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ENDURANTISM, PERDURANTISM AND SPECIAL RELATIVITY

BY STEVEN D. HALES AND TIMOTHY A. JOHNSON

There are two main theories about the persistence of objects through time. Endurantists hold that objects are three-dimensional, have only spatial parts, and wholly exist at each moment of their existence. Perdurantists hold that objects are four-dimensional, have temporal parts, and exist only partly at each moment of their existence. We argue that endurantism is poorly suited to describe the persistence of objects in a world governed by special relativity, and it can accommodate a relativistic world only at a high price not worth paying. Perdurantism, on the other hand, fits beautifully with our current scientific understanding of the world. We use only the implications of the Lorentz transformations, without appeal to geometrical interpretations, dimensional analogies or auxiliary premises like temporal eternalism.

I. INTRODUCTION

Philosophical puzzles about the persistence and change of physical objects have received much recent attention from metaphysicians. There are two main competing theories about how non-momentary objects relate to time: endurantism (or three-dimensionalism), and perdurantism (or four-dimensionalism). David Lewis roughly characterizes these terms thus:

> Let us say that something *persists* iff, somehow or other, it exists at various times; this is the neutral word. Something *perdures* iff it persists by having different temporal parts, or stages, at different times, though no part of it is wholly present at more than one time; whereas it *endures* iff it persists by being wholly present at more than one time.[1]

Endurantism, then, is the view that objects have three spatial dimensions and move through time. Persistence in three dimensions means that an object is at one time, then the next time, then the next time, and so on; things are wholly present at each time at which they exist. An object that is here now is entirely here now, and only here now. Nothing that is a part of an object now is somehow still around in the past, or waiting for us in the

[1] D. Lewis, *On the Plurality of Worlds* (Oxford: Blackwell, 1986), p. 202.

future. The second approach, perdurantism, is the denial of endurantism: objects are not wholly present at each time at which they exist. This may be positively characterized as the view that objects are composed of so-called temporal parts. When we see an object here and now, we are seeing the parts of it that are now – but there are other parts of it at other times that we might have encountered or might yet encounter. The usual arguments on either side are *a priori*, and attempt to show that one or the other view solves more effectively mereological conundrums such as Heraclitus' river, the ship of Theseus, the sorites paradox, and the like.[2]

Recently there has been a revival of interest in whether there are *a posteriori* reasons to prefer perdurantism over endurantism, and in particular whether Einstein's theory of special relativity (hereafter SR) supports a temporal-parts ontology. We shall argue that while endurantism can be reworked so as to be consistent with SR, the result is a profligate, Byzantine ontology with few redeeming qualities. Perdurantism, on the other hand, has a natural and elegant fit with the physical facts of our world.

Philosophers who have considered the relationship of SR to the metaphysics of persistence have thought that either (1) SR has no relevance to the purely *a priori* endurantism debate, or (2) SR undermines endurantism, but only if one can first establish intermediate propositions, for example, that temporal eternalism is true, or that Minkowski space-time is the correct geometrical interpretation of SR. We shall argue that both (1) and (2) are false. The empirical inseparability of space and time under SR is quite relevant to the nature and persistence of objects. We contend that given the uncontroversial central theses of SR, namely, (i) physics is the same in all inertial reference frames, and (ii) the speed of light in a vacuum is a constant, endurantism, an ontology more suited to an outmoded Galilean relativity, is revealed as inadequate to what are generally regarded as the facts of our Einsteinian world. Furthermore, our conclusions will not depend on the debate over eternalism or the findings of differential geometers.

We are well aware that not everyone accepts (i) and (ii). Around the time Einstein developed special relativity, various scientists investigated various non-relativistic alternatives, particularly an æther compensatory theory.

[2] Those who defend perdurantism in this way include W.V.O. Quine, 'Identity, Ostension, and Hypostasis', *Journal of Philosophy*, 47 (1950), pp. 621–32; D.M. Armstrong, 'Identity through Time', in P. van Inwagen (ed.), *Time and Cause* (Dordrecht: Reidel, 1980), pp. 67–78; M. Heller, *The Ontology of Physical Objects* (Cambridge UP, 1990); T. Sider, *Four-Dimensionalism* (Oxford UP, 2001). *A priori* defenders of endurantism include R. Chisholm, *Person and Object* (La Salle: Open Court, 1976); J.J. Thomson, 'Parthood and Identity across Time', *Journal of Philosophy*, 80 (1983), pp. 201–19; J. Van Cleve, 'Mereological Essentialism, Mereological Conjunctivism, and Identity through Time', in P. French *et al.* (eds), *Midwest Studies in Philosophy*, Vol. XI (Univ. of Minnesota Press, 1986), pp. 141–56; P. van Inwagen, 'Four-Dimensional Objects', *Noûs*, 24 (1990), pp. 245–55.

