

# Time in the Special Theory of Relativity

Steven Savitt

Department of Philosophy

The University of British Columbia

Prior to the revolutions in physics in the early decades of the twentieth century, reflective individuals would likely have agreed with the following remarks about time by Roberto Torretti (1983: 220):

In the Aristotelian philosophy that still shapes much of our common sense, the present time, called “the now” (*to nun*), separates and connects what has been (*to parelthon*) and what is yet to be (*to mellon*). Though the now, as the link of time (*sunekhei khronou*), the bridge and boundary between past and future, is always the same formally, materially it is ever different (*heteron kai heteron*), for the states and occurrences on either side of it are continually changing. Indeed, the so-called flow or flight of time is nothing but the ceaseless transit of events across the now, from the future to the past. If an event takes some time, then, while it happens, the now so to speak cuts through it, dividing that part of it which is already gone from that which is still to come. Two events which are thus cleaved by (materially) the same now are said to be *simultaneous*. Simultaneity, defined in this way, is evidently reflexive and symmetric, but it is not transitive. For a somewhat lengthy event—e.g. the French Revolution—can be simultaneous with two shorter ones—such as Faraday’s birth in 1791 and Lavoisier’s death in 1794—although the latter are not simultaneous with each other. However, if we conceive simultaneity as a relation between (idealized) *durationless* events, we automatically ensure that it is transitive and hence an equivalence. Thus conceived, simultaneity partitions the universe of such events

into equivalence classes, and time's flow can be readily thought of as the march of those classes in well-aligned squadrons past the now. The succession of events on a given object—a clock—linearly orders the classes to which those events belong. The linearly ordered quotient of the universe of events by simultaneity is what we mean by physical time.

A philosopher might have added that the colorful language of classes “marching” past the now could have been replaced without loss by bland talk of (equivalence classes of) events happening successively.<sup>1</sup> The logician Kurt Gödel captured this idea in the pithy but not wholly unambiguous sentence: “The existence of an objective lapse of time, however, means (or, at least, is equivalent to that fact) that reality consists of an infinity of layers of ‘now’ which come into existence successively.” (1949: 558)

It is not clear whether Gödel believed that these layers of ‘now’ come into existence and then remain in existence, being the foundation for a commonsense distinction between the past and future, or whether he thought that they come into existence then immediately cease to exist, as one might expect of events that are very brief or even durationless. This chapter will try to sidestep questions like this concerning ‘reality’ and ‘existence’ whenever possible, focusing instead on issues concerning the nature of simultaneity and the passage of time raised directly by the special theory of

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<sup>1</sup> A prescient philosopher might also have added a *metaphysically neutral* indexical account of ‘now’ (Markosian 2001: 622). According to such an account, ‘now’ picks out one’s temporal location without committing one to a particular account of the nature of that location, just as ‘here’ picks out one’s spatial location without committing one to a particular geometry or to a position in (say) the relationalist/substantialist debate.

I am not, by the way, suggesting that Torretti is unaware or opposed to such refinements. In the quoted paragraph he is simply summarizing the classical view without endorsing it.

relativity.<sup>2</sup> We will begin with a brief presentation of the theory itself, before examining the philosophical issues it raises.

## I

In his landmark 1905 paper Albert Einstein presented the special theory of relativity as the consequence of two postulates.<sup>3</sup> The first we shall call *the relativity principle*: “The laws by which the states of physical systems undergo change are not affected, whether these changes of state be referred to the one or the other of two systems of co-ordinates in uniform translatory motion.” (1905: 41)

Each system of co-ordinates is four-dimensional, consisting of three spatial dimensions and one temporal dimension. We may label the co-ordinates in one system  $(x,y,z,t)$  and those in another system  $(x',y',z',t')$ . Einstein specifies that these systems are to be such that in them “the equations of Newtonian mechanics hold good,” (1905: 38) at least to first approximation. We shall call such co-ordinate systems *frames of reference* or *inertial frames*.<sup>4</sup>

When there are two such reference frames under consideration, it is often helpful (though it is not necessary) to arrange them so that the origins of the two systems, O and O' (that is, the points that have co-ordinate values  $(0,0,0,0)$  in each system), coincide,

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<sup>2</sup> A reader who wishes to engage these questions is directed to Putnam (1967), Stein (1968, 1991), Clifton and Hogarth (1995), Callender (2000), Saunders (2000), Dorato (2006), Savitt (2006), and references therein.

<sup>3</sup> Most popular introductions to the special theory develop the theory in this manner. Two of the most readable books of this kind are Mermin (1968, 2005).

<sup>4</sup> See Norton (1993, §6.3) for a discussion of the difference between coordinate systems and frames of reference and DiSalle (2002, 2008) for further information regarding inertial frames.

that the corresponding pairs of axes  $y$  and  $y'$ ,  $z$  and  $z'$  are parallel, that the  $x$  and  $x'$  axes coincide, and that the second system is moving in the positive  $x$ -direction in respect to the first with some constant velocity  $v$ .<sup>5</sup> We can therefore consider the first system to be “stationary”, though we could with equal justice (given the relativity principle) regard the second as “stationary” and the first as moving in the negative  $x'$ -direction with velocity  $-v$ . Designating one or other of the two systems as “stationary” is a matter of expository convenience. We can now state Einstein’s second postulate, *the light principle*: “Any ray of light moves in the “stationary” system of co-ordinates with the determined velocity  $c$ , whether the ray be emitted by a stationary or by a moving body.” (1905: 41)

From these principles Einstein derived *the Lorentz transformations*,<sup>6</sup> mathematical rules expressing the relations of the co-ordinates in two such systems. If the “stationary” system has un-primed coordinates, the “moving” system primed co-ordinates, and the relative velocity is  $v$ , then

$$x' = \frac{x - vt}{\sqrt{1 - v^2/c^2}},$$

$$y' = y,$$

$$z' = z,$$

$$t' = \frac{t - vx/c^2}{\sqrt{1 - v^2/c^2}}.$$

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<sup>5</sup> Two co-ordinate systems so aligned are said to be *in standard configuration*.

<sup>6</sup> Purists will note that the transformations indicated below are only a subset of the full group of Lorentz transformations, even allowing for the convenience of aligning the two co-ordinate systems in standard configuration. The “Lorentz transformations” exhibited in the text reverse neither spatial nor temporal axes; they are *proper* and *orthochronous*. For a discussion from a modern perspective of what is necessary for the derivation of the Lorentz transformations see Friedman (1983; chapter 4, §2).

For convenience, the factor  $1/\sqrt{1-v^2/c^2}$  is frequently abbreviated by ‘ $\gamma$ ’. Note that when  $0 < \|v\| < c$ ,  $\gamma > 1$ .

