Reconciling Temporal Experience with Physical Time: An Integration of Phenomenology, Neuropsychology, and Physics

Robert M. Anderson Jr., Ph.D. and Alexandra T. Davis, M.S.

Chaminade University of Honolulu

Abstract

Many philosophers and physicists have come to believe that the human experience of time and time as described by physics are incommensurable. Some claim that temporal experience is not veridical or does not even exist. Others claim that theories such as relativity or thermodynamics are faulty. In this paper, we demonstrate how human temporal experience and these theories can be seen as compatible. When relativity and thermodynamics are applied locally, the incompatibility becomes vanishingly small. We interpret the human experience of the neuropsychologically defined specious present within the special and general theories of relativity using causal bicones and the Newtonian limit. We then expand this interpretation to include the human experience of transience and the past-present-future arrow of time. Finally, we explain how the human experience of the thermodynamic arrow, self-organizing systems arrow, and epistemological arrow of time is consistent with the physics of these arrows.

(© 2022 - Robert M. Anderson Jr. and Alexandra T. Davis)

1. Introduction
2. Time is Not an Object: It Is an Abstraction or Generalization from Change
3. Why Do Some Physicists and Philosophers Spatialize Time?
4. Reconciling the Temporal Experience of the Present with Relativity Theory
   1. The Phenomenal Conscious Present (Now) and Sensory Memory
   2. Newtonian Physics and Time
   3. Einstein’s Relativity Theory and Time
   4. The Compatibility of the Experienced Now with Relativity Theory
   5. The Newtonian Limit
5. Reconciling the Temporal Experience of Transience with Relativity Theory
   1. Some Arguments Against the Phenomenology of Transience
   2. Transience and Causal Bicones
6. Reconciling the Temporal Experience of the Arrow of Time with the Physical Arrow of Time
   1. Past-Present-Future Arrow of Time
   2. Thermodynamic Arrow of Time
   3. Self-Organization Arrow of Time
   4. Epistemological Arrow of Time
7. Conclusion

References

1. Introduction

Phenomenal time, or our experience of time, appears to be incommensurable with physical time as it is described by our most empirically established and scientifically accepted theories of the universe. In one’s subjective experience of time, it often seems that the present moment is special and that it exists now while the past is no longer being experienced, except as a less vivid memory, and the future is yet to be experienced. We also experience change (the transient or dynamic aspect of time). Some have described this, metaphorically, as the flow or passage of time. We also often feel that experiences arise out of the future and disappear into the past (Arstilla et al., 2019), that time has a direction (time’s arrow).

The veracity and even the existence of these experiences have been claimed to be incompatible with physics (Gödel, 1949; Grünbaum, 1963). In this paper, we attempt to show how the experiences of now, transience, and direction can be reconciled with physics. We will do this primarily by demonstrating that when these theories are applied locally to humans living on the earth, the incompatibility becomes vanishingly small. We will not, however, be arguing that physics is incomplete or that human temporal experience is illusory, but will instead demonstrate that they are compatible. But first some caveats:

1. The physics theories we will focus on will be primarily the special and general theories of relativity, classical thermodynamics, and statistical mechanics. Our focus will generally not be on quantum mechanics due to space limitations and the fact that, even though quantum mechanics is well-validated, there is no consensus among physicists on its ontological interpretation (Schlosshauer et al., 2013).
2. We are not framing our paper in terms of the philosophers’ A-theory – B-theory debate in hopes of presenting readers with a fresh look at the issues. Also, more than 1/3 of philosophers in the recent 2020 PhilPapers poll didn’t “accept or lean towards” either the A-theory or the B-theory (Bourget & Chalmers, 2021). Again, due to space limitations, we will not be able to exhaustively address the many arguments and multitude of issues that have been developed regarding the nature of time. We will, however, attempt to state our proposal as clearly as possible with the hope of inspiring discussion.

2. Time is Not an Object:

It is an Abstraction or Generalization from Change

We begin with some conceptual clarifications regarding time. First, time is not an object like an automobile or a river. To conceive of time in this way is a category mistake; where a category mistake is defined, following Ryle (1949, p.16), as representing something as if it belongs to one category when it actually belongs to another (Chi & Slotta, 1993; O’Sullivan, 2016).[[1]](#footnote-1) Objects exist in time, but it does not make sense to say that time exists in time. Similarly, it does not make sense to say that time flows or passes. A river flows in time, but it doesn’t make sense to say that time flows in time because it is of a different logical order or categorial type than a river. A car can pass us in time while we stand on the sidewalk, but time cannot pass us in time. Speaking of time as flowing or passing is part of our linguistic-cultural heritage and a metaphorical way in which we communicate about time. However, it is conceptually confused.

The concept of time is an abstraction or generalization from change, especially repetitive, regular change. Transience or change is the essence of time and is so fundamental that it cannot be defined in terms of anything more basic. It is this feature of time that makes it impossible to fully spatialize time (Galton, 2011). Transience is a ubiquitous and irreducible aspect of human experience. It is such a salient feature of conscious experience that it is difficult to understand why some philosophers try to prove that transience doesn’t exist (Hoerl, 2014; Torrengo, 2014). However, in Buddhism, impermanence is the first of the three primary characteristics of existence, the First Dharma Seal (Nhat Hanh, 1999). In this paper, we maintain not only that transience is a feature of human experience, it is also a fundamental characteristic of our local, everyday world.

An abstract concept has no specific, individual referent but applies to many specific instances of the category (Reed, 2016). Levels of abstraction can be revealed in a taxonomic analysis. Lower levels are easily imageable while higher levels are not (Burgoon et al., 2013). Abstract concepts develop through the perception of similarities and through inductive generalization (Sloutsky, 2003). For time, on the lowest level of abstraction, episodes of transience are experienced. On the next level, regular repetition and periodicity are observed. Finally, on a higher level of abstraction, measurements are made with artificial devices which can produce more reliable, regular, repetitive behavior.

Time is a high-level, abstract concept. Our current concept of time developed over millennia. Early *homo sapiens* experienced transience. They also experienced repetitive, regular patterns of change in their environment – day and night, seasons, phases of the moon. In the Upper Paleolithic era these patterns began to be documented (De Smedt & De Cruz, 2011). These observations were critical for efficient foraging and agriculture. Around 1500 B.C., Egyptians invented the sundial for keeping time during the day and the water clock for the night (Orzel, 2022). Clocks provided a way to organize and synchronize human behavior. The invention of pendulum and mechanical clocks further refined the concept of time. More recently, quartz clocks and clocks based on the vibration of cesium atoms which keep time with an error rate of 1 second in 10 million years have improved timekeeping (Jespersen & Fritz-Randolph, 1999). The history of time measurement is a history of a competition between clockmakers to develop a clock producing the most resilient, precise, and regular repetitive behavior; this competition in turn refined the abstract notion of time.

1. Why Do Some Physicists and Philosophers Spatialize Time?

Humans may tend to spatialize time, in part, because the behavioral and neural processing of time and space overlap (Crollen et al., 2013; Skagerlund et al., 2016). Brain areas include the intraparietal cortex, insula, premotor cortex, supplementary motor area, and the inferior frontal gyrus. Additional studies have revealed that, although there was an overlap, space tended to activate more anterior regions and time more posterior regions (Cona et al., 2021). An asymmetry between space and time activations has also been noted with time activations of shared brain regions stronger for time than for space (Winter et al., 2015). This suggests time processing may depend more on space processing than space on time.

