The Transient *nows*

In his "Intellectual Autobiography" the philosopher Rudolf Carnap (1963, 37) described a conversation he had with Albert Einstein at the Institute for Advanced Study in the early 1950's:

> Once Einstein said that the problem of the Now worried him seriously. He explained that the experience of the Now means something special for man, something essentially different from the past and the future, but that this important difference does not and cannot occur within physics. That this experience cannot be grasped by science seemed to him a matter of painful but inevitable resignation.

Other distinguished scientists have had similar qualms. Hermann Weyl (1949, 116) wrote:

> The objective world simply is, it does not happen. Only to the gaze of my consciousness, crawling upward along the life line of my body, does a section of this world come to life as a fleeting image in space which continuously changes in time.

Weyl is taken to be claiming that the "objective world" lacks passage, temporal becoming, or transience, a phenomenon that is merely subjective. P. C. W. Davies (1974, 1977, 21) endorses this view forthrightly:

> The four dimensional space-time of physics makes no provision whatever for either a 'present moment' or a 'movement' of time…. Rather than thinking in terms of a succession of experiences by a particular particle, we must instead deal with its entire world line in four dimensions; in the words of H. Weyl 'the objective world simply *is*, it does not *happen*.'

Finally Carlo Rovelli wrote, "[T]he notion of *present*, of the 'now', is completely absent from the description of the world in physical terms." (Rovelli, 1995) What Rovelli means by this claim is that Minkowski geometry can be formulated in an affine space, as opposed to a (real) vector space, and of course this claim is correct but may not settle the philosophical issue. Does if follow from this claim, *so understood*, that the notion of the present is "completely absent from the description of the world in physical terms"?

These views, expressed by distinguished scientists, are philosophical views and so open to philosophical examination. What I hope to do in this paper is show that there is a viable alternative picture to these views, a picture that includes, in some sense, a *now* and the passage of time. I cannot, like Einstein, talk about what can be grasped by 'science' or by 'physics'. I hope I can talk, coherently and persuasively and philosophically, about one small bit of physics, the special theory of relativity, and the treatment of time in Minkowski spacetime.

I. Closing the Circle

It is useful to begin with Carnap's response (1963, 37-8) to Einstein's problems with the Now:

> I remarked that all that occurs objectively can be described in science; on the one hand the temporal sequence of events is described in physics; and, on the other hand, the peculiarities of man's experience with respect to time,

> including his different attitude towards past, present, and future, can be described and (in principle) explained in psychology. But Einstein thought that these scientific descriptions cannot possibly satisfy our human needs…. I definitely had the impression that Einstein's thinking on this point involved a lack of distinction between experience and knowledge. Since science in principle can say all that can be said, there is no unanswerable question left. But though there is no theoretical question left, there is still the common human emotional experience, which is sometimes disturbing for special psychological reasons.

Carnap was the quintessential anti-metaphysician, and it is very tempting, for those of us who are similarly inclined, to agree with the sentiment that after all that Carnap says can be objectively described is described ("the temporal sequence of events" on the one hand, and "the peculiarities of man's experience with respect to time" on the other), then there is nothing left to be said. What I have been led to see by reading Abner Shimony is that there *is* something important left out, something left to be said. What is left out is an account of the relation between these two.

That, at least, is my way of construing the implications of his program of "closing the circle", a way of doing philosophy (or, at least, metaphysics and epistemology) that Shimony traces back to Aristotle and that lets him, in his version of it, stake out a position in opposition to the later Putnam and van Fraassen in the battle over realism. Here's his capsule description (Shimony, 1993, 40):

> The program [of closing the circle] envisages the identification of the knowing subject (or, more generally, the experiencing subject) with a natural system that interacts with other natural systems. In other words, the program regards the first person and an appropriate third person as the same entity. From the subjective standpoint the knowing subject is at the center of the cognitive universe, and from the objective

> standpoint it is an unimportant system in a corner of the universe.