Now consider two inertial frames in standard configuration, the system with unprimed co-ordinates being chosen to be “at rest” and the system with primed co-ordinates moving with some non-zero speed  $v$  relative to it along the  $x$ -axis. We can choose a pair of distinct points or events in spacetime, say the origin (the co-ordinates of which in the “stationary” co-ordinate system are of course  $(0,0,0,0)$ ) and an arbitrary point on the  $x$ -axis at time  $t = 0$  (the co-ordinates of which would then be  $(x,0,0,0)$  in that same system). Since these two events have the same fourth, or time, co-ordinate, we can say that they are *simultaneous*—at least relative to the unprimed co-ordinate system.<sup>7</sup>

The co-ordinates of these two points or events in the “moving” system may be found by applying the Lorentz transformations to their unprimed co-ordinates. We see that the co-ordinates of the origin remain  $(0,0,0,0)$  in the moving system, which should not be surprising given that the two co-ordinate systems were stipulated to be in standard configuration. The co-ordinates of  $(x,0,0,0)$  in the moving system, however, must be  $\left(\gamma x, 0, 0, \gamma\left(-\frac{vx}{c^2}\right)\right)$ , given the Lorentz transformations above. Since neither  $v$  nor  $x$  nor  $\gamma$  is equal to 0, the fourth primed co-ordinate  $t'$  is not equal to 0. That is, relative to the moving co-ordinate system the two points or events that were chosen to be simultaneous in the “stationary” co-ordinate system are *not* simultaneous, if sameness of fourth co-ordinate in a given co-ordinate system remains our indicator of simultaneity. This result

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<sup>7</sup> In the debate concerning the conventionality of simultaneity, which we will discuss in section II, this notion of simultaneity—identity of time coordinate in an inertial frame—is in older literature sometimes called *metrical simultaneity*. By way of contrast, two events are said to be *topologically simultaneous* iff they are spacelike separated. This latter concept will be explained below. By ‘simultaneity’ *tout court* I will mean metrical simultaneity, unless otherwise specified.

is quite general and is a startling but uncontroversial feature of the special theory of relativity known as *the relativity of simultaneity*.

Three years after Einstein introduced the special theory, Hermann Minkowski (1908) re-presented the theory in a different manner, developing it as a kind of four-dimensional geometry.<sup>8</sup> Choose again the coincident origins O and O' for two inertial frames in standard configuration. Imagine a burst of light at O (or O'). In time  $t$ , a particular light-ray will travel spatial distance  $ct$  to reach a point P that we will call  $(x,y,z,t)$ .<sup>9</sup> By the Pythagorean theorem the spatial distance of that point from the origin can be written as  $\sqrt{x^2 + y^2 + z^2}$ . We then have

$$\begin{aligned}x^2 + y^2 + z^2 &= (ct)^2, \quad \text{or} \\x^2 + y^2 + z^2 - (ct)^2 &= 0.\end{aligned}$$

But if we consider the point P in terms of the primed co-ordinates,  $(x',y',z',t')$ , the same reasoning (including the light principle) will convince us that

$$(x')^2 + (y')^2 + (z')^2 - (ct')^2 = 0$$

and therefore that

$$(x')^2 + (y')^2 + (z')^2 - (ct')^2 = x^2 + y^2 + z^2 - (ct)^2. \quad (1)$$

This last equation shows us that, while many quantities, like simultaneity, turn out rather surprisingly to be frame-dependent or relative to a chosen inertial frame, there is at least one quantity that is independent of or invariant between frames. This quantity is usually called the *spacetime interval*. In the example given, the spacetime interval is an invariant quantity determined by two points, the origin and the point P. But any point in

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<sup>8</sup> Most books on the general theory of relativity introduce the special theory geometrically. The classic introductory special relativity text in this vein is Taylor and Wheeler (1963).

<sup>9</sup> Here and throughout we ignore any complications that might arise from quantum theory.

the spacetime may be chosen as origin of a co-ordinate system, so the spacetime interval is an invariant quantity characterizing a relation between any two points in spacetime. But what relation is it?

The set of points or events that a light-ray from O can reach form an expanding spherical shell about O. If we suppress one spatial dimension, say  $z$ , then the points that a light-ray from O can reach form a cone, which Minkowski called *the back cone* but which is now usually called *the future light cone*. All these points by the reasoning above have spacetime interval 0 from the origin and have  $t$  co-ordinate greater than 0. Events with  $t$  co-ordinate less than 0 but spacetime interval 0 from the origin are events such that a light-ray from that event can just reach the origin. These points form what Minkowski called *the front light cone* but which is now usually called *the past light cone*. Since the spacetime interval is invariant, exactly the same set of events constitutes the light cone structure in the primed co-ordinate system.<sup>10</sup> The light cones are invariant structures in the special theory and events on the light cones of O are said to be *lightlike* or *null separated* from O.

One can easily see that, given the finite specified speed of light  $c$ , there must be events that are so far from O yet occur so soon after O (in the “stationary” co-ordinate system, say) that no light-rays from O can reach them. For such events  $\sqrt{x^2 + y^2 + z^2}$  must be greater than  $ct$ , and this relation must hold for the spatial and temporal co-ordinates in any inertial frame. In this case the invariant spacetime interval is greater than 0, and such events are said to be *spacelike separated* from O.

Conversely, there are evidently events such that  $\sqrt{x^2 + y^2 + z^2}$  is less than  $ct$ . These are events are sufficiently near to O that some object traveling at a speed less than light speed  $c$  can reach them from O. For such events the spacetime interval from O is less than 0, and they are said to be *timelike separated* from O.

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<sup>10</sup> If this all sounds a bit pedestrian, bear in mind that the light and relativity principles imply that the single expanding spherical shell from the burst of light at O must stay centered on both O and O' as they move apart.

Consider now an event (or, as Minkowski calls it, a *world-point*) that is spacelike separated from O. Minkowski notes that (1908: 84)

Any world-point between the front and back cones of O can be arranged by means of a system of reference [a co-ordinate system] so as to be simultaneous with O, but also just as well so as to be earlier than O or later than O.

We have, then, another way of expressing the relativity of simultaneity (for spacelike separated world-points or events). By choosing an appropriate value for  $v$ , the constant relative velocity of a “moving” frame with respect to the “stationary” frame, a frame can be specified in which any given point P' that is spacelike separated from O' (that is, O, when the two frames are in standard configuration) will be simultaneous with the origin O' in that frame.

Pre-relativistically, whether in (classical, Newtonian) physics or in our ordinary, commonsense way of thinking, simultaneity is by no means relative in this way. To our ordinary way of thinking, throughout the universe there are events taking place or occurring right now, as opposed to those that have taken place or are yet to take place at these various distant locations. There is one and only one now or present extended across the breadth of the universe. Aristotle captured part of this idea when he said (*Physics* 220<sup>b</sup>5): “there is the same time everywhere at once”. Newton may well be expressing the same thought when he says (1962: 137):

[W]e do not ascribe various durations to the different parts of space, but say that all endure together. The moment of duration is the same at Rome and at London, on the Earth and on the stars, and throughout all the heavens.

In classical or Newtonian physics, the transformation laws that connected coordinates in one inertial frame to another (in standard configuration) are the *Galileo transformations*:



$$\begin{aligned}
 x' &= x - vt, \\
 y' &= y, \\
 z' &= z, \\
 t' &= t.
 \end{aligned}$$

Evidently, when co-ordinates are transformed according to the Galileo transformations, events that are simultaneous in one inertial system are simultaneous in all, exactly as commonsense indicates that they should be.