Spatial metaphors are often used when describing time (Boroditsky, 2000; Casasanto & Boroditsky, 2008). For example, imagine a coach saying to her players, “Ok, that loss is behind us. We need to prepare for the big game ahead of us.” Spatial metaphors for time are common across cultures and languages. However, the way spatial metaphors are implemented may vary widely (de la Fuente et al., 2014; Pitt et al., 2021).

Physicists may tend to spatialize time so readily because the spatialization of time is pervasive in their culture and a common currency in their language. Also, human brains are organized so there is an overlap between the processing of space and time. Physicists use space to represent space – static marks, numbers, and symbols, on paper or on a digital medium.

However, a representation of the world might not be complete if it represented space, spatially and represented time spatially without the defining feature of time – transience. Perhaps one might represent time via a dynamic simulation modeled in a computer. Humans and other mammals continually create dynamic space, time simulations to navigate and act in the world (Currie & Ravenscroft, 1997; Dragoi & Tonegawa, 2010; Johson & Redish, 2007). Dynamic simulations allow humans to pick up a cup and even understand and have empathy for other humans (Decety & Grèzes, 2006; Decety & Jackson, 2006; Herbort & Butz, 2015).

Physicists may also tend to ignore the fundamental transitory nature of reality because they are so intently focused on finding the ultimate building blocks of nature. Some physicists maintain that time does not exist because it does not appear as a variable describing reality in the most fundamental theories of physics such as loop quantum gravity and string theory (Barbour, 1999; Rovelli, 2006). Sean Carroll (2013) has responded to this suggestion by stating that temperature and pressure didn’t stop being real once physicists realized they were emergent properties of underlying microscopic particles. Therefore, why should they infer from time being derivative that it doesn’t exist. Human beings exist, but they are not fundamental. They are not an illusion. The fact that something is supervenient or not fundamental does not demonstrate that it doesn’t exist.

The tendency among some physicists and philosophers to undervalue transience is significant because it may be part of the reason why they believe that relativity is inconsistent with temporal experience and that, therefore, human temporal experience is illusory. To the contrary, it is our contention that denigrating the importance or even existence of transience is a fundamental scientific and philosophical error.

1. Reconciling the Temporal Experience of the Present with Relativity Theory

4.1 The Phenomenal Conscious Present (Now) and Sensory Memory

When one experiences the present, one does not experience an infinitesimal temporal point. One experiences a temporal expanse. “The practically cognized present is no knife-edge, but a saddle-back, with a certain breadth of its own on which we sit perched, and from which we look in two directions into time” (James, 1890, p. 611). This is the idea of the specious present. If we consider the phenomenal conscious present to be one’s sensory experience of the present, then the phenomenal conscious present can be identified with sensory memory. Sensory memory is rich in detail but persists for only a brief time. Visual sensory memory or iconic memory persists for approximately 250 ms (Rensink, 2014), auditory sensory or echoic memory for 3-4 seconds (Crowder, 1982), and tactile or haptic sensory memory for 2 seconds (Millar, 1974; Sinclair et al., 2000). A possible substrate for iconic memory has been identified. Once stimulated, neurons in primary visual cortex continue firing. However, their firing does not have a long enough duration to account for the persistence of iconic memory. Neurons in higher stages of visual shape processing in the inferior temporal cortex and anterior superior temporal sulcus fire with the necessary persistence and, therefore, must be included in the neural correlates of sensory memory (Keysers et al., 2005).

4.2 Newtonian Physics and Time

Newton’s classical physics provided an excellent description of the world of middle-sized objects at rest or moving at slow to moderate speeds (Disalle, 2006; Newton, 1687/1846). His laws were also applied successfully to the solar system. Due to the fact that his physics accurately described our everyday world, his ideas persisted relatively unchallenged for over a century (Rynaseiwicz, 2014) . Newton’s physics did not seem inconsistent with our experience of time. He postulated the existence of what has been referred to as absolute space and absolute time. This meant that spatial measurements would be invariant from any perspective or frame of reference, whether moving or still. It was assumed that there was an absolute frame of reference with respect to which something was moving or at rest. Similarly, it was assumed that there was an absolute time that was the same throughout space and for all frames of reference, whether moving or at rest.

Newton’s physics was consistent with our experience of time. The present could be special, and it could be that the only things that exist are in the present moment because the present moment is the same throughout the universe. A classical Now could be “a global hypersurface of simultaneous events” (Savitt, 2009, p. 352). Transience could be “the successive occurrence of global Nows” (Savitt, 2009, p.354). The past could fade into nonexistence, and the future could be yet to exist. The future could pass or flow into the present and then into the past. It was possible to envision different fully determined spatial states coming into existence in the universal now and in synch with the now of experience. Time could “flow” both phenomenally and physically, and time could have a direction from the past, to the present, and toward the future. This could be represented as a four-dimensional hyperspace with three dimensions of space and one of time (Freidman, 1977). Then, in the early twentieth century, there were two revolutions in physics – relativity theory and quantum theory.

4.3 Einstein’s Relativity Theory and Time

It was assumed in classical physics that light had a wave nature and, therefore, like the waves in the ocean, needed a medium (ether) within which to propagate. Since the earth’s speed around the sun is approximately 30 km/s, it was believed that the speed of light would be different when measured on one side of the sun from the speed when measured as the earth was on the opposite side of the sun going in the opposite direction. Michelson and Morley (1887) did these measurements and found no difference. Einstein (1905, 1996, 1916/2010) was able to make sense of the observations of the Michelson-Morley experiment by dropping the assumptions of absolute space and time and instead assuming that the speed of light was constant for all perspectives or frames of reference. But this reconceptualization had vast consequences for physicists’ understanding of space and time. A distance in space was not the same from all perspectives. Neither was a duration in time the same from all frames of reference. Events were not simultaneous or even in the same order for all frames of reference. Now, simultaneity, past, present, and future were all relative to frame of reference.

Since simultaneity was no longer common throughout the universe and universal, simultaneous change was no longer taking place, it became difficult to understand where the experience of now as uniquely existing as part of the “flow” of time fit into the physical universe. According to the special theory of relativity, only space-time intervals where invariant to frame of reference. The universe was conceptualized as a space-time world-block with no events in the world-block being real or existing more than any other events. Without absolute simultaneity, presentism, the idea that only simultaneous events in the present exist, was no longer tenable (Saunders, 2002).

4.4 The Compatibility of the Experienced Now with Relativity Theory

As previously noted, if relativity theory is true, there is no such thing as simultaneity throughout space in the universe, and the present cannot be the same throughout the universe. Nevertheless, it is still possible to reconcile one’s experience of the present with relativity theory. Steven Savitt (2000, 2006, 2009) and Richard Arthur (2006; 2010) developed an excellent explanation of how one’s subjective, conscious experience of the present moment or now can be reconciled with special relativity. In special relativity, there are no global Nows, however, there could be local Nows and transience could then be the successive occurrence of local Nows along a timelike worldline.

A timelike worldline through a point P is a line within P’s light cone (See Figure 1, pp. 44-45). For such a worldline, where P has the coordinates (x, y, z, t) the equation for the timelike vector *dx*, *dy*, *dz*, *dt* along the line would be:

*dτ* = (*c*2*dt*2-*dx*2-*dy*2-*dz*2)/*c* (Minkowski, 1908/1952, p.85)

The integral along the line from beginning point PO to end point P is the proper time of P. The Minkowski spacetime proper time is:

*τ* = (*c*2*dt*2-*dx*2-*dy*2-*dz*2)/*c* Where *τ* = proper time (Arthur, 2010, p. 160)

Proper time is invariant and independent of coordinates.

Proper time is represented in general relativity by:

*τ* = (-*g*αβ*d*xα*d*xβ)1/2 (Misner et al., 1973, p. 393)

Due, in part, to the strong equivalence principle, proper time is also invariant in general relativity.