Often associated with this view are Henri Poincaré and H.A. Lorentz. However, even they were hardly devoted defenders of the æther. For example, in *La science et l'hypothèse* (1902), Poincaré writes 'We don't care whether the æther really exists ... a day will doubtless come when the æther will be discarded as useless'. Similarly, Lorentz, in his Columbia Lectures of 1906, gives Einstein credit 'for making us see, in the negative result of experiments like those of Michelson, Rayleigh, and Brace, not a fortuitous compensation of opposing effects, but the manifestation of a general and fundamental principle'.[3] This 'fundamental principle' is of course Einstein's principle of relativity, the first premise of special relativity, and accepted as canonical among the vast majority of physicists for the past century. Here we simply register our agreement with, and acceptance of, the established view.

In §II we give a quick sketch of the features of SR relevant to issues of persistence. In §III we canvass the recent literature addressing the relationship of SR to endurance *vs* perdurance, and show that it does not quite get matters right. In §IV we present our own argument that endurantism should be rejected in the light of SR. In §V we offer our conclusion.

II. SPECIAL RELATIVITY AND THE LORENTZ TRANSFORMATION

Special relativity, when it was introduced almost 100 years ago, profoundly changed scientists' understanding of space and time. Without developing the theory and its results in detail, we shall briefly outline those aspects of SR that are fundamental to our argument: the relationship between the temporal and spatial co-ordinates of objects in inertial reference frames in relative motion.

Within a local approximation, at least, the universe is governed by special relativity. The geometry of space-time, as understood within general relativity, is a four-dimensional space-time manifold, curved by the presence of mass. The local approximation is a region of that space small enough to approximate the flat space-time of special relativity. (This is analogous to treating the surface of the earth as if it were flat, a good approximation of human-scale interactions with the earth.) In a world governed by SR, coordinates in different inertial reference frames are related through the Lorentz transformation. The Lorentz transformation falls naturally out of the two fundamental premises of SR, and derivations or demonstrations can

[3] Both these quotations are cited from R. Torretti, *Relativity and Geometry* (New York: Dover, 1983), pp. 86, 85.

be found in any number of introductory texts on special relativity.[4] We shall consider two reference frames in relative motion in a spatial direction which we identify with the x-axis in both frames; the constant relative velocity is v. It is not possible to determine which frame is in motion and which is 'at rest', but both frames agree on their relative velocity. If we take a point in space-time which, in one reference frame, has spatial co-ordinates x, y and z and temporal co-ordinate t, the Lorentz transformation allows us to determine the co-ordinates of that point in the other reference frame. The Lorentz transformation for the space and time co-ordinates of these reference frames can be expressed thus:

$$x = \gamma(x' + \beta(ct'))$$
$$y = y'$$
$$z = z'$$
$$t = \gamma(ct' + \beta x')$$

where the primed co-ordinates are the co-ordinates as measured in the other frame, c is the speed of light, $\beta = (v/c)$, and $\gamma = (1 - \beta^2)^{-\frac{1}{2}}$. ($|\beta|$ is always less than 1, since nothing can move faster than light, and thus γ is always greater than 1. For a relative velocity of approximately $0{\cdot}87c$, $\beta^2 = 0{\cdot}75$, and $\gamma = 2$.) We shall examine a few special cases of these transformations. First, simultaneous measurements of a distance in one frame from the other frame:

$$\Delta x = \gamma \Delta x'.$$

That is, a distance measured in one frame is measured smaller in a frame moving with respect to that frame: length contraction.

Next, time elapsed at a fixed point:

$$(c\Delta t) = \gamma(c\Delta t').$$

In the time it takes a clock in one frame to tick off one second, a clock in a frame moving with respect to that frame will have ticked off less than one second: time dilation.

Finally, events simultaneous, but not coincident, in one reference frame as seen from another:

$$(c\Delta t') = -\beta \Delta x'.$$

The events occur at different times as measured in a frame in relative motion: failure of simultaneity.

It is the failure of simultaneity which is significant for the metaphysics of persistence. It is essential to be clear about this point: the failure of

[4] See, for example, E.F. Taylor and J.A. Wheeler, *Spacetime Physics: Introduction to Special Relativity*, 2nd edn (New York: Freeman, 1992), ch. 3.

simultaneity is not an effect dependent upon an observer, nor is it a function of the delay between an event and light from that event reaching hypothetical observer. There is an intrinsic connection between time and space revealed by the Lorentz transformation, and this intrinsic connection, as we shall show, recommends the rejection of any ontology such as endurantism that fails to accommodate the co-existence of temporal parts.