Pre-relativistically, the successive occurrence of global nows or presents constitutes the passage of time or temporal becoming, the dynamic quality of time that distinguishes it from space and that seems to be essential to its nature. The relativity of simultaneity challenges not only the uniqueness of the now but also our understanding of the passage of time as well. If each inertial frame has its own sets of simultaneous events and if the principle of relativity states that no physical experiment or system (and we human beings are physical systems too) can distinguish one such frame or another as (say) genuinely at rest, then we are able to discern no particular set of simultaneous events as constituting *the* now or *the* present. If the passage of time is the succession of global nows or presents, then the notion of passage threatens to become unintelligible. Yet what phenomenon seems more important or more intuitively evident to us than the passage of time?

Late in his life, looking back on his scientific achievements and their philosophical importance, Albert Einstein wrote the following (1949: 61):

We shall now inquire into the insights of definite nature which physics owes to the special theory of relativity.

(1) There is no such thing as simultaneity of distant events...

This chapter is an elaboration of Einstein's remark in three distinct but related areas: the conventionality of simultaneity, the relativity of simultaneity and the passage of time (or temporal becoming). Einstein's presentation of the special theory of relativity in 1905 initiated two decades in which new theories in physics (the general theory of relativity,

quantum mechanics) arose to challenge many philosophical preconceptions. Questions raised by these theories are still the subject of intense debate, but questions raised by the special theory of relativity regarding the nature of time are also still deeply puzzling. Minkowski elegantly modeled a world with no privileged distant simultaneity, but integrating this model with our intuitive understanding of time is still—more than a century after the advent of the special theory of relativity--no mean feat.

## II.

In order to introduce the special theory of relativity--in particular the relativity of simultaneity--to the reader, the presentation in section I skipped over the most famous and arguably the most important (both physically and philosophically) insight in Einstein's paper. The discussion in section I concerned ideas developed in §§2-3 of Einstein (1905), but we need now to consider §1, "Definition of Simultaneity".<sup>11</sup>

The light postulate introduced above states that light (*in vacuo*) has a certain determinate constant velocity  $v$ . How could one determine what exactly this velocity is? It seems that what one must do is start a light ray at some point (Call it "A") at some time  $t_A$  and then see at what time  $t_B$  the ray reaches a distinct point  $B$ . If one knows the distance from  $A$  to  $B$ , which can be in principle determined by a measuring rod, one can determine the velocity of the ray, which is the distance from  $A$  to  $B$  divided by the elapsed time  $t_B - t_A$ .

One can determine the relevant times  $t_A$  and  $t_B$  if there are *synchronized* clocks at the points  $A$  and  $B$ . The clocks must be synchronized if their readings are to indicate a

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<sup>11</sup> In this section of my paper, all quotes from Einstein (1905) will come from the translation of that paper in Stachel (1998). The reason for the switch is that in the classic Perrett and Jeffery translation in *The Principle of Relativity* there is a notorious mistranslation at a key point. The (mis)translation is discussed in detail in Jammer (2006: 111-15).

definite time difference. So we next ask, how does one synchronize clocks at distinct points  $A$  and  $B$ ? One obvious way to do this would be determine the distance from  $A$  to  $B$ , note the time at  $A$ , and send a signal to  $B$ . One could then set the clock at  $B$  to the reading of the clock at  $A$  plus  $v$  times the distance from  $A$  to  $B$ —*if* one knew the velocity  $v$  of the signal. But, alas, determination of this velocity seems to require that we have synchronized clocks (as we saw above). We have landed in a circle—synchronizing distant clocks requires knowing signal velocities but determining signal velocities requires synchronized distant clocks.

The existence of this circle explains the following otherwise surprising remark of Einstein’s regarding the comparison of times at distinct locations:

If there is a clock at point  $A$  in space, then an observer located at  $A$  can evaluate the time of events in the immediate vicinity of  $A$  by finding the positions of the hands of the clock that are simultaneous with these events. If there is another clock at point  $B$  that in all respects resembles the one at  $A$ , then the time of events in the immediate vicinity of  $B$  can be evaluated by an observer at  $B$ . But it is not possible to compare the time of an event at  $A$  with one at  $B$  without further stipulation. (126)

What sort of “stipulation” does Einstein think is required? He continues the above train of thought:

So far we have defined only an “ $A$ -time” and a “ $B$ -time,” but not a common “time” for  $A$  and  $B$ . The latter can now be determined by establishing *by definition* that the “time” required for light to travel from  $A$  to  $B$  is equal to the “time” it requires to travel from  $B$  to  $A$ . For, suppose a ray of light leaves from  $A$  for  $B$  at “ $A$ -time”  $t_A$ , is reflected from  $B$  towards  $A$  at “ $B$ -time”  $t_B$ , and arrives back at  $A$  at “ $A$ -time”  $t'_A$ . The two clocks are synchronous by definition if

$$t_B - t_A = t'_A - t_B.$$

That is, common time is arrived at by setting the clocks at  $A$  and  $B$  so that the time taken for light to travel from  $A$  to  $B$  is the same as the time it takes for the same signal to travel back from  $B$  to  $A$ . This way of synchronizing distant clocks is called *standard* or *Einstein* or *Poincaré-Einstein synchronization*.

It is useful to write the displayed equation above in a slightly different form:

$$t_B = t_A + \frac{1}{2}(t'_A - t_A). \quad (2)$$

Equation (2) tells us that the event that occurs at  $A$  at the same time as the event  $t_B$ --that is, the event at  $A$  that is *simultaneous* with the event  $t_B$ , the event at  $B$  at which the light signal from  $A$  is reflected—is, according to Einstein synchronization, the event that occurs at  $A$  exactly half-way between the time of the emission and the time of the reception of the reflected light signal. This way of synchronizing clocks is so natural that one is apt to overlook the fact that there is a choice to be made.

To see how choice enters the picture, recall that the light principle says that the speed of light in any inertial frame is  $c$ . As the special theory of relativity is usually understood, this speed is taken to be an upper limit for the speed of propagation of *any* causal process.<sup>12</sup> In classical physics there is no upper limit to the speed of causal propagation. In Roberto Torretti's words:

Before Einstein... nobody appears to have seriously disputed that any two events might be causally related to each other, regardless of their spatial and temporal distance. The denial of this seemingly modest statement is perhaps the deepest innovation in natural philosophy brought about by Relativity.<sup>13</sup> (1983: 247)

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<sup>12</sup> A useful discussion of this idea may be found in Grünbaum (1973: chapter 12 (C)).

<sup>13</sup> The Lorentz-Fitzgerald contraction hypothesis had been invoked to explain the null result of the Michaelson-Morley experiment since the early 1890s. (See

Hans Reichenbach argued that temporal order is fixed by causal order. (1958: §21) That is, if event  $e'$  is the (or an) effect of event  $e$ , then it is later than  $e$ . Applied to Einstein's example above, Reichenbach's principle (or "axiom," as he calls it) implies that  $t'_A$  is later than  $t_B$ , which in turn is later than  $t_A$ , but it leaves indeterminate with respect to  $t_B$  the time ordering of all events at  $A$  later than  $t_A$  (since no causal process or signal leaving  $A$  later than  $t_A$  can reach  $t_B$ ) and earlier than  $t'_A$ , (since no causal process leaving  $t_B$  can reach any event at  $A$  earlier than  $t'_A$ ). Any event in that interval, according to Reichenbach, may be chosen to be simultaneous with  $t_B$ . According to Reichenbach, then, one may replace (2) by

$$t_B = t_A + \varepsilon(t'_A - t_A), \quad (3)$$

where  $0 < \varepsilon < 1$ . Reichenbach's thesis is called *the conventionality of simultaneity*.