Local Nows are based on the temporal persistence of consciousness, the specious present. Savitt (2009) developed the idea of an extended and briefly persistent (1 second) specious present based on a discussion he had with an unnamed psychologist. Arthur (2006) used the duration of 1/50th of a second based on movies projecting at 25 frames per second. In other words, he based his choice for temporal interval on the temporal discrimination limits of the visual system – flicker fusion frequency. Limits to visual perception of external stimuli, however, are not directly relevant to the conscious experience of now. This is because perception partly depends on receptor cells such as rods and cones in the retina which take time to reset after being stimulated and thereby contribute to how long it takes for the sensory system to reset and be prepared to respond to a new stimulus, not how long a stimulus persists in consciousness. Savitt’s estimate of the duration of the specious present is based on a suggestion of an anonymous colleague, not on specific psychological research results. A more accurate estimate should be based on specific empirical studies.

Given the durations of sensory memory reported above in Section 4.1 of this paper, the temporal duration for the specious present should probably be 250 milliseconds to 4 seconds. The local Now can then be derived from this estimate using John Winnie’s (1977) description of the Alexandroff interval. The Alexandroff interval for two events e1 and e2 in space-time (ALEX (e1, e2)) is “the set of all events chronologically between e1 and e2” (Winnie, 1977, p. 156). When e1 and e2 are chronologically connected, then the Alexandroff interval consists of those events in the interior of the intersection of their light cones. Savitt (2009, p. 357) proposed that “ALEX (e1, e2) is the present for the interval from e1 to e2 along” the timelike worldline in proper time. However, in mathematical physics, a line is a series of infinitesimal points and not representative of a human being. An experiencing person is a physical system, an embodied set of brain processes, which could perhaps be represented more accurately by a timelike *worldtube* in relativistic space-time (Butterfield, 2006; Dieks, 2006).

Thus, sense is made of a local present within the context of special relativity. The geometrical shape with two dimensions of space and one of time would correctly be called a “bicone” (See Figure 2, pp. 46-47). In three dimensions of space and one of time, it would be termed a “hyperbicone.”

This analysis can help explain the face validity of Newtonian space-time. In the Alexandroff interval (causal bicone), the local present of events is quite extensive. In the “specious present, light travels a spatial distance that bears a very large ratio to the spatial extent of our bodies or of ordinary objects” (Stein, 1991, p.161). Light travels in one second, in a vacuum, approximately 300,000 km. Therefore, in the specious present (250 millisecond to 4 seconds duration in proper time), light travels 75.000 to 1,200,000 km. The circumference of the earth is 40,070 km (National Aeronautics and Space Administration, n.d.). Therefore, this distance would contain the events that are locally present in a human causal bicone which would extend to contain the entire surface of the earth or biosphere, all the everyday activities of human beings.

Timelike worldtubes and invariant proper time also exist in general relativity (Arthur, 2008; Schutz, 2009). Therefore, the Alexandroff interval strategy to reconcile the experience of now and special relativity should be applicable to the general theory of relativity.

4.5 The Newtonian Limit

No objects move at the speed of light around us except electromagnetic radiation and tiny particles like cosmic rays. We don’t experience these particles directly. Due to the large magnitude of the speed of light, relativistic effects such length contraction and time dilation are generally not relevant to or noticeable in our daily lives. According to special relativity, calculation of the length contraction made for a vehicle 20 meters long going 100 kilometers per hour relative to an outside observer would yield: Length =20m X .999999999999 ~ 20m. The change in the length of the vehicle going 100 km/hr would be negligible.

For time dilation, consider the following:

Frame 1 (truck) is moving relative to Frame 2 (sidewalk) at a velocity v

Δt1 is the change in clock time in Frame 1 (truck) measured from Frame 1 (truck)

Δt2 is the change in clock time in Frame 1 (truck) measured from Frame 2 (sidewalk)

The equation for time dilation is (Bohm, 1965/2009; Resnick,1968):

Δt2 = (Δt1+vΔx/c2)/(1-v2/c2)1/2

Notice that if v is very small with respect to c, (1-v2/c2)1/2 approaches 1, vΔx/c2 approaches 0, and the t1-t2 difference becomes miniscule. If v equals a driving speed of 100 km/hr then (1-v2/c2)1/2 becomes approximately (1-10-14)1/2 ~ 1. There is no noticeable effect on time in either the truck frame or the sidewalk frame.

This is why special relativistic effects are negligible in our daily lives and also why Newton’s physics is a close fit to our common-sense picture of the world. Some philosophers have said that when a new theory of the universe is confirmed one should discard the old theory and completely replace it with new theory (Feyerabend, 1965; Kuhn, 1962). Given the success of Newtonian physics, however, the special theory of relativity must demonstrate that it approaches Newtonian physics at the Newtonian limit when v<<c.

The same reasoning holds for general relativity. Collier (2012) has demonstrated how Newton’s laws can be derived from the formalism of general relativity. The Newtonian limit is specified with three assumptions:

1. A particle of negligible mass is moving slowly relative to the speed of light.
2. There is a weak gravity field.
3. The field is static (Collier, 2012, p. 180).

Under these conditions, Newton’s First Law is derived as d2x/dt2 = 0 (Collier, 2012, p. 181). The Second Law is given as Fμ = DPμ/dτ (Collier, 2012, p. 181), where Fμ is force, Pμ is momentum, and D is the absolute derivative. The vector form of Newton’s law of universal gravitation is derived as **F** = (Gm1m2/I**r**I2)**ȓ** (Collier, 2012, p. 184). Thus, at the Newtonian limit, the general theory of relativity converges on Newtonian physics. Under similar assumptions, Rovelli (2021) also has derived Newton’s law of gravitation.

General relativity predicts time dilation – clocks run slower in stronger gravity. Rovelli (2021) describes a situation where one clock is on the surface of the earth, and another is taken to an altitude h. Then the up-clock is brought back to earth and compared with the down-clock. “Here, the proper time is T*up* = ((1 + 2*gh*)*dt*2)1/2 ∼ (1 + *gh*)*t* > T*down*“ (Rovelli, 2021, p. 79). In calculating the time difference when the upper clock is one meter higher than the lower clock for 100 days, Rovelli finds the lower clock to be one nanosecond (a billionth of a second) late relative to the upper clock. Hardly a difference that makes a difference for daily life.

Chou et al. (2010) measured the effect of gravitational time dilation at a difference of 33 centimeters. They found the time difference to be approximately 90 billionths of a second over a human life span, much too small for humans to perceive directly (National Institute of Standards and Technology, 2010). Again, not a noticeable difference.

Both general and special relativity converge on the Newtonian limit at the speeds and gravity we experience in our everyday world. It is our experience of this quasi-Newtonian world, completely compatible with special and general relativity, along with our internal experiences that results in our temporal experience and our everyday understanding of time. In addition, our first-person experience of the specious present is no illusion and can be interpreted as underpinning a local *now* within the framework of special and general relativity. We have, therefore, demonstrated that human experience of the present is veridical for all practical purposes and perfectly compatible with relativity.