This program guides his discussion of realism. I suggest that the program can be adapted to the philosophy of time as well, in the form of the following slogan: *Philosophy of time should aim at an integrated picture of the experiencing subject with its felt time in an experienced universe with its spatiotemporal structure*. This rationale underlies and shapes the picture of time in Minkowski spacetime that I will sketch in the rest of this paper.[1]

Shimony's summary statement of the nature of closing the circle is followed by a particularly elegant diagnosis of what goes wrong in an unbalanced discussion:

> If either the subjective or the objective aspect of the knowing subject is played down, or if the substantial identity of their two aspects is neglected, then the problem… is flattened, or—to use quasimathematical language—it is projected into a subspace of smaller dimensionality than it deserves. (Shimony, 1993, 40)

This last remark exactly captures my feeling as to what is wrong with contemporary discussions of time. Many analytic philosophers concentrate single-mindedly on the subjective side of time and find

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[1] I would be remiss, however, if I did not mention that my views are everywhere shaped by those of two additional thinkers. The first is Howard Stein, a friend of Shimony's, whose papers on time in relativity theory are beacons of light in dark waters, and C. D. Broad, a British philosopher of the generation before them.

I am also indebted to Richard Arthur, Craig Callender, Carl Hoefer, and Wayne Myrvold for helpful discussions and suggestions as the paper evolved. Arthur was a pioneer in directing attention to what I now call Alexandroff presents. In addition, I have received individual support from the Social Sciences and Humanities Research Council, but participation in the TaU cluster, which SSHRC supports, has provided valuable opportunities to engage with others on the topics of this paper.

nothing more to it than the Now. Others, like the three scientists I quoted at the beginning of this talk, look first to the spacetime of physics and cannot find a Now at all. I think we will only begin to do justice to time (and all I can hope to do here is to begin to do justice to it) if we look at *both* sides *and* at the hitherto missing connection between them—if, that is, we try to close the circle.

II. What Transience is Not

The first step towards finding relativistic notions of the Now and transience (the passage, flow, or lapsing of time) must be elucidation of the classical notions. The classical Now is straightforward and not controversial. A classical Now is a global hypersurface of simultaneous events. Any given event, if idealized as having no duration, is contained in precisely one such global hypersurface, its Now. These global hypersurfaces foliate spacetime into equivalence classes that are mutually exclusive but exhaustive Nows.

Transience is the successive occurrence of these global hypersurfaces. As Kurt Gödel (1949, 558) put it succinctly:

> The existence of an objective lapse of time… means (or, at least, is equivalent to the fact) that reality consists of an infinity of layers of "now" which come into existence successively.

If the "objective" lapsing of time requires frame- or observer-independent hyperplanes of simultaneity, then Gödel is right that there is no lapsing of time in Minkowski spacetime.

Gödel then presents the well-known argument that this global version of transience runs into insurmountable difficulties if transferred to a special relativistic setting:

> But, if simultaneity is something relative in the sense just explained,[2] 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 systems of layers can claim the prerogative of representing the objective lapse of time. (Ibid.)

There is a variant of this argument that appears in recent paper by Dennis Dieks that I find very suggestive. Dieks argues (1) that the experiences of observers are of such short duration and occupy such a small amount of space that they can, without loss, be idealized as point-like, (2) amongst these experiences are those that convince us that time flows or passes, and (3) given the upper limit of speed of propagation of causal signals, so that no event spacelike separated from a given event can influence it causally, it follows that (4) the human experiences that suggest at any event *e* in the history of an observer that time flows are invariant under different choices of global hypersurface containing *e*. (Dieks, 2006, §1)

The moral I draw from Dieks' argument is, at this point, conditional. *If* there is such a thing in special relativity theory as the

[2] "The very starting point of special relativity theory consists in the discovery of a new and very astonishing property of time, namely the relativity of simultaneity, which to a large extent implies that of succession. The assertion that the events *A* and *B* are simultaneous (and, for a large class of pairs of events, also the assertion that *A* happened before *B*) loses its objective meaning, in so far as another observer, with the same claim to correctness, can assert that *A* and *B* are not simultaneous (or that *B* happened before *A*)." (Gödel, 1949, 557)

passage of time and *if* it is to relate to the experiences of creatures like us in spacetime, then global hypersurfaces are irrelevant to it. This conclusion is deeply shocking to common sense metaphysics, since global Nows permeate pre-relativistic thinking about time. It is difficult to think about time without them, yet David Mermin has reminded us recently that special relativity is a radical theory (2005, xii). "That no inherent meaning can be assigned to the simultaneity of distant events is the single most important lesson to be learned from relativity." Time, we must learn, is *not* spread through space.