The conventionality of simultaneity is quite different from the relativity of simultaneity. Given an "observer" or (in the example most used nowadays) a space ship far from any planets or stars that is not accelerating, its path in spacetime is a straight line. Given that particular straight line, the conventionality thesis claims that clocks distant from it can be synchronized with the space ship clocks in many ways—in fact, an infinite number of ways—although one way does seem simpler than the others and so is usually preferred. That preference is just that, conventionalists say, a preference. It reflects no matter of fact as to what distant events are simultaneous with the events in the space ship. There is in their view no such matter of fact.

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Lorentz (1895) and references therein. See also §1.2 of Brown (2005) on Fitzgerald's neglected 1889 letter and article.) Robert Rynasiewicz pointed out to me that if in light of this hypothesis one thinks about what happens to any massive object as its speed approaches that of light, one might well surmise that  $c$  is a limiting speed for it and even for any form of causal influence.

The relativity of simultaneity, on the other hand supposes that in a given inertial frame clocks are synchronized according to the Einstein convention.<sup>14</sup> It then asserts that in any inertial frame moving with respect to the first frame, there are pairs of events that are simultaneous according to its clocks but not simultaneous according the clocks of the first frame (and *vice versa*, of course). As Adolf Grünbaum expressed it:

[I]f *each* Galilean observer adopts the particular metrical synchronization rule adopted by Einstein in Section 1 of his fundamental [1905] paper and if the spatial separation of  $P_1$  and  $P_2$  has a component along the line of the relative motion of the Galilean frames, then that relative motion issues in their choosing as metrically simultaneous *different pairs of events* from within the class of topologically simultaneous events at  $P_1$  and  $P_2$ ... (1973: 353)

Grünbaum is careful to emphasize in his discussion the difference between the conventionality and the relativity of simultaneity.

If one takes the special theory of relativity seriously, then one must take the relativity of simultaneity seriously since, as we saw above, it follows from the fundamental postulates of the theory. The status of the conventionality thesis is more controversial, and it has evoked a wide range of reactions. Indeed, the bulk of Jammer's (2006) monograph, *Concepts of Simultaneity*, is given over to discussion of the conventionality of simultaneity. In this chapter, I will be able only to sketch a few of the most important battle lines.

Hans Reichenbach (1958: §19), along with his notable students Adolf Grünbaum (1973: chapter 12) and Wesley Salmon (1975: chapter 4), vigorously defended the conventionality thesis. One job of the philosopher of science, as they saw it, is to separate factual from conventional elements in scientific theories, and they thought it was a triumph of modern physics *cum* philosophical analysis to have discovered that

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<sup>14</sup> Actually, any value of  $\epsilon$  may be chosen, as long as the same value is chosen in all inertial frames.

simultaneity—long thought to have some deep physical and even metaphysical reality--is (merely) conventional.

Since the conventionality thesis (at least in Reichenbach's classic presentation in §19 of his 1958 book) rests on the circularity argument given above (synchronizing clocks at distant points requires knowing the speed of the signal sent from one clock to the other, but finding the speed of anything, including a signal, requires synchronized clocks at distant points), it is tempting to think that the conventionality thesis can be undermined by showing that the claim of circularity is unsound. Why must one rely, for example, on a *signal* traveling (to revert to Einstein's notation) from *A* to *B*? Perhaps one could synchronize two clocks at *A* and then transport one of the clocks to *B*. Would we not then have synchronized clocks at both *A* and *B*? We would, Reichenbach wrote (1958, §20) *if* we could assume that the rate of the clock that traveled from *A* to *B* was not affected by its speed or path during its journey, but the special theory implies that neither assumption is true.

To take a slightly different tack, then, suppose that we synchronized many clocks at *A* and then transported them to *B* ever more slowly. Could we not find a limit to the series of times indicated by the slow-transported clocks and use the limit to synchronize distant clocks (Bridgman 1962: 64-67, Ellis and Bowman 1967)? It turns out that the limit exists and the synchronization agrees with standard synchrony. This proposal is considerably more complex and controversial than the first. The interested reader should look at the discussion of the Ellis and Bowman paper by Grünbaum, Salmon, van Fraassen, and Janis in the March, 1969 issue of *Philosophy of Science*, Friedman (1977, 1983), and chapter 13 of Jammer (2006).<sup>15</sup> The members of the 1969 "Pittsburgh Panel" all argue, one way or another, that

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<sup>15</sup> Although Jammer's book is remarkable in scope, it fails to discuss the argument in Friedman (1983: 309-317) that the standard simultaneity relation can be fixed by slow clock transport in a way that avoids any circularity or question-begging assumptions.

Ellis and Bowman have not proved that the standard simultaneity relation is nonconventional, which it is not, but have succeeded in exhibiting some alternative conventions which also yield that simultaneity relation. (van Fraassen 1969: 73)

There have also been numerous ingenious attempts to break out of the second half of the circle and argue that one can determine “one-way” light speeds (that is, the speed of a light signal from *A* to *B*, as opposed to a “round-trip” light speed in which the travel time of a light signal emitted and received at one location but reflected from a distant place is measured by one stationary clock) without the use of synchronized clocks. Indeed, it is not at all obvious that the first determination of the speed of light by Ole Rømer in 1676 is not a one-way determination.<sup>16</sup> Salmon (1977) is a comprehensive discussion of all such proposals then known. He concludes:

I have presented and discussed a number of methods which have been proposed for ascertaining the one-way speed of light, and I have given references to others. Some of these approaches represent methods which have actually been used to measure the speed of light. Others are obviously “thought experiments.” Some are quite new; others have been around for quite a while. In all of these cases, I believe, the arguments show that the methods under discussion do not provide convention-free means of ascertaining the one-way speed of light (although some of them are excellent ways of measuring the round-trip speed). I am inclined to conclude that the evidence, thus far, favors those who have claimed that the one-way speed of light unavoidably involves a non-trivial conventional element. (288)

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<sup>16</sup> See Holton and Brush 2001: 343-344 for a brief account of the measurement. Salmon (1977) of course offers an account of the measurement and an argument that it is not one-way. Bridgman (1962: 68-9) offers a completely different explanation for the measurement’s not being one-way.



By an odd coincidence, Salmon's extended defense of the conventionality thesis was followed in the same journal issue by a short article by David Malament (1977) that is widely thought to be the definitive refutation of the view. Malament proves the following result:

*Proposition 2* Suppose  $S$  is a two-place relation on  $R^4$  where

- i.  $S$  is (even just) implicitly definable from  $\kappa$  and  $O$ ;
- ii.  $S$  is an equivalence relation;
- iii.  $S$  is non-trivial in the sense that there exist points  $p \in O$  and  $q \notin O$  such that  $S(p,q)$ ;
- iv.  $S$  is not the universal relation (which holds of all points),

Then  $S$  is  $\text{Sim}_O$ .