III. THE CURRENT DEBATE

Despite the recent surge of interest in the implications of SR for perdurantism, no one has come right out and endorsed the thesis which we shall be defending, namely, that the central theses of SR alone serve to undercut endurantism. Both friends and foes of perdurantism tend to argue that whatever support SR offers for perdurantism is either indirect or requires other premises to be adduced along the way.

Michael C. Rea claims that there are 'only two arguments' that lead from SR to perdurantism.[5] One of these is the argument from eternalism:

1. If SR is true, then eternalism is true
2. If eternalism is true, then endurantism is false
3. Therefore if SR is true, endurantism is false.

Eternalists are temporal egalitarians, holding that all times are equally real, with no particular time enjoying ontological privilege. The only thing special about the present time is that it is this time, just as what is special about the present place is that it is here. This is one place among many and one time among many. Opposing eternalism are the presentists, who maintain that all that exists does so at the present time: the present alone is real. This matter is the subject of much current debate. Rea and D.H. Mellor argue that the first premise of the argument from eternalism is true. Trenton Merricks argues that the second premise is true. Rea and Ted Sider reject the second premise, although for somewhat different reasons.[6] We mention this debate only to set it aside: whether eternalism is true or presentism is true is immaterial to the argument we shall present. If Merricks (p. 524) is right that 'presentism entails that there are no perduring, four-dimensional objects', then our results may be taken as an excellent reason for accepting eternalism. As we shall argue, there are four-dimensional objects with

[5] M.C. Rea, 'Temporal Parts Unmotivated', *Philosophical Review*, 107 (1998), pp. 225–60, at p. 226.

[6] Rea, pp. 237–8; D.H. Mellor, *Real Time*, Vol. II (London: Routledge, 1998), pp. 56–7; T. Merricks, 'On the Incompatibility of Enduring and Perduring Entities', *Mind*, 104 (1995), pp. 523–31; Sider, pp. 68–73.

temporal parts, and so Merricks' principle along with *modus tollens* shows that presentism is false. However, our argument for perdurantism will not require eternalism as a lemma.

J.J.C. Smart has defended perdurantism on the basis of SR. He argues that a realist interpretation of SR entails Minkowski space-time as the correct geometry of the world.[7] If the Lorentz transformations determine the co-ordinate transformations and invariants of the universe, then the geometric interpretation of those equations is the four-dimensional manifold of Minkowski space-time. Minkowski space-time was Einstein's own mature view of the geometry implied by SR: 'space and time must be regarded as a four-dimensional continuum that is objectively unresolvable'.[8] Moreover, it is canonical among contemporary physicists that the geometry of the world under SR is Minkowskian. Smart maintains that once one accepts this geometry, then it is natural to understand the extension of bodies in a four-dimensional perdurantist way.

Critics of perdurantism tend to agree with Smart that any road from SR to temporal parts travels through Minkowski space-time. For example, William Lane Craig has recently accepted Smart's implication, while denying his conclusion. Unhappy with perdurantism, Craig takes Smart's reasoning as a *modus tollens*, and so rejects Minkowski space-time, ultimately casting his lot with those trying to resurrect some form of a luminiferous æther.[9] Even Yuri Balashov, who defends perdurantism, suspects that Minkowski space-time is somehow needed to link perdurantism to special relativity.[10] Rea concurs that without Minkowski space-time it is hard to give a relativistic argument for perdurantism. In addition to the argument from eternalism, Rea discusses the so-called argument from spatial analogy, which arises from the geometry of Minkowski space-time. Among the recent critics, Rea has given the most extensive assessment of the implications of SR for perdurantism, and it is worth examining his argument in detail. Here is the argument as he presents it:

1. Space and time are fundamentally alike in nature [we shall call this the similarity thesis]
2. Therefore there is no reason to think that objects relate to time differently from the way in which they relate to space

[7] J.J.C. Smart, 'Space-Time and Individuals', in R. Rudner and I. Scheffler (eds), *Logic and Art: Essays in Honor of Nelson Goodman* (Indianapolis: Bobbs-Merrill, 1972), pp. 3–20, at p. 6.

[8] Einstein, *Relativity: the Special and the General Theory*, 15th edn (New York: Random House, 1952), p. 149.

[9] W.L. Craig, 'Who's Afraid of Absolute Time?', paper read at the APA at Albuquerque, 2000, and *Time and the Metaphysics of Relativity* (Dordrecht: Kluwer, 2001).