So far my argument is conditional and negative. If there is such a thing as transience countenanced in Minkowski spacetime, it won't be the successive occurrence of global hypersurfaces. Transience, if such there be, would have to a local rather than a global notion. But is there such a thing, relativistically, as transience? It is time, I submit, to turn to poetry.

III. Time goes, you say?

Consider the following clever couplet from Henry Austin Dobson (1905):

> Time goes, you say? Ah no!
> Alas, Time stays, *we* go…

I hope that you have the same two-fold reaction to this verse that I do. First, one's attention is drawn from the transience of time to the transience of self, as Dobson intended. But then I hope you ask yourself, "Is there really a difference here? Isn't this a cheat, some poetical slight-of-hand or misdirection?"

I think it is. I believe that there is no difference between our going and time's going, no difference (that is) between ordered events or objects moving in or through time and time's moving along or by ordered but static events or objects, no difference (that is, again) between on the one hand future events "approaching" us, becoming present, and then "receding" from us into the past or, on the other hand, our leaving the past ever further behind as we "move" into the future. The "motion" is relative to whichever of the two, time or objects, one chooses to think of as "static", and one may choose either.

I do not think that it useful to try to understand the passage of time as a kind of motion, since motion has to be understood as change of position through time. Nevertheless, I think the point of the previous paragraph is general. *If* there is a way to make sense of the passage of time (and it is a notoriously difficult idea to make sense of in any terms), then in whatever terms prove successful there will be only a verbal difference between (on the one hand) speaking of time's passing or "going" and our remaining still and (on the other hand) speaking of our going or progressing through a "static" time.

This point may seem innocuous, but when combined with the idea of the last section that special relativity constrains one to construe transience locally rather than globally, the resulting point of view is anything but commonplace. Let us reconsider in this new light, for instance, the supposedly anti-passage remark of Weyl cited earlier in the paper:

> The objective world simply is, it does not happen. Only to the gaze of my consciousness, *crawling upward along the life line of my body,* [emphasis added] does a section of this world come to life as a fleeting image in space which continuously changes in time.

Is there a difference between my consciousness "crawling" along my world line (on the one hand), as opposed to my consciousness being static but time itself "passing" along my world line? If not (as we have agreed), then Weyl cannot simply be read as a partisan of a static universe, as Davies does. Weyl can also be read as a proponent of the local passage of time.

Perhaps I am taking advantage of an unfortunate turn of phrase to misconstrue Weyl. Perhaps. But note that in one other famous remark of Weyl's on time the same phrasing recurs.

> However deep the chasm may be that separates the intuitive nature of space from that of time in our experience, nothing of this qualitative difference enters into the objective world which physics endeavours to crystallize out of direct experience. It is a four-dimensional continuum which is neither "time" nor "space". Only the consciousness *that passes on in one portion of this world* [emphasis added] experiences the detached piece which comes to meet it and passes behind it, as history, that is, as a process that is going forward in time and takes place in space. (1921, 1952, 217)

Suppose, then, that Weyl can be read as backhandedly legitimizing the local passage of time. Is there a local structure that can support such a notion of transience? If the program of closing the circle is to be our guide and if that program starts with the experiencing subject, then we must immediately note that this subject, as a physical system in spacetime, is represented by a timelike curve. The program of closing the circle suggests, then, that we look to timelike curves. If classical transience is the successive occurrence of global Nows, perhaps special relativistic transience is the successive occurrence of local *nows* along a timelike curve. But what can a local *now* be?