1. Reconciling the Temporal Experience of Transience with Relativity Theory

5.1 Some Arguments Against the Phenomenology of Transience

Leaving the issue of the past, present, and future aside for now, transience or change is a salient feature of human temporal experience. Transience is often referred to metaphorically as the “flow or passage of time.” We will not use this, as noted previously, conceptually confused metaphor and will use “transience” or “change” instead. We will first examine a claim that the experience of transience is an illusion. For example, Robin Le Poidevin (2007) maintains that the fact that some experiences of motion are illusions due to the mind projecting motion on the world suggests that the perception of motion is not just a passive phenomenon, but involves constructive mental activity. He then states that, therefore, one should be wary of concluding from one’s perception of motion or change that transience exists in the world (i.e., time flows). Clearly, this argument is fallacious because it does not follow from some experiences of motion or change being illusory that all or even many are illusory. Although behavioral studies have demonstrated that our perceptual systems have imperfections, such as the attentional blink (Shapiro et al., 1997) and jittery eye movements (Bridgeman et al., 1994), the nervous system often has ways of compensating for these challenges (Martens & Wyble, 2010). Nevertheless, perception is never perfect.

L. A. Paul (2010) in her paper, “Temporal Experience,” cites several studies of illusory motion including the “color-phi” experiment in which nothing is moving but dots appear to change color as they move (Kolers & Grünau, 1976). In summary, she argues that because these studies demonstrate that illusory motion is possible, the statement that we experience change because our brains produce an illusion of change is just as reasonable as the statement that we experience change because our brain perceives change occurring in the world. Again, this appears to be an unwarranted generalization from some anomalous cases.[[2]](#footnote-2)

What motivates philosophers to advance weak or even invalid arguments such as these? Miller (2019) believes that many philosophers argue for transience being an illusion or a cognitive error because they are motivated by the belief that contemporary physics is incompatible with transience. In the following section, we demonstrate that relativity and our experience of transience are compatible and that there is no reason to argue for unsupported alternatives to transience in experience or in physics.

5.2 Transience and Causal Bicones

In previous sections, 4.4 and 4.5, we explained how our temporal experience of now could be reconciled with relativity theory by identifying the experienced now with an Alexandroff interval on a timelike worldtube in proper time. We demonstrated how the special and general theories converge toward a Newtonian description of our everyday world of v<<c and weak, stable gravity. These ideas can be used to reconcile the human experience of transience with relativity theory.

Transience is a fundamental feature of human temporal experience. According to Henri Bergson (1922/1965, p. 65), “time is succession.” Husserl (1965/1991), in his *On the Phenomenology of Consciousness of Internal Time*, states that when we experience the present, our experience includes an intentional act directed toward the present (*presentation*), a residue from the past (*retention*), and an anticipation of the future (*protention*). This allows for the perception of duration and succession (Gallagher, 2017).

Since there is no global Now or universal temporal hyperplanes in relativistic spacetime, it might seem impossible for relativity to be compatible with the temporal experience of transience. However, a reconciliation of relativity theory with the human experience of transience can be accomplished by demonstrating how there can be a local succession of Alexandroff intervals, causal bicones, or local Nows (Savitt, 2020). The succession of partially-ordered, local causal bicones in proper time along timelike worldtubes would be consistent with relativity theory. Proper time is critical to this model because, “… its intervals are path-dependent, frame-independent, and invariant under change of reference frame” (Arthur, 2008, p. 226). Of course, one would need to give up the possibility of universe-wide hyperplanes of simultaneity. Instead, one would have a multiplicity of partially-ordered, causal bicones on timelike worldltubes consistent with both our experience of transitivity and relativity theory. These bicones would overlap, not perfectly, but sufficiently so that there would be no noticeable asynchrony for earth-bound human beings. Thus, we have reconciled the human experience of transience with relativity theory.

1. Reconciling the Temporal Experience of the Arrow of Time with the Physical Arrow of Time

Just as the key to reconciling the special and general relativity theories with human temporal experience was to emphasize local application rather global application of the theories, the same will be the case for the arrow of time. By focusing on local consequences of theories, we will be able to achieve a reconciliation between the human experience of the direction of time and physical theories of time.

6.1 Past-Present-Future Arrow of Time

Human beings distinguish the past, present, and future. According to G. J. Whitrow (1972), “In man’s case, awareness of the distinction between past, present and future must have been the result of conscious reflection on the human situation” (p. 3). According to Whitrow, this ability is unique to human beings. At least in modern industrialized societies, where our lives are governed by the clock, we make a fairly well-defined distinction between the past, present, and future. For example, years ago, one of the authors assisted in making malasadas (a fried dough coated with sugar) at a high school carnival event. Now that event is in the past, but it has left traces. He has memories of the event, and he has a colorfully printed “MALASADA” t-shirt. He doesn’t know when the t-shirt will disintegrate in the future. This example illustrates one way in which we experience time having a direction – the past-present-future arrow of time.

The distinction between past, present, and future is fundamental to Husserl’s theory of time consciousness (Grush, 2006; Husserl, 1965/1991; Mensch, 2014). Psychologists study the human experience of the past, present and future. People who tend to brood think about the past more than the future, while the reverse is true for optimists (Beaty et al, 2019). When people mentally time travel to an imagined past event or future event, or actually remember a past event, the activated regions in their brains are different from when they imagine the event in the present (Nyberg et al., 2010). The Zimbardo Time Perception Inventory was developed to evaluate attitudes toward the past, present and future (Zimbardo & Boyd, 1999). This is only a tiny sampling of psychological studies on the human experience of tense. It should be clear that this experience is a fundamental aspect of human temporal experience.

We will now show how the human temporal experience of past, present, and future can be reconciled with physics. In the last section, we demonstrated how the experience of transience can be reconciled with relativity theory. The past, present, and future can be understood as a sequence or continuity of local *nows*, Alexandroff intervals or causal bicones along a timelike worldtube in proper time. If, following Hawking and Ellis (1973), we accept a reasonable chronology condition, causality condition, or strong causality condition, closed timelike curves can be ruled out (Arthur, 2008). Then the present would be the causal bicone corresponding to the current specious present on a person’s worldtube. The past would be the causal bicones on their worldtube prior to the current causal bicone and the future would be the causal bicones after the current causal bicone.

Even though there is no global hyperplane of simultaneity, a shared past, present and future could be conceptualized as follows: The biosphere of the earth would contain billions of human timelike worldtubes and corresponding sequences of causal bicones. The sequences of bicones would overlap but not completely. However, since the effects of special and general relativity (as we have demonstrated) are miniscule and irrelevant for daily life, any discrepancies between humans would be inconsequential. Humans, for all practical purposes, would share a common past, present, and future.

6.2 Thermodynamic Arrow of Time

We observe changes in our environment that appear to be irreversible. An egg cracked into a frying pan never reconstructs itself; a burnt piece of paper turns into smoke and ashes and never converts itself back into paper. These observations contribute to our feeling that time has a direction. Fortunately, thermodynamics and statistical mechanics have provided at least a partial explanation of these phenomena.

According to Lebowitz (1993b, p. 2), Boltzmann developed a statistical theory of time-asymmetric and irreversible, nonequilibrium behavior relating microstates to macrostates. He created an equation for entropy (SB) based, in part, upon the phase space volume of a macrostate and was able to relate SB to Clausius’ macroscopic entropy. Lebowitz (1993a) illustrates this by considering a cubic container divided into two equal parts by a wall separating two liquids. When the wall is removed, the phase space increases dramatically. Where N equals the number of particles, “for one mole of fluid in a 1-liter container the volume ratio of the unconstrained region to the constrained one is of the order of 2N or 10^10^20,” where “^” means “to the power” (Lebowitz, 1993a, p. 35). There will be a movement to newly available regions of phase space until equilibrium is achieved. At that point, there will be, “only small fluctuations from equilibrium unless we wait for times that are much larger than the age of the universe” (Lebowitz, 1993a, p. 35). The laws governing particles are reversible, but the wait time for a full reversal can be more than astronomical.[[3]](#footnote-3)

Although these probabilities and temporal periods are staggering, due to the temporal invariance of the laws governing particles of matter, they do not fully explain the thermodynamic arrow of time. Cosmological assumptions must be made (Price, 2004). The most common hypothesis proposed by physicists is that the universe was in an exceedingly low entropy state shortly after the big bang (Callender, 2021). This allowed the clumping together of matter to form stars and galaxies – our medium entropy universe in which processes move from lower to higher states of entropy (Carroll, 2010). However, this is but one of a plethora of hypotheses advanced by physicists, and the science does not appear to be settled at this time (Barbour et al., 2014; Carroll & Chen, 2005).