[10] Y. Balashov, 'Enduring and Perduring Objects in Minkowski Space-Time', *Philosophical Studies*, 99 (2000), pp. 129–66, at pp. 159–60.

3. Therefore if objects are extended in space by being only partially present at every spatial point at which they exist, then similarly they must be extended in time by being only partially present at every temporal point at which they exist
4. Objects are extended in space by being only partially present at every spatial point at which they exist
5. Therefore endurantism is false.

Although Rea claims that the argument from spatial analogy 'is one of the most popular arguments for perdurantism', he does not cite a single person who defends it. This is just as well, since the argument is highly dubious. Claims (2), (3) and (4) seem to presuppose that space and time are empirically separable but connected by a 'similarity' relation. The spatial analogy argument thus contains an implicit classical Newtonian/Galilean framework in which space and time are separate entities. Perdurantists relying on SR, as we do, would not accept this, since one of the consequences of SR is that space and time cannot be meaningfully prised apart. Rea (p. 227) argues that the only reason to accept the first premise is that 'SR seems to support the following space-time thesis [i.e., Minkowski space-time]: space and time (as we know them) are in fact merely appearances of a more fundamental reality, namely, space-time'. Given this, there are two ways to undermine the first premise: showing that Minkowski space-time is not the correct geometric interpretation of SR, or arguing that Minkowski space-time does not support the similarity thesis anyway. Rea is sympathetic to both approaches.

He is not convinced that SR entails Minkowski space-time, hinting (p. 228, without argument) that space and time might be ontologically basic, and space-time derivative. His scepticism about Minkowski space-time comes from Ferrel Christensen, who canvasses alternative interpretations of SR while not ultimately discarding Minkowski.[11] It is our view that Christensen does not offer persuasive reasons to reject Minkowski space-time as the best geometrical interpretation of SR. However, it is also our view that it does not matter one way or the other; our defence of perdurantism will not rely in any way on an argument from Minkowski space-time. Even the most charitable reading of Christensen will do nothing to undermine perdurantism.

Rea also pursues the second strategy, granting that SR might support Minkowski space-time, although he considers this a 'substantial concession to the perdurantist' (p. 257), and argues that Minkowski space-time does not support the similarity thesis. His argument is simultaneously wrong-headed

[11] F. Christensen, 'Special Relativity and Space-like Time', *British Journal for the Philosophy of Science*, 32 (1981), pp. 37–53.

and insufficiently far-reaching. He offers these interpretations of the similarity thesis (pp. 229–30):

SIM1. Space (as we know it) and time (as we know it) are fundamentally similar in nature
SIM2. Space-time is fundamentally similar to time as we know it
SIM3. Space-time is fundamentally similar to space as we know it
SIM4. Space-time is fundamentally similar in nature to space-time.

The last is an uninteresting tautology, and we set it aside. The problem with the first three versions is not that they fail to follow from Minkowski space-time (which is what Rea argues), but that no right-minded perdurantist would endorse them. 'Space as we know it' seems to be no more than shorthand for the classical three-dimensional conception of space, which like Galilean relativity may have attractions, but has long been overthrown by advances in modern physics. Likewise Rea's 'time as we know it' seems to be no more than 'time as human beings perceive it', or 'the understanding of time we are used to'. Again the classical picture of time as a metric independent of space seems to be presupposed. The lesson of SR is that time and space are not 'as we know them', but are connected in unexpected ways. So Rea's argument against the similarity thesis amounts to this. He asserts that the only reason to believe the similarity thesis is if Minkowski space-time supports it. Then he cashes the similarity thesis in such a way that it presupposes an implicit classical understanding of space and time. Finally he shows that the classical picture does not follow from Minkowski space-time. Far from being a surprising result, this is exactly what we should expect: traditional notions of space and time are not consistent with special relativity.

In one sense Rea is right: the similarity thesis is false, not because of the reason he offers (that Minkowski space-time fails to show the similarity of our classical conceptions of space and time), but because under SR the temporal and spatial dimensions are not strictly analogous. This can be demonstrated geometrically by considering transformations and invariants in two dimensions where both dimensions are space-like, and where one dimension is space-like and one is time-like. In two space-like dimensions, the equivalent of the Lorentz transformation is a rotation in the plane, and the invariant quantity is the distance $x^2 + y^2$. The equation $x^2 + y^2 = constant$ describes a circle in the plane. In a plane with one space-like and one time-like dimension, the space-time interval $x^2 - (ct)^2$ is invariant under the two-dimensional Lorentz transformation, but $x^2 - (ct)^2 = constant$ describes a hyperbola, not a circle. The time-like dimension (at least, one consistent with special relativity) is dramatically different from the space-like dimension: they are not similar at all, and thus no scientifically minded perdurantist would entertain an argument grounded on a hypothetical similarity of spatial and temporal dimensions. Were the argument for perdurantism to depend on the similarity thesis, it would be doomed: Minkowski space-time is not similar either to the classical conception of space or to the classical conception of time. Nevertheless the consequences which SR has for perdurantism do not require interpretations involving the nature of Minkowski space-time.