IV Interlude

Before proceeding further, it will be useful to be a bit more explicit about a few matters. For instance, I will consider *the special theory of relativity* to be the theory developed in the early chapters, especially chapters 4 and 5, of Hartle (2003).[3] The setting of the theory is a four-dimensional real vector space, $\mathbb{R}^4$, along with a metric to endow it with geometric structure. We can indicate points in $\mathbb{R}^4$ by using four coordinates, suggestively labeled (t,x,y,z), and we can define a spacetime "distance" function on pairs of points (t^0,x^0,y^0,z^0) and (t^1,x^1,y^1,z^1) in $\mathbb{R}^4$ as

$$(\Delta S)^2 = -(\Delta t)^2 + (\Delta x)^2 + (\Delta y)^2 + (\Delta z)^2, \qquad (1)$$

where $\Delta t = t^1 - t^0$, etc. Hartle shows that, given the Principle of Relativity ("Identical experiments carried out in different inertial frames give identical results."), the quantity $(\Delta S)^2$ does not change when one switches from the coordinates of one inertial frame to those of another. Since the directed line segment from (t^0,x^0,y^0,z^0) to (t^1,x^1,y^1,z^1) is a vector, one can use the invariant quantity of spacetime distance to divide vectors at (t^0,x^0,y^0,z^0) (or any other point in the spacetime, for that matter) into three kinds:

1. those for which $\Delta S^2 > 0$, the *spacelike* vectors,

[3] In some places I will appeal to Naber (1988) for mathematical notions that do not appear in Hartle's presentation

2. those for which $\Delta S^2 = 0$, the *null* vectors, and
3. those for which $\Delta S^2 < 0$, the *timelike* vectors.

Equation (1) is often written in the infinitesimal form:

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

When discussing timelike vectors and time, it is convenient to multiply equation (2) by −1, in order to change the negative quantities. The result is written

$$d\tau^2 = dt^2 - dx^2 - dy^2 - dz^2. \qquad (3)$$

The quantity 'τ' is known as *proper time*.

We will call the set $\mathbb{R}^4$ with a (Lorentz) metric like (2) *Minkowski spacetime*, $\mathcal{M}$. If we choose a point $p \in \mathcal{M}$, the set of points whose spacetime distance from p = 0 comprise the (exterior of) the *null cone* at *p*. A curve through a set of points that is inside the null cone of any point that it goes through is a *timelike curve*. The histories or careers of ordinary objects (like us), whose rest mass is greater than 0, are to be represented by timelike curves (world lines) in $\mathcal{M}$.

Timelike curves or world lines can be parameterized by proper time, τ. We can define proper time lengths between two points *A* and *B* on a timelike line, τ_{AB} as:

$$\tau_{AB} = \int_A^B d\tau = \int_A^B [dt^2 - (dx^2 + dy^2 + dz^2)]^{1/2}. \qquad (4)$$

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

$$\tau_A = \tau_{0A} \qquad (5)$$

From (4) one can easily derive a useful relation between proper time τ and coordinate time *t:*

$$\tau_{AB} = \int_{\tau_A}^{\tau_B} dt[1 - \vec{V}^{\,2}(t)]^{1/2}, \tag{6}$$

where $\vec{V}$ is a three-dimensional velocity vector.

In order to do physics properly and relativistically in $\mathcal{M}$ we must have four-dimensional quantities or *four-vectors*. For instance, the four-velocity **u** of a moving object is:

$$\boldsymbol{u} = (dt/d\tau, dx/d\tau, dy/d\tau, dz/d\tau), \tag{7}$$

where boldface type is used to distinguish four-vectors. One can then go on to define four-acceleration and the relativistic analogs of Newton's laws in order to do special relativistic dynamics.

It will be useful to note here one further fact. Suppose that we write

$$\mathbf{u}\cdot\mathbf{u} = -\frac{dt^2}{d\tau^2} + \frac{dx^2}{d\tau^2} + \frac{dy^2}{d\tau^2} + \frac{dz^2}{d\tau^2} = \frac{ds^2}{d\tau^2} = -1. \tag{8}$$

Then we see that, for any massive particle or object, its velocity four-vector is a timelike vector of unit length, since the length of a timelike four-vector is $\sqrt{-\boldsymbol{u}\bullet\boldsymbol{u}}$. Since speed is the length of the velocity vector, we have the odd result that all massive objects have the same speed in spacetime, 1.