Regarding the goal of this paper, to reconcile our experience of time with the physics of time, it appears that most physicists accept the thermodynamic arrow of time that we experience, even though the explanation of the phenomenon is not yet complete.

6.3 Self-Organization Arrow of Time

All living organisms are self-organizing systems, take in energy from the environment, maintain or develop a more complex organization, and release entropy into the environment. In the 1700’s, Kant (1790/1914) described an organized and self-organizing being as one for which “its parts should so combine in the unity of a whole that they are reciprocally cause and effect of each other’s form. Only in this way can the Idea of the whole conversely (reciprocally) determine the form and combination of all the parts” (Section 65).

Although entropic processes may underlie one arrow of time, the increase in organization and complexity in the earth’s biosphere supports another arrow. Self-organizing systems may be defined as physical-biological, hierarchical systems in which higher-level structures develop from interactions between lower-level components of the system (Camazine, 2006). Self-organizing systems can change their internal structure and, thereby, change their function to adapt to external fluctuations (Banzhaf, 2009). They are open, dissipative systems. They operate far from thermodynamic equilibrium and exchange energy and matter with the environment. Since they are open systems, they can avoid violating the Second Law of Thermodynamics by “paying” for an increase in organization with an increase in entropy in the environment (Davies et al., 2013; Kondepudi et al., 2020).[[4]](#footnote-4)

Life forms not only self-organize, they evolve into more diverse and complex forms through random-variation and selective-retention and many other evolutionary processes (Gould, 2002). Through a variety of biochemical reactions (Smith, 2013), self-organization and evolution, a biosphere has formed on the surface of the earth (Kauffman, 2019), a biosphere of increasing diversity and complexity. Humans live in this biosphere, experience the increase in complexity, and know of it through written and paleontological-archeological records. Clearly, this is one source of the local, humanly experienced arrow of time.

6.4 Epistemological Arrow of Time

Another source of our experience of the direction of time is the anisotropy of knowledge – the epistemological arrow of time. A precondition for the existence of this arrow may be the low entropy initial conditions of the universe (Callender, 2021). Nevertheless, the experience is universal. One can determine what the exact closing price of a stock, say Netflix, was on a specific day a month ago simply by checking online or the Wall Street Journal. However, one cannot predict with anywhere near the same degree of specificity what the stock price will be on a day one month in the future (Malkiel, 1973). The best one could do would be to estimate the probability that Netflix’s price would lie in a certain range (Mandelbrot, 1999).

Although all alleged knowledge is fallible, we seem to have much more precise and detailed knowledge of the past than we do of the future. We have verifiable knowledge of the past but only guesses about what the future will hold. And these guesses are based primarily on our knowledge of the past through memories in our brains and external traces in the environment (Addis et al., 2007; Schacter et al., 2007; Talluri et al., 2021). Our autobiographical memories provide us with a concept of our self over time (Addis & Tippett, 2013; Martinelli et al., 2012). We can consult written history, archeological digs, and the geologic record to arrive at an understanding of the history of the earth (Ogg, 2004).

Our light cone integrated through human history captures an exceedingly thin slice of what has been happening, but it reveals the way things were over a long range of time in a large universe that offers a lot to see and to seek to interpret. (Peebles, 2020, p. 2)

We don’t know the future with any surety or specificity because it hasn’t happened yet on our collective worldtubes.

There are many other arrows of time. The mutability arrow: we feel the future is changeable or open while the past is fixed or closed; the past has happened, the future hasn’t happened. The emotion arrow: we feel differently about the future than we do about the past. The causal arrow: we experience causes to occur before their effects (Reichenbach, 1956). Due to space considerations, we will not be able to consider these arrows of time in this paper.

7. Conclusion

To sum up, we demonstrated how when physical theories are applied locally, the alleged incompatibilities between human temporal experience and these theories becomes vanishingly small. We identified the definitive feature of time to be transience. Time is a higher level, abstract concept which has evolved over millennia. We explained how humans in general and physicists in particular are prone to spatialize time. This may be part of the explanation of why physicists tend to exclude transience from their theories. We then used the concept of Alexandroff intervals or causal bicones and the interpretation of relativity theory at the Newtonian limit to demonstrate how the special and general theories of relativity are compatible with the human temporal experience of the present, transience, and the past-present-future arrow of time. We then explained how the human temporal experience of the thermodynamic arrow, the self-organizing systems arrow, and the epistemological arrow of time is consistent with physical descriptions of these arrows when physics is interpreted locally.

It is our hope that this reconciliation of temporal experience with the physics of time, the manifest image with the scientific image of time, will encourage philosophers and physicists to search for more ways to integrate physical theories with experience instead of rejecting the veridical nature of human experience or even its reality.

References

Addis, D. R., & Tippett, L. J. (2008). The contributions of autobiographical memory to the content and continuity of identity: A social cognitive neuroscience approach. In F. Sani (Ed.). *Self continuity: Individual and collective perspectives* (pp. 71-84). Psychology Press.

Addis, D. R., Wong, A. T., & Schacter, D. L. (2007). Remembering the past and imagining the future: Common and distinct neural substrates during event construction and elaboration. *Neuropsychologia*, *45*(7), 1363-1377. <https://doi.org/10.1016/j.neuropsychologia.2006.10.016>

Arthur, R. T. W. (2006). Minkowski spacetime and the dimensions of the present. In D. Dieks (Ed.),*The ontology of spacetime* (pp. 129-155). Elsevier. https://doi.org/10.1016/S1871-1774(06)01007-2

Arthur, R. T. W. (2008) Time lapse and the degeneracy of time: Gödel, proper time and becoming in relativity theory. In D. Dieks (Ed.). *The ontology of spacetime II* (pp.207-227). Elselvier. <https://doi.org/10.1016/S1871-1774(08)00011-9>

Arthur, R. T. W. (2010). Minkowski’s proper time and the status of the clock hypothesis. In V. Petkov (Ed.), *Space, time, and spacetime* (pp. 159-179). Springer. https://doi.org/10.1007/978-3-642-13538-5\_7

Arstilla, V., Bardon, A., Power, S. E., & Vatakis, A. (2019). *The Illusions of time: Philosophical and phenomenological essays on timing and perception*. Palgrave Macmillan.

Banzhaf, W. (2009). Self-organizing systems. In R. A. Meyers (Ed.), *Encyclopedia of complexity and systems science* (pp. 8040-8050). Springer. https://doi.org/10.1007/978-0-387-30440-3\_475

Barbour, J. (1999). *The end of time*. Oxford University Press.