In Proposition 2 ' $\kappa$ ' designates the relation of causal connectibility. Two points are *causally connectible* iff they are either lightlike or timelike separated.  $O$  is a timelike line representing an inertial observer.  $\text{Sim}_O$  is standard Einstein simultaneity relative to  $O$ .

What is the significance of Proposition 2?<sup>17</sup> Malament begins his paper by observing that one of the major defenders of conventionalism, Grünbaum, is committed to the following two assertions:

- (1) The relation [of simultaneity relative to an inertial observer] is not uniquely definable from the relation of causal connectibility [that is, from invariant causal relations].
- (2) Temporal relations are non-conventional if and only if they are so definable.(1977: 293).

Malament's Proposition 2 shows that (1) is false and therefore by (2) that temporal relations, in particular standard simultaneity, are *non-conventional*.

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<sup>17</sup> The reader is urged to look at the details in Malament's paper or, failing that, the semi-popular account in Norton (1992).

Malament's result has clarified but not ended the discussion. One can always raise doubts about the reasonableness of the required conditions. Indeed, Norton (1992: 225) worries about the delicate dependence of the result of Proposition 2 on its conditions.<sup>18</sup> He also reports (226) that Grünbaum has pointed out to him that condition (ii) might not be as innocent as it initially appears, and the extended discussion of the symmetry and transitivity of the simultaneity relation in Jammer (2006: chapter 11) gives this concern some weight. Grünbaum (forthcoming) reiterates this point but also questions Malament's first condition, a topic to which we will now turn.

The very brief explication of the conditions of Proposition 2 omitted any discussion of 'definition'. While this might seem over-fussy, Sarkar and Stachel (1999) raise serious concerns over the precise form of definition employed by Malament. Roughly, a structure is defined if it is invariant under a class of transformations.  $\text{Sim}_O$  is the unique, non-trivial simultaneity relation left invariant under a class of transformations that Malament calls the *O causal automorphisms*. Amongst the *O causal automorphisms* are temporal reflections, mappings of a spacetime to itself by reflection about a hyperplane that take the given inertial line *O* to itself and preserve the relation  $\kappa$ . It should be intuitively clear that such mapping will leave the hyperplane in place (invariant) but flip a past light cone into a future light cone and *vice versa*.

Sarkar and Stachel (1999: 213-215) argue that it is physically unreasonable to include such mappings in the set used to define simultaneity. "Since reflections are not physically implementable as active transformations<sup>19</sup>, it is not physically reasonable to demand that all relations between events be universally preserved under them." (215) If one removes all reflections from the set of *O causal automorphisms* (resulting in a set Sarkar and Stachel call the *O causal' automorphisms*), then, they claim,  $\text{Sim}_O$  is no longer uniquely definable. They claim that, given an event *e*, its past light cone and future light cone are each definable by  $\lambda$ , the relation of lightlike or null separation, alone (and so a

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<sup>18</sup> Regarding this point, one should see the discussion in Budden (1998).

<sup>19</sup> That is, while we can translate and rotate objects, we cannot reverse time.

*fortiori* are definable from  $\kappa$ ) and claim that the definability of these structures is a clear counterexample to Malament's uniqueness result.<sup>20</sup>

In a response to Sarkar and Stachel's argument Rynasiewicz (2000) offers, amongst other things, a brief primer on the varieties of definition. At the end of his discussion of definition he writes:

The punch line is now this. No matter what notion of definability is in question, the preservation of a relation under automorphisms of the structure or structures in question is a necessary condition for the definability of a relation. In the case of Minkowski spacetime, the automorphisms include temporal reflections and thus

uniquely definable from  $\kappa$  and  $O$ . We seem to be back to squabbling over the conditions of Malament's theorem, but Rynasiewicz adds an unexpected and disquieting final paragraph to his paper.

The most serious question... is this. Described as neutrally as possible, what Malament establishes is that the only (interesting) equivalence relation definable from  $\kappa$  and  $O$  is that of lying on the same hypersurface spacetime-orthogonal to  $O$ . Now, as silly or contentious as it may sound, we should ask, what does spacetime orthogonality have to do physically with simultaneity? The force of the question is more easily recognized if reframed as follows. Suppose an inertial observer emits a light pulse in all directions. Consider the intersection of the resulting light cone with some subsequent hypersurface orthogonal to the observer. Does causal connectivity (plus  $O$  if you like) completely determine the spatial geometry of the light pulse on the hypersurface in the absence of some stipulation as to the one-way velocity of light? If not (and I urge you to think not), then relative simultaneity does involve a conventional component corresponding to a degree of freedom in choosing a (3+1)-dimensional representation of an intrinsically four-dimensional geometry. (S357)

In this light Malament's result, far from being a decisive refutation of conventionalism, looks to be nearly irrelevant to the thesis! Even granting the unique definability of the hypersurface orthogonal to  $O$  from  $\kappa$  and  $O$  itself, why would one suppose that the light sphere generated by a pulse of light from  $O$  at an earlier time intersects that hyperplane at a set of points equidistant from  $O$ ? In the absence of some way to break Reichenbach's circle, only a stipulation that one-way lights speeds are the same in all directions will do. What is going on?

A partial answer may be found in a distinction drawn in Friedman (1977 426).

It seems to me that there are at bottom only two arguments for the conventionality of simultaneity in the literature: Reichenbach's and Grünbaum's. Reichenbach argues from an epistemological point of view; he argues that certain statements are conventional as opposed to "factual" because they are unverifiable in principle. Grünbaum argues from an ontological point of view; he argues that certain statements are conventional because there is a sense in which the properties and relations with which they purportedly deal do not really exist, they are not really part of the objective physical world.

Insofar as Grünbaum admits the existence of causal structure and insofar as Malament proves the unique specification of simultaneity in terms of causal structure, Grünbaum's version of conventionalism seems to be untenable.<sup>22</sup> Reichenbach's version seems, in contrast, to remain untouched by Malament's argument, though Friedman argues against Reichenbach's verificationism on other grounds, claiming that it rests on a dubious semantics.<sup>23</sup> (1977: 426-428)

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<sup>22</sup> A useful way of looking at this matter was pointed out to me by Rynasiewicz. Grünbaum's propositions (1) and (2) suffice for conventionalism, and Malament's construction shows that Grünbaum's argument is unsound. But conventionalism itself does not entail (1) and (2), so their falsity does not entail the falsity of conventionalism.

Yet another way to look at the matter is to be found in Stein (2009), which appeared after this chapter was written. Stein carefully argues that the major differences between Malament and Grünbaum result from different ways that they understand the issues. "I think we should acknowledge," writes Stein, "side by side, the points made by Grünbaum and the points made by Malament et al." (437) There is much else in Stein's article to enlighten the reader.