To sum up the current debate, no one has correctly limned the connection between SR and perdurantism. Endurantists have misconstrued matters rather seriously. They get bogged down in debating either the argument from eternalism or the argument from spatial analogy. The first we have claimed is unnecessary for defending perdurantism on the basis of SR, and the second we have shown to be a bad argument at best, and a straw man at worst. Perdurantists, on the other hand, have maintained that an acceptance of Minkowski space-time naturally leads to perdurantism. While we agree that Minkowski space-time suggests perdurantism, this is an unnecessary argumentative detour. Perdurantism is supported by the Lorentz transformations directly, through the failure of simultaneity to be preserved between inertial frames, without any discussion of the geometry of the universe required.

IV. OUR SOLUTION

As we have noted, accepting that physics is the same in all inertial reference frames, and that the speed of light is a constant, leads to (among other things) the profound realization that simultaneity is not preserved between inertial reference frames in relative motion. Thus if there is an inertial reference frame in which non-coincident events p and q are simultaneous, there will be another inertial reference frame in which p and q are not simultaneous. To show how this undermines endurantism, we need to make clear what endurantism demands. Axiomatic for the endurantist view is the notion that objects are wholly present at each moment of their existence. We can formulate this as a necessary condition for endurantism: something is an enduring object only if it is wholly present at each time in which it exists. An object is wholly present at a time if all of its parts co-exist at that time. Put contrapositively, the principle states that if an object is not wholly present at each time at which it exists (if all its parts do not co-exist at each time at which it exists) then it is not an enduring object. While it is beyond the scope of this article to advance a complete and careful definition of co-existence, it seems clear that the following properties of co-existence can be accepted. First, simultaneity is sufficient for co-existence: if two things exist at the same time, they co-exist. Secondly, co-existence is transitive: if p and q co-exist, and q and r co-exist, then p and r co-exist.[12] Let A_1 and B_1 represent two proper parts of an object in that object's rest frame at time t_1, and let them be simultaneous but not coincident. Let A_2 and B_2 represent those proper parts simultaneous in their rest frame at a different time t_2. In the rest frame of the object, A_1 and B_1 co-exist, and A_2 and B_2 co-exist. We can construct another inertial reference frame, moving with respect to the rest frame of the object, such that the proper parts of the object that are simultaneous are A_1 and B_2. In our example, A_1 and B_1 co-exist as measured in one frame, and A_1 and B_2 co-exist as measured in the other; thus B_1 and B_2 must also co-exist.

This seems to drive a stake through the heart of presentism: if t_1 is now, and t_2 is not now, that things at 'not now' can co-exist with things at 'now' seems to indicate that things at other times are certainly real.[13] But it poses just as serious a problem for the endurantist. If B_1 and B_2 co-exist, then the object composed of parts A and B is not wholly present at t_1: it has a part B_2 present at t_2, just as real as B_1 at t_1. Furthermore, the object as seen from the reference frame in relative motion is composed of A_1 and B_2 – that is, A at t_1 and B at t_2. The object does not have all of its parts present at one time. Of course, one might argue that A at t_1 and B at t_2 are simultaneous (at one time) according to clocks in the moving frame – but if we want to index the times of A and B by the times in the moving frame, then the object will be composed of parts at different times as viewed from its rest frame. There is an inertial reference frame – there are many, many frames – in which the object is composed of co-existing parts at different times.

In order to make this more concrete (and, we hope, clearer) we present a simple thought-experiment involving a relativistic train. Then we shall address how a committed endurantist could make an attempt to accommodate special relativity. The following example includes talk of observers and timepieces, but these are purely heuristic devices that are not essential in any way to SR or the defence of perdurantism. When we write about 'what Sally sees' or 'what Dave sees', we are simply using a semantic shorthand to refer to how an object exists in relation to Sally's or to Dave's frame of reference. Furthermore, similar examples can be given for any spatially extended physical object and any speed: the underlying reasoning is completely general.

[12] It is natural and common to assume that co-existence is transitive. For example, Hilary Putnam, 'Time and Physical Geometry', *Journal of Philosophy*, 44 (1967), pp. 240–7, and Howard Stein, 'On Einstein–Minkowski Space-Time', *Journal of Philosophy*, 45 (1968), pp. 5–23, at pp. 18–19, disagree with each other about related matters, but both accept the principle.