Barbour, J., Koslowski, T., & Mercati, F. (2014). Identification of a gravitational arrow of time. *Physical Review Letters*, *113*, 181101. https://doi.org/10.1103/PhysRevLett.113.181101

Beatty, R. E., Seli, P., Schacter, D. L. (2019). Thinking about the past and future in daily life: An experience sampling study of individual differences in mental time travel. *Psychological Research*, *83*(4), 805-816. https://doi.org/10.1007/s00426-018-1075-7

Bergson, H. (1965). *Duration and simultaneity* (L. Jacobsen, Trans.). Bobbs-Merrill. (Original work published 1922)

Bohm, D. (2009). *The special theory of relativity*. Routledge. (Original work published 1965)

Boroditsky, L. (2000). Metaphoric structuring: Understanding time through spatial metaphors. *Cognition*, *75*, 1-28. https://doi.org/10.1016/S0010-0277(99)00073-6

Bourget, B., & Chalmers, D. (2021). *Philosophers on philosophy: The 2020 PhilPapers study*. Philarchive. https://philarchive.org/archive/BOUPOP-3

Bridgeman, B., Van der Heijden, A. H. C., & Velichkovsky, B. M. (1994). A theory of visual stability across saccadic eye movements. *Behavioral and Brain Sciences*, *17*(2), 247-258. https://doi.org/10.1017/S0140525X0003461

Burgoon, E. M., Herderson, M. D., & Markman, M. B. (2013). There are many ways to see the forest for the trees: A tour guide for abstraction. *Perspectives on Psychological Science*, *8*(5), 501-520. https://doi.org/10.1177/1745691613497964

Butterfield, J. (2006). Against *pointillisme* about mechanics. *British Journal for the Philosophy of Science*. *57*(4), 709-753. <https://doi.org/10.1093/bjps.axl026>

Callender, C. (2021). Thermodynamic asymmetry in time. In E. N. Zalta (Ed.). *The Stanford encyclopedia of philosophy* (Summer 2021 ed.). Stanford University. https://plato.stanford.edu/archives/sum2021/entries/time-thermo/

Camazine, S. (2006). Self-organizing systems. In L. Nadel (Ed.), *Encyclopedia of cognitive science* (pp 1-4). John Wiley & Sons. https://doi.org/10.1002/0470018860.s00644

Carroll, S. M., & Chen, J. (2005). Does inflation provide natural initial conditions for the universe? *International Journal of Modern Physics D*, *14*(12), 2335-2340. <https://doi.org/10.1142/S0218271805008054>

Carroll, S. M. (2010). *From eternity to here: The quest for the ultimate theory of time*. Dutton.

Carroll, S.M. (2013, October 18). Is time real? https://www.preposterousuniverse.com/blog/2013/10/18/is-time-real/

Casasanto, D., & Boroditsky, L. (2008). Time in the mind: Using space to think about time. *Cognition*, *106*, 579-593. https://doi.org/10.1016/j.cognition.2007.03.004

Chi, M. T. H., & Slotta, J. D. (1993). The ontological coherence of intuitive physics. *Cognition and Instruction*. *10*(2/3), 249-260.

Chou, C. W., Hume, D. B., Rosenband, T., & Wineland, D. J. (2010). Optical clocks and relativity. *Science*. *329*, 1630-1633. https://doi.org/10.1126/science.1192720

Collier, P. (2012). *A most incomprehensible thing: Notes toward a very gentle introduction to the mathematics of relativity*. Incomprehensible books.

Cona, G., Wiener, M., & Scarpazza, C. (2021). From ATOM to GradiATOM: Cortical gradients support time and space processing as revealed by a meta-analysis of neuroimaging studies. *NeuroImage*, *224*, Article 117407. https://doi.org/10.1016/j.neuroimage.2020.117407

Crowder, R. G. (1982). The demise of short-term memory. *Acta Psychologica*, *50*, 291-323. <https://doi.org/10.1016/0001-6918(82)90044-0>

Crollen, V., Grade, S., Pesenti, M., & Dormal, V. (2013). A common metric magnitude system for the perception numerosity, length, and duration. *Frontiers in Psychology*, *4*, Article 449. https://doi.org/fpsyg.2013.00449

Currie, G., & Ravenscroft, I. (1997). Mental simulation and motor imagery. *Philosophy of Science*. *64*(1), 161-180. https://doi.org/10.1086/392541

Davies, P.C.W., Rieper, E., & Tuszynski, J.A. (2013). Self-organization and entropy reduction in a living cell. *BioSystems*, *111*, 1-10. <https://doi.org/10.1016/j.biosystems.2012.10.005>

Decety, J., & Grèzes, J. (2006). The power of simulation: Imagining one’s own and other’s behavior*. Brain Research*, *1079*(1), 4-14. <https://doi.org/10.1016/j.brainres.2005.12.115>

Decety, J., & Jackson, P. L. (2006). A social-neuroscience perspective on empathy. *Current Directions in Psychological Science*, *15*(2), 54-58. [https://doi.org/10.1111/j.0963-7214.2006.00406.x](https://doi.org/10.1111%2Fj.0963-7214.2006.00406.x)

De la Fuente, J., Santiago, J., Ronán, A., Dumitrache, C., & Casasanto, D. (2014). When you think about it, your past is in front of you: How culture shapes spatial conceptions of time. *Psychological Science*, *25*(9), 1682-1690. https://doi.org/10.1177/0956797614534695

De Smedt, J., & De Cruz, H. (2011). The role of material culture in human time representation: Calendrical systems as extensions of mental time travel. *Adaptive Behavior*, *19*(1), 63-76. [https://doi.org/10.1177/1059712310396382](https://doi.org/10.1177%2F1059712310396382)

Deng, N. (2013). On explaining why time seems to pass. *Southern Journal of Philosophy*, *51*(3), 367-382. https://doi.org/10.1111/sjp.12033

Dieks,. D. (2006). Becoming, relativity, and locality. In D. Dieks (Ed.), *The ontology of spacetime* (pp. 157-176). Elsevier. <https://doi.org/10.1016/S1871-1774(06)01008-4>

Disalle, R. (2006). *Understanding space-time: The philosophical development of physics from Newton to Einstein*. Cambridge University Press.

Dragoi, G., & Tonegawa, S. (2011). Preplay of future place cell sequences by hippocampal cellular assemblies. *Nature*, *469***,**397–401. https://doi.org/10.1038/nature09633

Einstein, A. (1905). Zur elektrodynamik bewegter Körper. *Annalen der Physik*,*17*, 891–921.

Einstein, A. (1996). *Einstein’s 1912 manuscript on the special theory of relativity: A facsimile*. George Braziller.

Einstein, A., & Lawson, R. W. (2010). *Relativity: The special and general theory* (R. W. Lawson, Trans.). Dover. (Original work published 1916)

Feyerabend, P. K. (1965). Problems of Empiricism. In R. G. Colodny (Ed.). Beyond the edge of certainty: Essays in contemporary science and philosophy. (pp. 145-260). Prentice-Hall.

Friedman, M. (1977). Simultaneity in Newtonian mechanics and special relativity. In J. S. Earman, C. N. Glymour & J. J. Stachel (Eds.), Minnesota Studies in the Philosophy of Science: Vol. 8. Foundations of Space-Time Theories (pp. 403-432). Minneapolis, Minnesota: University of Minnesota Press.

Gallagher, S. (2017). The past, present and future of time-consciousness: From Husserl to Valera and beyond. *Constructivist Foundations*, *13*(1), 91-97.

Galton, A. (2011). Time flies space does not: Limits to the spatialization of time. *Journal of Pragmatics*, *43*, 695-703. https://doi.org/j.pragma.2010.07.002

Gödel, K. (1949). A remark about the relationship between relativity theory and idealistic philosophy. In P. A. Schilpp (Ed.). *Albert Einstein: Philosopher-scientist* (pp. 557-562). Library of Living Philosophers.

Gould, S. J. (2002). *The structure of evolutionary theory*. Harvard University Press. https://doi.org/10.2307/j.ctvjsf433

Grünbaum, A. (1963). *Philosophical problems of space and time*. Alfred A. Knopf.