<sup>23</sup> Others, like Dieks (forthcoming) would argue that Reichenbach's argument fails because it relies on an overly restrictive epistemology. Following this up would take us too far afield, but it does indicate the entanglement of the conventionality issue with other major philosophical issues.

Another possible source of some of the perplexity here is the notion of general covariance. The conventionality of simultaneity is supposed to be an exciting thesis. One (naively, perhaps) supposes that light travels with some definite speed to a distant location and with a definite speed back from there to its origin. Conventionalists say that there is no fact of the matter with respect to these speeds, either (as we have just noted) on verificationist or straightforwardly ontological grounds. The physicist Peter Havas (1987) thought that conventionalism is true, but for essentially formal and unsurprising reasons. The general theory of relativity (and Minkowski spacetime is one particular general relativistic spacetime) is generally covariant, permitting “the formulation of the theory using arbitrary space-time coordinates.” (444) According to Havas, “What Malament has shown... is that in Minkowski space-time... one can always introduce time-orthogonal coordinates..., an obvious and well-known result which implies  $\epsilon = \frac{1}{2}$ .” (444) A straightforward reading of Malament’s and Rynasiewicz’s papers indicates, however, that they are about the definability of the standard simultaneity relation in terms of causal connection, rather than its mere introduction in a given spacetime. If there is some reason that this straightforward reading cannot be sustained, it is not to be found in Havas’s paper, though there is much of interest there on general covariance and the range of permissible coordinate systems for Minkowski spacetime.

One final consideration should be brought to bear on the conventionalism debate. Of the seven basic units in the SI (Système Internationale) system of measurement, time can be measured the most precisely. In 1983 the Conférence Générale des Poids et Mesures (CGPM), the highest authority in definitions of units, defined the meter as “the length of the path traveled by light in vacuum during the time interval of  $1/299,792,458$  of a second”. (Jones 2000: 156-160; Audoin & Guinot 2001: 287-289) Then *by definition* the speed of light in *any* direction is 299,792,458 meters per second. As Roberto Torretti (1999: 275) remarks in the only philosophical discussion of this episode known to me, “The definition of the meter ratifies Reichenbach’s view of the one-way speed of light as conventional but also undercuts his claim that its two-way speed is factual.”

What is surprising is not that there is choice to be made when it comes to fundamental units, but the breadth and variety of theoretical and practical considerations that constrain the “convention”. But if there is a line to be drawn between statements that are factual and those that are conventional, then my conclusion in this section must be rather an odd one. Whether or not the conventionality of simultaneity was refuted by Ellis and Bowman in 1967 or by Malament in 1977, it has been true since the CGPM defined the meter in 1983.

### III

Let us turn now to some problems raised by the relativity of simultaneity. If one synchronizes distant clocks in various inertial frames using standard Einstein synchrony, whether conventional or not, then we find (as noted in section I) that different frames disagree as to which events happen simultaneously. This basic result raises questions about nowness and about passage, questions that seemed reasonably straightforward in the classical view sketched at the beginning of this chapter. Here is one well-known version of the problem:

Change becomes possible only through the lapse of time. The existence of an objective lapse of time, however, means (or, at least, is equivalent to the fact) that reality consists of an infinity of layers of “now” which come into existence successively. But, if simultaneity is something relative in the sense just explained, reality cannot be split up into such layers in an objectively determined way. Each observer has his own set of “nows,” and none of these various layers can claim the prerogative of representing the objective lapse of time. (Gödel 1949: 558)

If the passage of time has something to do with the advance of *the* now or with (as Torretti preferred to put it) the advance of events (from past to future) through *the* now, then passage is undermined by the fact that there is no longer a unique now to serve as *the* now. There are (at least) as many nows as inertial frames, and there are a non-denumerable infinity of such frames. On this view, if there is no unique now, then there can be no objective lapsing of time or passage.

A second problem for passage raised by the relativity of simultaneity is that (recalling the quote from Minkowski in section I) events that are spacelike separated from a given event O have no definite time order in respect to it. If e is spacelike separated from O, then in some frames it precedes O temporally, while in others it follows O. In precisely one frame e is simultaneous with O. It is claimed, though, that if there is no objective ordering of events as past, present, and future, then there is no passage (that which turns future events into past events) either. As the physicist Olivier Costa de Beauregard wrote:

In Newtonian kinematics the separation between past and future was objective, in the sense that it was determined by a single instant of universal time, the present. This is no longer true in relativistic kinematics: the separation of space-time at each point of space and instant of time is not a dichotomy but a trichotomy (past, future, elsewhere). Therefore there can no longer be any objective and essential (that is, not arbitrary) division of space-time between “events which have already occurred” and “events which have not yet occurred.” There is inherent in this fact a small philosophical revolution. (1981: 429)



The upshot of this argument, the result of the revolution, is that the special theory of relativity is supposed to show that we live in a static or “block”<sup>24</sup> universe. Here is Costa de Beauregard’s depiction of it:

This is why first Minkowski, then Einstein, Weyl, Fantappiè, Feynman, and many others have imagined space-time and its material contents as spread out in four dimensions. For those authors, of whom I am one... relativity is a theory in which everything is “written” and where change is only relative to the perceptual mode of living beings. (1981: 430)

These two arguments carry the weight and prestige of an important scientific theory and are endorsed, we learn, by physicists of the highest order. Yet it may be possible to find, within the confines of the special theory of relativity (or in the geometrical model of it called *Minkowski spacetime*) and within Einstein’s stricture that there is no distant simultaneity, enough remnants of the pre-relativistic notion of becoming that one might hesitate to call the resulting picture of time in the special theory “static”.

The first step in this direction is to note that in Minkowski spacetime the concept of time bifurcates. We have so far been discussing *coordinate time*, time spread from the origin an inertial system throughout the rest of space. One can also define what is called *proper time* along the world line of a material particle. The path or world line of a material particle consists of points that are mutually or pair-wise timelike separated. Such

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<sup>24</sup> This unfortunate expression originated in William James’s brilliant characterization of determinism in James (1897: 569-570), but it has become a standard designation for a “static” or non-dynamic universe, one that supposedly lacks passage. The two ideas are distinct but they are continually conflated. The confusions leading to their conflation are effectively exposed in Grünbaum (1971: section VI; 1973: chapter 10), but no amount of pesticide seems able to kill this weed.

a path is called a *timelike world line* or a *timelike curve*. We can write the invariant spacetime interval that we found in equation (1) in its infinitesimal form as

$$ds^2 = -dt^2 + dx^2 + dy^2 + dz^2. \quad (4)$$

If we multiply (4) by  $-1$ , which of course still leaves it invariant, we can write

$$d\tau^2 = dt^2 - dx^2 - dy^2 - dz^2. \quad (5)$$

The quantity ' $\tau$ ' is the *proper time*.