V. Now, *now*

To return to the main line of argument, we now know what a timelike line is. In addition, in my characterization of transience as the *successive* occurrence of events on a timelike world line, I am supposing that we know what it means for one event to occur *after* another. I am, therefore, supposing not only that our timelike curves occur in a temporally orientable manifold, but also that one of the orientations has been chosen as future (and the other as past). I do not know how this orientation is selected. Perhaps the choice is based on some asymmetry amongst the fundamental laws of physics, but that is a (deep) problem for another day. I will assume that an orientation is given.[4]

Recall the way I understand "closing the circle" in thinking about time:

> Philosophy of time should aim at an integrated picture of the experiencing subject with its felt time in an experienced universe with its spatiotemporal structure.

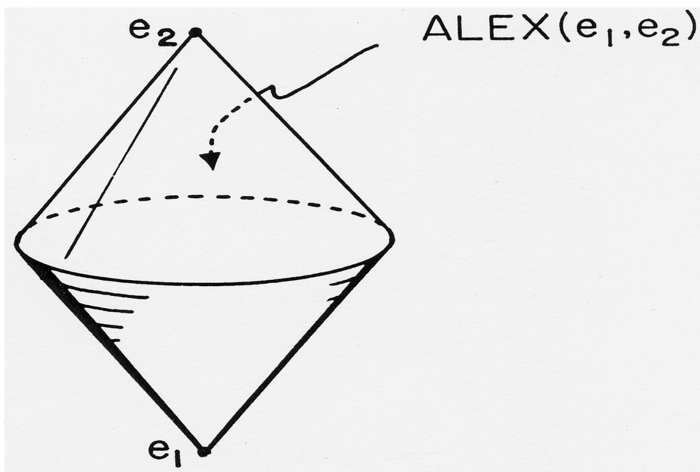
If we begin with the experiencing subject, we notice that its present is not point-like; it is extended. We experience the whole of a spoken sentence or a musical phrase, for example, as occurring now.

This phenomenon has traditionally been referred to as *the specious present*, but has recently come to be called *the psychological present*. The temporal extent of this temporally extended present no doubt varies both inter- and intra-personally. An eminent psychologist has told me that the *specious* or *psychological* present is variously

[4] Tim Maudlin (2002) defends passage in Minkowski spacetime, but he takes the notion as basic or primitive and uses it to select an orientation as future.

estimated to last from .5 to 3 seconds, and I will fix on a middling value of 1 second for the sake of convenience in this discussion.[5] Extending the present opens up new possibilities, as we shall see.[6]

Suppose that we parameterize the timelike curves in Minkowski spacetime $\mathcal{M}$ with proper time (as characterized in the preceding section). Suppose also that we choose two events, e_1 and e_2 (with e_1 earlier than e_2) that are one second apart on a timelike curve, λ. Call the set of events in the intersection of the interior of the future light cone of e_1 with the interior of the past light cone of e_2 *ALEX*(e_1, e_2).[7] Here is a picture of this set of events, taken from Winnie (1997, 156).



I propose that ALEX(e_1, e_2) is *the present for the interval from* e_1 *to* e_2 *along* λ*.* If the passage of time or transience pre-relativistically

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[5] There is a recent account of the specious present in Dainton (2001, chapter 7). This chapter contains useful references, but I think that the account of the specious present in chapter 35 of Broad (1938) is not adequately represented.

[6] I would like to emphasize from the outset that considering an extended present makes neither the present, as I characterize it below, nor the passage of time subjective. Once τ_{AB} is fixed, the present for such an interval is an invariant open subset of Minkowski spacetime.

[7] These open sets are elements of the Alexandroff topology for $\mathcal{M}$ discussed in Winnie (1977, §3). Winnie calls them *Alexandroff intervals*, and I will call them *Alexandroff presents*.

is a succession of world-instants or Nows, then its relativistic successor concept must be the succession of presents (in the sense of $ALEX(e_1,e_2)$) along a timelike curve λ.