Grush, R. (2006). How to, and how not to, bridge computational neuroscience and Husserlian phenomenology of time consciousness. *Synthese*, *153*(3), 417-450. https://doi.org/10.1007/s11229-006-9100-6

Haken, H. (2007). *Brain dynamics: Synchronization and activity patterns in pulse-coupled neural nets with delays and noise*. Springer.

Hawking, S. W. & Ellis, G. F. R. (1973). *Large scale structure of space-time*. Cambridge University Press.

Herbort, O., & Butz, M. V. (2015). Planning grasps for object manipulation: integrating internal preferences and external constraints. *Cognitive Processing*, *16***,**249–253. https://doi.org/10.1007/s10339-015-0703-z

Hoerl, C. (2014). Do we (seem to) perceive passage? *Philosophical Explorations*, *17*(2), 188-202. https://doi.org/10.1080/13869795.2013.852615

Husserl, E, (1991). *On the phenomenology of consciousness of internal time (1893-1917)* (J. Brough, Trans.). Kluwer Academic. (Original work published 1966)

James, W. (1890). *Principles of psychology*. Henry Holt.

Jespersen, J., & Fritz-Randolph, J. (1999). *From sundials to atomic clocks: Understanding time and frequency*. National Institute of Standards and Technology.

Johnson, R., & Redish, A. D. (2007). Natural ensembles in CA3 transiently encode paths forward of the animal at a decision point. *Journal of Neuroscience*, *27*, 12176-12189. https://doi.org/10.1523/JNEUROSCI.3761-07.2007

Kant, I. (1914). *Critique of judgement*. (J. H. Bernard, Trans.; 2nd ed., revised). Macmillan. (Original work published 1790)

Kauffman, S. A. (2019). *A world beyond physics: The emergence and evolution of life*. Oxford University Press.

Kelso, J. A. S. (1995). *Dynamic patterns: The self-organization of brain and behavior*. Massachusetts Institute of Technology.

Keysers, C., Xiao, D. K., Foldiak, P., & Perrett, D. I. (2005). Out of sight but not out of mind: The neurophysiology of iconic memory in the superior temporal sulcus. *Cognitive Neuropsychology*, *22*(3/4), 316-332. <https://doi.org/10.1080/02643290442000103>

Kolers, P., & von Grünau, M. (1976). Shape and color in apparent motion. *Vision Research*, *16*(4), 329-335. <https://doi.org/10.1016/0042-6989(76)90192-9>

Kondepudi, D. K., De Bari, B., & Dixon, J. A. (2020). Dissipative structures, organisms and evolution. *Entropy*, *22*, Article e22111305. https://doi.org/10.3390/e22111305

Kuhn, T. S. (1962). *The structure of scientific revolution*s. University of Chicago Press.

Lebowitz, J. L. (1993a). Boltmann’s entropy and time’s arrow. *Physics Today*, *46*(9), 32-38. <https://doi.org/10.1063/1.881363>

Lebowitz, J. L. (1993b). Microscopic laws, microscopic dynamics, time’s arrow and Boltzmann’s entropy. *Physica A*, *194*, 1-27. <https://doi.org/10.1016/0378-4371(93)90336-3>

Le Poidevin, R. (2007). *The images of time: An essay on temporal representation*. Oxford University Press.

Lowenstein, W. R. (2003). Two arrows from a mighty bow. In N. H. Gregersen (Ed.). *From complexity to life: On the emergence of life and meaning* (pp. 151-173). Oxford University Press.

Magidor, O. (2022). Category mistakes. In E. N. Zalta & U. Nodelman (Eds.). *The Stanford encyclopedia of philosophy* (Summer 2022 ed.). Stanford University. https://plato.stanford.edu/archives/fall2022/entries/category-mistakes/

Malkiel, B. G. (1973). *A random walk down Wall Street: The time-tested strategy for successful investing*. Norton.

Mandelbrot, B. B. (1999). A multifractal walk down Wall Street. *Scientific American*, *280*(2), 70-73. https://doi.org/[10.1038/scientificamerican0299-70](https://ui.adsabs.harvard.edu/link_gateway/1999SciAm.280b..70M/doi:10.1038/scientificamerican0299-70)

Martens, S., & Wyble, B. (2010). The attentional blink: Past, present, and future of a blind spot in perceptual awareness. *Neuroscience and Biobehavioral Reviews*, *34*(6), 947-957. https://doi.org/10.1016/j.neubiorev.2009.12.005

Martinelli, P., Sperduti, M., & Piolino, P. (2012). Neural substrates of the self-memory system: New insights from a meta-analysis. *Human Brain Mapping*, *34*(7), 1515-1529. <https://doi.org/10.1002/hbm.22008>

Mensch, J. (2014). A brief account of Husserl’s conception of our consciousness of time. In V. Arstilla & D. Lloyd (Eds.). *Subjective time: The philosophy, psychology, and neuroscience of temporality* (pp. 43-59). MIT Press.

Michelson, A. A., & Morely, E. W. (1887). On the relative motion of the earth and the luminous ether. *American Journal of Science*, *34*(203), 333-345.

Millar, S. (1974). Tactile short-term memory by blind and sighted children. *British Journal of Psychology*, *65*(2), 253-263. <https://doi.org/10.1111/j.2044-8295.1974.tb01399.x>

Miller, K. (2019). Does it really seem to us as though time passes? In V. Arstila, A. Bardon, S. E. Power, & A, Vitakis. (Eds.). *The illusions of time: Philosophical and psychological essays on timing and time perception* (pp.17-33). Palgrave Macmillan.

Minkowski, H. (1952). Space and time. In H. A. Lorentz, A. Einstein, H. Minkowski, & Weyl (Eds.). *The principle of relativity: A collection of original memoirs on the special and general theory of relativity* (W. Perrett & G. B. Jeffrey Trans.; pp. 73-91). Dover. (Original work published 1908).

Misner, C. W., Thorne, K. S., & Wheeler, J. A. (1973). *Gravitation*. W. H. Freeman and Company.

Nhat Hanh, T. (1999). *The heart of Buddha’s teaching: Transforming suffering into peace, joy, and liberation: The four noble truths, the noble eightfold path, and other basic Buddhist teachings*. Broadway Books.

National Aeronautics and Space Administration (n.d.). The cosmic distance scale: The earth. National Aeronautics and Space Administration. Retrieved June 4, 2022, from https://imagine.gsfc.nasa.gov/features/cosmic/earth-info.html

National Institute of Standards and Technology. (2010). NIST pair of aluminum atomic clocks reveal Einstein’s relativity at a personal scale. National Institute of Standards and Technology. Retrieved from https://www.nist.gov/news-events/news/2010/09/nist-pair-aluminum-atomic-clocks-reveal-einsteins-relativity-personal-scale

Newton, I, (1846). *Newton’s Principia: The mathematical principles of natural philosophy* (A. Motte, Trans.). New York, NY: Daniel Adee. (Original work published 1687)

Nyberg, L., Kim, A. S. N., Habib, R., Levine, B., & Tulving, E. (2010). Consciousness of subjective time in the brain. *PNAS*, *107*(51). 22356-22359. https://doi.org/10.1073/pnas.1016823108

Ogg, J. G. (2004). Status of divisions of the International Geologic Time Scale. *Lethaia*, *37*, 183-199. https://doi.org/10.1080/00241160410006492

Orzel, C. (2022). *A brief history of time keeping: The science of marking time from Stonehenge to atomic clocks*. BenBella Books.