Timelike curves or world lines can be parameterized by proper time,  $\tau$ . We can define proper time lengths between two points A and B on a timelike curve,  $\tau_{AB}$  as:

$$\tau_{AB} = \int_A^B d\tau = \int_A^B [dt^2 - (dx^2 + dy^2 + dz^2)]^{1/2}. \quad (6)$$

If we choose some point on the timelike line and assign it proper time 0, we can then define the proper time function along the timelike line by:

$$\tau_A = \tau_{0A} \quad (7)$$

We can begin to see the importance of proper time in that, according to the clock hypothesis (Naber 1992: 52; Brown 2005: 94-95), ideal clocks measure proper time.<sup>25</sup> Suppose we then conjecture the following (Arthur 1982: 107): “It is this proper time which is understood to measure *the* rate of becoming for the possible process following this timelike line (or *worldline*).” It is this idea of becoming along a timelike line, local becoming, that underlies my negative evaluation of the two anti-passage arguments presented above.

It is important to note one more fact about proper time. Since proper time is a function of all four variables  $x, y, z, t$ , if two ideal clocks are transported from event A to

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<sup>25</sup> The standard clocks of inertial observers indicate proper time; but in general clocks during their history may be accelerated. It is a non-trivial demand on a real clock that even when accelerated it read proper time (Sobel 1995).

event B along different paths, they will in general indicate different proper times. For example, a clock that moves inertially from A to B will yield proper time change equal to co-ordinate time change, since  $dx^2+dy^2+dz^2 = 0$ . If the clock is not inertial, then  $dx^2+dy^2+dz^2 > 0$  (at least for some portions of the journey from A to B), and the change in its proper time will be less than the co-ordinate time, the change in proper time for the inertial clock.<sup>26</sup>

Let us now return—slowly—to the two anti-passage arguments based on the special theory of relativity presented above by considering a classic article (Grünbaum 1971) that takes them—or at least the conclusion that “change is only relative to the perceptual mode of living beings” very seriously. The thesis of Grünbaum’s article is this: “Becoming is mind-dependent because it is not an attribute of physical events per se but requires the occurrence of certain conceptualized conscious experiences of the occurrence of certain events.” (1971: 197) But what, according to Grünbaum, is this becoming that is mind-dependent?

In the common-sense view of the world, it is of the very essence of time that events occur now, or are past, or future. Furthermore, events are held to change with respect to belonging to the future or the present. Our commonplace use of tenses codifies our experience that any particular present is superseded by another whose event-content thereby ‘comes into being’. It is this occurring now or coming into being of previously future events and their subsequent belonging to the past which is called ‘becoming’ or ‘passage’. Thus, by involving reference to present occurrence, becoming involves more than mere occurrence at various serially ordered clock times. The past and future can be characterized as respectively before and after the present. (1971: 195)

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<sup>26</sup> Hence, in the so-called *twin paradox*, the traveling twin must return younger than the stay-at-home (inertial) twin. For further discussion of this feature of the special theory see the chapter by Luminet in this volume and Marder (1971).

There are two elements in this passage that I wish to separate. The first is the common-sense idea indicated at the outset that events naturally sort themselves out into those that are present, past, and future. This aspect of time is typically called *tense* by philosophers.<sup>27</sup> Second is the distinction Grünbaum makes between becoming and the “mere occurrence [of events] at various serially ordered clock times”. Grünbaum has no objection to (and, in fact, insists upon) the mind-independence of the latter.

[T]o assert in this context that becoming is mind-dependent is not to assert that the obtaining of the relation of temporal precedence is mind-dependent. Nor is it to assert that the mere occurrence of events at various serially ordered clock times is mind-dependent.  
(1971: 197)

I suggested briefly in the introduction to this chapter that a philosopher might wish to consider the “mere occurrence [of events] at various serially ordered clock times” to be becoming, and I have defended the idea at greater length elsewhere (Savitt 2002). I argue there that this usage captures the mainstream, metaphysically unobjectionable content of the concept of passage. Of course, this is essentially a terminological matter, but given the way I believe the term *becoming* has been used traditionally, if we do agree to use the term in that way, then Grünbaum and I *agree* that becoming is mind-*independent*.

We also agree that something else is mind-*dependent*, and that something else is tense. Grünbaum claims this directly. I claim it indirectly by claiming directly that the terms for tense, like ‘now’, ‘past’, and ‘future’, are indexical terms. Without minds there could not be language-users.<sup>28</sup> Without language-users there could not be languages. Without languages there could not be indexical terms.

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<sup>27</sup> This usage is unfortunate, in my view, since it conflates linguistic and ontological matters, but the usage is so ubiquitous that it would be quixotic to fight it. I will nevertheless try to keep linguistic and ontological issues distinct.

<sup>28</sup> Perhaps we will come to believe that machines can use language. Perhaps then we’ll come to believe that those machines have minds.

Whatever the differences between these two views, both agree to the extent that they entail the following key claim (Grunbaum 1971: 206):

[W]hat qualifies a physical event at a time  $t$  as belonging to the present or as now is not some physical attribute of the event or some relation it sustains to other purely<sup>[29]</sup> physical events.

Once one disjoins passage from tense, one can see that the first argument against passage from the relativity of simultaneity, the one above presented by Gödel, is invalid. From the fact that in different inertial frames different events are simultaneous (or, to put it more tendentiously, from the fact that in different inertial frames different events merely share the same  $t$ -coordinate), there is no conclusion to be drawn regarding passage, the successive occurrence of events. The failure of the first argument can be seen even more clearly if one recalls Einstein's stricture, the guiding insight of this chapter, that there is no distant simultaneity. The successive occurrence of events need not rely on distant simultaneity. It can be a *local* process, confined to a world line, possessing a proper time that is measured by a clock (Arthur 2008: section 2).

Is this intelligible? Do we *really* have time if we have only this local process? That is, do we *really* have time if there is no way to say of events not on a world line that they are past, present or future (relative to events on that world line)? That is, can there be passage without tense? This question, however, has an incorrect presupposition, as we shall see in our examination of the second anti-passage argument described above.

If the passage of time involves the future, "events which have not yet occurred" becoming the past, "events which have already occurred", how can there be passage if

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<sup>29</sup> 'Purely' was doubtless added to avoid begging any questions with respect to the mind-body problem. To put this point in terms of a distinction introduced by Meehl and Sellars (1956, 252), one can deny that some item or process is "purely" or narrowly physical (that is,  $\text{physical}_2$ )—roughly, describable in physics—without being committed to its being broadly non-physical (or not  $\text{physical}_1$ )—that is, outside the spacetime network.

there is no objective way of separating events into these two classes (as well as “events that are occurring now”)? The second argument, Costa de Beauregard’s argument, notes that there is no objective (that is, frame independent) way to make this division for spacelike separated events. In the absence of tense, it concludes there can be no passage.

Does it follow, if the time ordering of spacelike separated events is frame dependent, that there is no tense? There are events, those that are timelike or lightlike separated, for which the time ordering is not frame dependent. (Čapek, 1976) These are precisely the events that, given an event or spatio-temporal location  $O$ , are within or on  $O$ ’s past light cone and so can have some effect on it, or are within or on  $O$  ’s future light cone and so can be effected by it. Given the limiting speed  $c$  of any causal process, the events spacelike separated from  $O$  and so not temporally ordered with respect to it in some frame-invariant way are also causally irrelevant to anything that happens at  $O$ . Why should one, then, despair of “tense” in Minkowski spacetime if there is an absolute (that is, not frame dependent) past and an absolute future at each event, even if there are some events that are neither?