[13] Putnam gives a similar argument. His 'relation R' is our co-existence relation.

Imagine Dave, travelling on a new ultra-high-speed train. With respect to the tracks, this train travels at a substantial fraction of the speed of light: it is relativistic. Dave is seated at the midpoint of the train, which has clocks at either end, and he has synchronized his watch to the train's clocks. Two terrorists have also boarded the train, one at either end of it. They have also synchronized their clocks to those of the train, but their clocks are timing mechanisms on bombs, both set to go off at exactly noon.

At 12:00 train time, while the train is passing a station (without stopping), the bombs go off, and the front and rear of the train are damaged. The designers, prepared for every contingency, have engineered the train so well that the bombs do not destroy the undercarriage, and it continues on its way, albeit the worse for wear, without slowing down. While an example involving bombs and terrorists may seem insensitive, it has the particular virtue of making very distinct the parts of the train at times before 12:00 train time (unexploded), at 12:00 (the explosion has been triggered), and at times after 12:00 (the front and rear of the train are burnt and shattered hulks).

At 12:00 on the train, according to Dave, who is in the rest frame of the train, the wrecked front and rear of the train are yet to come in the train's future. The whole and undamaged train is in the train's past. The instant of the explosion is in the present, is *now*. Dave's version of events is consistent with a three-dimensional, endurantist description of the universe. The train exists wholly in the now, it used to exist wholly in the past, and it will exist wholly in the future ('wholly' allowing for bomb damage); that is, it endures, as best it can, through time, so it appears to Dave.

Standing on the station platform is Sally. Sally watches Dave's train race by. What exactly does she see? She sees Dave's train, the whole of it, though she would measure it as shortened because of the relativistic Lorentz contraction of the length. Were she able to observe in motion the second-hand of a clock in Dave's train, she would notice that it was taking an unusually long time to move around the face of the clock. She happens to be directly across the platform from Dave when his watch registers 12:00, and sees him, his face not yet registering his surprise at the bombs which are just going off. What does Sally see at the front and the rear of the train? ('What Sally sees' is a convenient shorthand for what parts of the train are simultaneous with her in *her* reference frame.)

While it is certainly true that Sally would say she is seeing a whole train at one time (her time), she sees the front of the train intact and undamaged, in other words, what Dave at noon considers the train's past. At the rear of the train, she sees the aftermath of the explosion, the train blackened and twisted, that is, the future of the train from Dave's point of view. To be explicit, if the train had a length of L in its rest frame, it would have a length of L/γ in Sally's reference frame. The clock in the front of the train would show 12:00 + $\delta t/2$, and the clock at the rear would show 12:00 – $\delta t/2$, where $\delta t = -\gamma vL/c^2$ (because v is in the positive x-direction, $\delta t < 0$, and thus the clock at the front of the train is showing slightly *before* noon, while the clock at the rear of the train is showing slightly *after* noon).

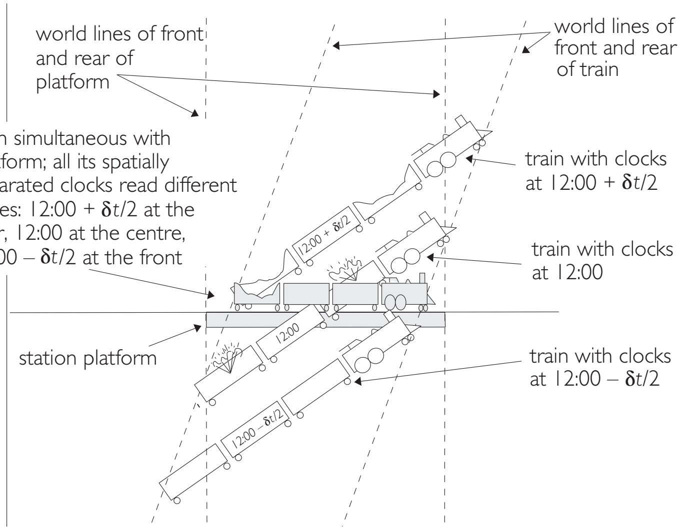
Sally plainly sees what anyone sharing a Newtonian three-dimensional notion of time and space would agree corresponds to the past, present and future of different parts of the train. She sees a whole train, one which, using endurantist language, does not wholly exist at one time; proper parts of the train exist at different times (the rear of the train exists in the future of the front of the train). To restate this and highlight the point, Dave at his noon co-exists with Sally waiting on the platform. Dave at his noon co-exists with the front and rear of the train at the instant the bombs are set off. Sally co-exists with the unexploded front of the train and the exploded rear of the train. Thus the unexploded front of the train co-exists with the front of the train at the moment of the explosion, and the exploded rear of the train co-exists with the rear of the train at the moment of explosion. Clearly the train does not exist 'all at one time', and so endurantism, at least as we have expressed it so far, is inconsistent with a relativistic world.