O’Sullivan, L. (2016). The idea of a category mistake: From Ryle to Habermas and beyond. *History of European Ideas*. *42*(2), 178-194. https://doi.org/10.1080/01916599.2014.931052

Paul, L. A. (2010). Temporal experience. *Journal of Philosophy*, *107*(7), 333-359. https://doi.org/10.5840/jphil2010107727

Peebles, P. J. E. (2020). *Cosmology’s century: An inside history of our modern understanding of the universe*. Princeton University Press.

Pitt, B., Ferrigno, S., Cantion, J. F., Casasanto, D,, Gibson, E., & Plantadosi, S.T. (2021). Spatial concepts of number, size, and time in an indigenous culture. *Science Advances*, *7*, Article eabg4141. https://doi.org/10.1126/sciadv.abg4141

Price, H. (2004). On the origins of the arrow of time: Why there is still a puzzle about the low-entropy past. In C. Hitchcock (Ed.). *Contemporary debates in the philosophy of science* (pp. 219-239). Blackwell.

Reed, S. K. (2016). A taxonomic analysis of abstraction. *Perspectives on Psychological Science*, *11*(6), 817-837. https://doi.org/S10.1177/17456916166463

Reichenbach, H. (1956). *The direction of time* (M. Reichenbach, Ed.). Dover.

Rensink, R. A. (2014). Limits to the usability of iconic memory. *Frontiers in Psychology*, *5*(971), 1-9. <https://doi.org/10.3389/fpsyg.2014.00971>

Resnick, R. (1968). *Introduction to special relativity*. John Wiley and Sons.

Rovelli, C. (2006). The disappearance of space and time. In D. Dieks (Ed.). *The ontology of spacetime* (pp. 25-36). Elsevier. https://doi.org/10.1016/S1871-1771(06)01002-3

Rovelli, C. (2021) *General relativity: The essentials*. Cambridge University Press.

Ryle, G. (1949). *The concept of mind*. Hutchinson’s University Library.

Rynaseiwicz, R. (2014). Newton’s views on space, time, and motion. In E. N. Zalta (Ed.), *The Stanford encyclopedia of philosophy* (Summer 2014 ed.). https://plato.stanford.edu/archives/sum2014/entries/newton-stm/

Saunders, S. (2002). How relativity contradicts presentism. *Royal Institutes Philosophy Supplements*, *50*, 277-292. doi:10.1017/S1358246100010602

Savitt, S. F. (2000). There’s no time like the present (in Minkowski spacetime). *Philosophy of Science, Supplement. Proceedings of the 1998 Biennial Meetings of the Philosophy of Science Association. Part II: Symposium Papers*, *67*, S563-S574. https://doi.org/10.1086/392846

Savitt, S. F. (2006). Presentism and eternalism in perspective. In D. Dieks (Ed.), *The ontology of spacetime* (pp. 111-127). Elsevier. <https://doi.org/10.1016/S1871-1774(06)01006-0>

Savitt, S. F. (2009). The transient *nows*. In W. C. Myrvold & J. Christian (Eds.), *Quantum reality, relativistic causality, and closing the epistemic circle* (pp. 349-362). Springer. https://doi.org/10.1007/978-1-4020-9107-0\_18

Savitt, S. (2015). I [heart] [diamond] s. *Studies in the History and Philosophy of Modern Physics*, *50*, 19-24. https://doi.org/10.1016/j.shpsb.2015.02.001

Savitt, S. F. (2020). In search of passing time. In R. J. Slagter & Z. Keresztes (Eds.). *Spacetime 1909 – 2019: Selected peer-reviewed papers at the Second Hermann MInkowski on the foundations of spacetime physics* (pp. 87- 100). Montreal Institute Press.

Schacter, D. L., Addis, D. R., & Buckner, R. L. (2007). Remembering the past to imagine the future: The prospective brain. *Nature Reviews Neuroscience*, *8*, 657-661. https://doi.org/10.1038/nrn2213

Schlosshauer. M., Kofler, J., & Zeilinger, A. (2013). A snapshot of foundational attitudes toward quantum mechanics. *Studies in the History and Philosophy of Science Part B: Studies in the History and Philosophy of Modern Physics*, *44*(3), 222-230. https://doi.org/10.1016/shpsb.2013.04.004

Schutz, B. F. (2009). *A first course in general relativity* (2nd ed.). Cambridge University Press.

Shapiro, K. L., Arnell, K. M., & Raymond, J. E. (1997). The attentional blink. *Trends in Cognitive Sciences*, *1*(8), 291-296. https://doi.org/10.1016/S1364-6613(97)01094-2

Sinclair, R. J., Kuo, J. J., & Burton, H. (2000). Effects on discrimination performance of selective attention to tactile features. *Somatosensory and Motor Research*, *17*(2), 145-157. <https://doi.org/10.1080/08990220050020562>

Skagerlund, K., Karisson, T., & Trӓff, U. (2016). Magnitude processing in the brain: An fMRI study of time, space, and numerosity as a shared cortical system. *Frontiers in Human Neuroscience*, *10*, Article 500. https://doi.org/10.3389/fnhum.2016.00500

Slousky, V. M. (2003). The role of similarity in the development of categorization. *Trends in Cognitive Sciences*, *7*(6), 246-251. <https://doi.org/10.1016/S1364-6613(03)00109-8>

Smith, E. (2013). Emergent order in processes: The interplay of complexity, robustness, correlation, and hierarchy in the biosphere. In C. H. Lineweaver, P. C. W. Davies, & M. Ruse (Eds.). *Complexity and the arrow of time* (pp. 190-223.). Cambridge University Press.

Stein, H. (1991). On relativity theory and openness of the future. *Philosophy of Science*, *58*(2), 147-167. <https://doi.org/10.1086/289609>

Talluri, B. C., Braun, A., & Donner, T. H. (2021). Decision making: How the past guides the future in the frontal cortex. *Current Biology*, *31*, R282-R309. https://doi.org/10.1016/j.cub.2021.01.020

Torrengo, G. (2017). Feeling the passing of time. *Journal of Philosophy*, *114*(4), 165-188. https://doi.org/10.5840/phil2017114415

Whitrow, J. G. (1972). *What is time?* Oxford University Press.

Winnie, J. A. (1977). The causal theory of space-time. In J. S. Earman, C. N. Glymour, & J. J. Stachel (Eds.). Minnesota Studies in the Philosophy of Science: Vol. 8. Foundations of Space-Time Theories. (pp. 134-205) University of Minnesota Press.

Winter, B., Marghetis, T., & Matlock, T. (2015). Of magnitudes and metaphors: Explaining cognitive interactions between space, time, and number. *Cortex*, *64*, 209-224. https://doi.org/10.1016/j.cortex.2014.10.015

Zimbardo, P. G., & Boyd, J. N. (1999). Putting time in perspective: A valid, reliable individual differences metric. *Journal of Personality and Social Psychology*, *77*(6), 1271-1288. https://doi.org/10.1037/0022-3514.77.6.1271

Figure 1. Past and future light cones of point P with vertical timelike worldline.

Shape

Description automatically generated with low confidence

Figure 2. A human specious-present, timelike worldtube (exaggerated in size) with future light cone of A and past light cone of B.



1. Although the concept of a category mistake decreased in philosophical interest beginning in the eighties, it continues to be a useful analytical tool (Magidor, 2022). [↑](#footnote-ref-1)
2. Deng (2013), in her paper, “On Explaining Why Time Seems to Pass,” has provided a more detailed critique of these arguments. [↑](#footnote-ref-2)
3. Loewenstein (2003) calculates the time for a reversal of a drop of saltwater 101,000,000,000,000 years while the time since the big bang is only 1010 years. [↑](#footnote-ref-3)
4. Self-organization is an essential feature of brains, especially human brains (Haken, 2007; Kelso, 1995). [↑](#footnote-ref-4)