To put the same thought more formally, in the classical view of time as described by Torretti at the beginning of this chapter, there is a relation of *earlier than* ( $<$ ) that completely orders events. The relation ‘ $<$ ’ is irreflexive, anti-symmetric, and transitive, and for any two events  $a$  and  $b$ , either  $a<b$  or  $b<a$  or  $a=b$ . In Minkowski spacetime there is still a relation of earlier than that is irreflexive, anti-symmetric and transitive, but the clause “either  $a<b$  or  $b<a$  or  $a=b$ ” is no longer true. The ordering imposed by ‘ $<$ ’ is only partial rather than complete. Is complete ordering an essential feature of tense? Or should one rather say that in the shift to the special theory of relativity we learned that tense in fact was a partial rather than a complete ordering of events in spacetime? If one takes this latter course, then the second argument against passage in Minkowski spacetime, that the absence of tense implies the absence of passage, fails. The premise that there is no tense is incorrect.

There is a residual oddity in this view. (Putnam 1967: 246) If being present is tied to being simultaneous with (no matter how distant) and if there is no distant simultaneity,

then in the history of some material object or person an event not on its world line can at some earlier times be in its future and at some later times be in its past without ever being present.

It is tempting to take a high-handed approach to this complaint. The empirical evidence for the special theory (as opposed to classical mechanics) is overwhelming. If the evidence supports a theory that forces us to an odd conclusion, common sense must bow to the evidence. It might be worth noting, however, that there are two ways in which one might attempt to mitigate the oddity of the conclusion.

First of all, one might simply identify the entire region of Minkowski spacetime that is spacelike separated from some event  $O$ , its “elsewhere,” as its present.<sup>30</sup> One motivation for such a thought was provided by Minkowski himself, since he noted in his original paper (1908: 77-79) in effect that if the speed  $c$  (of electromagnetic radiation *in vacuo*) is allowed to increase without bound, then the region of spacelike separated points approaches as a limit the flat plane of events orthogonal to  $O$ 's world line. If one then thinks of the elsewhere as a relativistic counterpart of the classical present in virtue of this reduction relation, it is then true that any event that is once future must be present before it is past.

Nevertheless, it is worth noting that two events  $e$  and  $e'$  that are both spacelike separated from some event  $O$  and so both “present” in this sense to or for  $O$  may themselves be timelike separated and so invariantly time ordered. In fact, there is no upper bound on the proper time between  $e$  and  $e'$ . Identifying the elsewhere with the present does not seem to decrease oddity.

What, then, is the second way that might mitigate the oddity? To approach this idea, let us recognize that when we use indexical terms like ‘now’ and ‘here’ to indicate temporal or spatial location, the exact temporal or spatial extent or boundaries are context-dependent. When I say ‘here’, I might mean *in this room*, or *in British Columbia*,

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<sup>30</sup> As noted above, the “elsewhere” of  $O$  has also been called the *topological present*.

or even *on Earth*, since there is water here but not on Neptune. Similarly, with temporal terms I might wish to indicate a very short period of time (“Go to your room *now*.”) or a much longer one (“Since we now have cell phones, public pay phones are disappearing.”). All these *heres* are more-or-less spatially extended. All the *nows* are more-or-less temporally extended.

The *now* or *present* of experience is also extended. The extent may vary—estimates for normal human experience put the range from about .5 seconds to 3 seconds. That’s the (varying) duration that we typically perceive as present or happening now—the period of time, say, that it takes to hear a sentence or a musical phrase. This period is called the *specious* or *psychological present*. To make the following discussion simpler (but without compromising any matters of principle, I hope), I will take the psychological present to be of one fixed convenient length, 1 second.<sup>31</sup>

The second proposal specifies a relativistic counterpart of the present by employing a period of (proper) time represented by a specious present. Suppose one chooses two events on a given timelike curve, say  $e_0$  and  $e_1$ , that are one second apart. Then consider the region of spacetime that is the intersection of the future light cone of  $e_0$  and the past light cone of  $e_1$ . This is the set of events that, at least in principle, can be reached by a causal process from  $e_0$  and are also able then to reach  $e_1$ . In Savitt (2009) I call this structure the *Alexandroff present* for the interval  $e_0$  to  $e_1$  along the given timelike curve (assuming that it is parameterized by proper time) in honor of the Russian mathematician who first investigated these sets.<sup>32</sup>

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<sup>31</sup> This period of time is a completely objective matter, though the extent of its duration is set by subjective and pragmatic considerations.

<sup>32</sup> Others prefer to call it the *Stein present*, in honour of Howard Stein, since those of us who have been toying with this structure lately were all more-or-less independently and more-or-less at the same time inspired to it by a remarkable set of reflections at the end of Stein (1991). Still others call it a *diamond present* given its shape when one or two spatial dimensions are suppressed and when units are adjusted such that the numerical value of  $c$  is 1. It might in fact best be called the



To return, finally, to the claim that it is odd that a future event can become past without ever being present, one can note that an Alexandroff present is about 300,000 km wide at its waist, given the convention adopted above that the interval between beginning and end is one second. This means that at least events in one's vicinity cannot become past without being present, if Alexandroff presents are deemed to be reasonable relativistic stand-ins or counterparts of the classical present. The oddity can happen with events on Saturn but not events in Sydney. Perhaps that helps.<sup>33</sup>

#### IV

In section III of this chapter I tried to show that a certain common view concerning time and the special theory of relativity is not true. The view is that the special theory mandates a “block” or static universe. I interpret this view to mean that there is no becoming, no passing or lapsing time, in Minkowski spacetime.

Since ‘time’ is an ambiguous term,<sup>34</sup> I tried to disambiguate it in this context into two strands, passage and tense. When these two strands are clearly separated, the two

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*causal present*, since it is the set of all events that can causally interact with any pair of events on the given world line between  $e_0$  and  $e_1$ .

<sup>33</sup> The arguments in this section were influenced by the writings of and by conversations with Richard Arthur, Dennis Dieks, and Abner Shimony. The relevant papers will be found listed amongst the references. One can find a related view in Maudlin (2002), and Dorato (2006: 107) writes that he defends in his way the same view as Maudlin. I have been helped throughout by the advice of Robert Rynasiewicz, who has saved me from numerous errors and who no doubt wishes that he had saved me from even more. I wish also to thank the editor and Christian Wuthrich for helpful suggestions.

<sup>34</sup> Rovelli (1995: 81) exhibits “ten distinct versions of the concept of time”, and he is restricting his attention only to time in physical theories.

main arguments for the “Special Relativity implies block universe” view fail. Moreover, we saw that there are two concepts of time in the special theory itself, co-ordinate time and proper time, the latter being a kind of time perfectly apt for becoming. What is surprising about the special theory (at least in this regard; there are other surprises of course) is that time qua passage is a *local* phenomenon, tied to a world line. For eons we have tied passage to an advancing *global* now, and this idea is buried deep in our worldview. It is an idea that we must transcend.<sup>35</sup>

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<sup>35</sup> This essay will appear in *The Oxford Handbook of Time*, edited by Craig Callender and published (in 2010?) by Oxford University Press.

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