In a nutshell, here is our argument against endurantism.

1. Endurantism is defined in this way: *o* is an enduring object iff *o* wholly exists at each moment of its existence. That is, at every time *t* at which *o* exists, every proper part of *o* is at *t* — definition
2. If SR is correct, then in the rest frame of an object *o*, each proper part of *o* is at a specific time *t*, and that time is the same for all parts. But for an inertial reference frame moving with respect to an object *o*, each proper part of *o* at a different position along the direction of relative motion is at a different time. That is, in a frame moving relative to *o*, *o* has proper parts at *t*, before *t* and after *t* — premise
3. SR is correct — premise
4. Thus if there is a reference frame moving with respect to an object *o*, then in that frame *o* has proper parts at *t*, before *t* and after *t* — from 2, 3
5. The universe is not static, and so for any object there are inertial frames other than the rest frame — premise
6. Thus every object has proper parts at different times — from 4, 5
7. Hence no object wholly exists at each moment of its existence, and endurantism as defined in (1) is false. — from 1, 6

Premise (1) is a definition, and so there is little to argue about here. We have spent the bulk of this section defending premise (2), and we have used the example of the train to illustrate the spatiotemporal spread of parts under special relativity. Premise (3) has been a cornerstone of physics for a century, and we are assuming it here without argument. (SR has, in a sense, been superseded by general relativity. However, in a 'local approximation' where the curvature of space is negligible over the range of space-time being considered, GR is approximated by SR. Our argument is based on the empirically realizable failure of simultaneity, and adding the theoretical complications of GR does not affect this result under these circumstances.) Premise (5) states that things move, a claim which we doubt anyone would seriously deny. Everything else is a logical consequence of those premises.

No aspect of the relativistic train poses a problem for the perdurantist's view of objects. From a perdurantist perspective, Sally sees one set of temporal parts of the train, and Dave sees a different set of temporal parts – a different time-slice, as it were. In fact, the notion of a time-slice is particularly apt. Dave in the train's rest-frame sees a time-slice of his object that



is perpendicular to the time axis (that is, all at one time). Sally, in a frame in motion with respect to the train, sees an oblique time-slice of the train (a slice which ranges in time from $-\delta t/2$ to $+\delta t/2$), and, for the same reason, a contracted train length. This is illustrated schematically in the accompanying diagram, which shows from the reference-frame of the platform the world lines of the train and the platform. Indicated are (a) the train simultaneous with Dave, at three times, before, at the moment of and after the explosion; and (b) the train simultaneous with Sally, when Dave (at noon on his clock) is directly across the platform from her. Perdurantism has a natural and beautiful fit with the facts of special relativity: Dave and Sally can both speak of the train; both agree on what it is and what its history was; they disagree only on questions of simultaneity.

Endurantism has a much more difficult time handling the failure of simultaneity entailed by modern physics. It is possible to develop an ontology based upon endurance that is consistent with SR, though it proves unwieldy in the extreme. One can identify 'the train' as those train-like spatio-temporal parts (of some hyperobject) which are simultaneous in a particular reference-frame, at a particular time. Thus for Dave at noon, the train consists of those train parts simultaneous with Dave at 12:00 in their shared rest-frame. For Dave before noon, the train consists of the unexploded train parts simultaneous with Dave, and after noon, of the exploded and unexploded parts simultaneous with him then. For Sally, the train consists of the parts, no matter at what time they appear in the train's rest-frame, that are simultaneous with her. In a world in which there were no relativistic effects, or in which we observed no macroscopic relativistic effects, such a view of persistence would not impose any particular hardships. However, where relativistic effects *can* be measured, this frame-relative view of persistence means that an expression such as 'Can you see the train?' must carry with it the implicit baggage of 'at such and such a time, at such and such a relative velocity'. The endurantist must account not only for time (since we cannot be assured that only the parts 'now' exist), but also for the particular inertial reference-frame that includes the vantage point.

