive universals as reflections of the world. *Behavioral and Brain Sciences*, *24*, 581–601.
Smart, J.J.C. (1980). Time and becoming. In P. Van Inwagen (Ed.), *Time and cause* (pp. 3–15). Boston: Reidel Publishing.
Steinman, R.M., Pizlo, Z., and Pizlo, F.J. (2000). Phi is not beta, and why Wertheimer's discovery launched the Gestalt revolution. *Vision Research*, *40*, 25–32.
Sternberg, R.J. (2006). Reviewing theory articles. In R.J. Sternberg (Ed.), *Reviewing scientific works in psychology* (pp. 43–58). Washington, DC: American Psychological Association.
Taylor, E.F., and Wheeler, J.A. (1992). *Spacetime physics*. New York: W.H. Freeman and Co.
VanRullen, R., Reddy, L., and Koch, C. (2006). The continuous wagon wheel illusion is associated with changes in electrocencephalogram power at ~13 Hz. *Journal of Neuroscience*, *26*, 502–507.
Wolf, F.A. (1985). The quantum physics of consciousness: Towards a new psychology. *Integrative Psychiatry*, *3*, 236–242.
Zaman, L.F. (2002). Nature's psychogenic forces: Localized quantum consciousness. *Journal of Mind and Behavior*, *23*, 351–374.