Perhaps even worse, endurance under SR leads to a profligate multiplicity of trains which is metaphysically unsettling. One would naturally think that the train that Sally sees is the same train as Dave is travelling on – after all, she sees him on the train. However, if one is to preserve endurance in a relativistic world, the train that Sally sees Dave riding in cannot be the same train as the one Dave thinks he is riding in. If the two trains are the same, then the train does not have all its parts at one time: endurance fails. Therefore the composition of objects for an endurantist must be radically frame-relative. The endurantist view that all the parts of an object are 'at one time' is, under SR, sensible only as 'simultaneous in a particular inertial reference-frame'. In fact, besides the train Dave thinks he is riding in and the train Sally thinks Dave is riding in, every inertial reference-frame with a different relative velocity will have a different set of simultaneous train-parts – a different train. There will be as many trains as there are inertial reference-frames at different relative velocities. With an infinite range of possible relative velocities, there are an infinite number of reference-frames and so an infinite number of trains. Endurantism can thus accommodate SR, but rather in the same fashion as Ptolemaeic astronomy can account for planetary motion – through an ever more complex series of epicycles. While we acknowledge that such a frame-relative endurance is consistent with SR, it seems a burdensome price to pay, when the alternative, perdurance, has none of these defects. For perdurantism, there is one train with parts at different times, and the set of temporal parts with which one is simultaneous depends upon one's reference-frame.

V. CONCLUSION

Einstein's theory of special relativity shook the philosophical world. It was once thought to be true *a priori* that Euclidean geometry correctly describes our universe. SR showed that the geometry of the universe is an empirical matter: not *a priori*, and, incidentally, connected with time in a way Euclid never imagined. Newton and Leibniz skirmished over the merits of an absolute *vs* a relative conception of space, each wielding the weapons of pure reason. Again SR settled the issue empirically. In the case of temporal parts too, armchair philosophy must give way before the physical facts of our world. As Josh Parsons writes, 'it is an empirical matter whether any given object has spatial parts [and] we should likewise think it an empirical matter whether any given object has temporal parts'.[14] An ontology of enduring objects with all their parts in the 'now' is outmoded and bizarre, given a universe in which physics does not change in different inertial reference-frames and the speed of light is a constant.

Our argument depends on nothing that is scientifically controversial. We assume only that that the speed of light in a vacuum is a constant, and that to preserve this fact, distances and times must transform according to the Lorentz transformation between frames in relative motion. The Lorentz transformation is not like the Copenhagen interpretation in quantum mechanics, a way of leaping from theoretical states to real objects: it is essentially no more than the Pythagorean theorem revised to account for the way in which time and space behave under special relativity. For reference-frames in relative motion, the Lorentz transformation reveals the intrinsic connection between spatial and temporal extension: a displacement in space is coupled with a displacement in time when measured outside the rest-frame. Thus objects do not exist wholly at one time; they do not endure. Furthermore, as our result depends only on the failure of simultaneity as shown

[14] J. Parsons, 'Must a Four-Dimensionalist Believe in Temporal Parts?', *Monist*, 83 (2000), pp. 399–418, at p. 415.

through the Lorentz contraction, it does not depend on the interpretations of differential geometers, and it will survive any further advances, such as general relativity, which change some features of the theory under certain conditions without restoring a frame-independent simultaneity.

It is true that endurantism, like Newtonian physics, will appear to be correct much of the time, since we move slowly (in relation to light), and relativistic effects are not readily apparent. The same is true of a Galilean relativity in which simultaneity is preserved. These theories are close to the truth as people perceive it, and therefore have a powerful pull. Nevertheless neither is correct, and they must be rejected as no more than approximate descriptions of reality. It would be misguided to argue that since relativistic effects are negligible at human speeds, we are free to disregard them in order to keep endurantism. Spatial and temporal distances are coupled at any speed; this effect only becomes measurable by human beings as the relative speed approaches the speed of light. But our predilection for slow-moving middle-sized dry goods is not a licence for philosophy to pretend that such things are all we need consider. When physicists describe the interaction between a proton and an electron, they do not include the gravitational force, since it is too small to be significant when compared to the electromagnetic force between them. However, this does not mean that protons and electrons do not exert a gravitational pull: it is their combined might that keeps us on the Earth's surface. Just as the best account of the world must acknowledge the gravitational pull of protons even under conditions in which it is pragmatically ignored, so too the best account of the world should accept that physical objects perdure, even when this can be pragmatically ignored. In short, it is a truism that science often shows naïve empirical thinking to be misguided. As Smart writes, 'It is quite possible that we have been programmed by natural selection to a false but useful way of perceiving the world, and that it is only in our studies, when we read Minkowski, and so on, that we can overcome this sort of original sin' (p. 19).

Where our prejudices about the persistence of objects diverge from a four-dimensional perdurantist ontology consistent with SR, they should be abandoned.[15]

Bloomsburg University, Pennsylvania
Rudolph Technologies Inc., New Jersey

[15] Thanks to an audience at Virginia Tech for their encouragement after hearing an earlier version of this paper.