I would like to point out three advantages of this proposal. The first advantage applies not just in Minkowski spacetime but in any general relativistic spacetime that is *stably causal*—i.e., one that admits a global time function $t: M \to \mathcal{R}$, which in turn means that for all distinct events $p, q \in M$, if $p << q$ (that is, if there is a smooth, future-directed timelike curve from p to q), then $t(p) < t(q)$. In such a spacetime if $e' \in ALEX(e_1, e_2)$, then $t(e_1) < t(e') < t(e_2)$. If one defines a present or *now* based on an interval $[e_1, e_2]$, then one surely would want it to meet this condition.

One reasonable demand on a scientific successor concept to a previous scientific concept or even to a folk concept is that it explain why the earlier concept is as useful or salient as it is. The explanation on offer for our commonsense or Newtonian notion of the present as the universe-at-an-instant is inspired by section V of Stein, 1991. He there observes that in a psychological present "light travels a spatial distance that bears a very large ratio to the spatial extent of our bodies or of ordinary objects." (p. 161) In one second, for instance, light travels in *vacuo* about 300,000 km, meaning that $ALEX(e_1,e_2)$, with the small proper time duration of 1 second, is 300,000 km across at its widest. In the course of human conceptual development, it would be no more surprising that we developed the idea that this brief, fat structure was unbounded than that we developed the idea that the surface of the earth was flat.

Nor is it surprising that we developed the idea that we share a common present. Suppose that you walk past me at a reasonable pace of 4 km/hour, that we call our meeting e, and that we compare the volumes of your present and my present, assuming they are symmetric about e (that is, each present extends .5 seconds to the future and to the past along our two world lines. Then our two presents agree—that is, include the same events—up to about one half of one millionth of one percent ($\sim 5 \times 10^{-9}$).[8]

VI Reservations and Rejoinders

The first reservation that is apt to occur to one is that there is something arbitrary about the claim that the Alexandroff present is the special relativistic successor of the classical world-at-a-time. We can generate other structures by adding or deleting from an Alexandroff present. Why not them?

Note, though, that if we consider supersets of the closure of ALEX(e_1, e_2), then we must give up the first advantage that I claimed for it above. Call a superset of the closure of ALEX(e_1, e_2) that is a putative present *PRES*(e_1, e_2). In a spacetime that is oriented and stably causal, it would no longer follow that if $e' \in$ PRES(e_1, e_2), then $t(e_1) < t(e') < t(e_2)$. I think such structures would lack a feature that a *now* ought to have.

If we consider subsets of ALEX(e_1, e_2), then the one set available that is defined invariantly is just the set of events in the intersection of ALEX(e_1, e_2) with the world line λ which contains e_1 and

[8] My thanks to Alexandre Korolev for this calculation.

e_2. I believe that this is the structure thought of as *now* in Shimony (1993) and in Dieks (2006), but conceiving of the relativistic *now* this way forfeits the second and third advantages that I highlighted above.

Nevertheless, this view raises a second question or challenge. As we noted above in §2, Dieks (2006, §§1-3) argues that the passage of time must be construed locally. Then in §§4-5 he sketches of view of temporal becoming or transience that seems more austere than the one offered here. The existence of an event is just its happening,[9] and these happenings are constrained in the temporal dimension only by the partial ordering familiar from the special theory of relativity. There is no *now* and, especially, no *moving now*, since that (in his view) would require "the *addition* of something to the four-dimensional continuum." (Dieks, 21)

What has to be added, according to Dieks, is "a moving very narrow 'window' through which a small portion of the continuum is made visible (or 'real')." (ibid) This metaphysics is indeed suspect, even in the classical case, as I argue elsewhere (Savitt, 2006). But the *nows* as I construe them are well-defined subsets of Minkowski spacetime and are no addition to it. The *nows* along a timelike worldline can be totally ordered, given the simplifying assumption of a fixed length for the psychological present, and the *nows* in spacetime can be partially ordered by extending in an obvious way the usual partial ordering for the events of which they are comprised. Transience, along a timelike line, is just the succession of *nows* according to this ordering, and Dieks is committed to this sort of "motion" no less than I. Of course one cannot think of all the events in one *now* as "co-occurring" since many pairs of events in a *now*—such

[9] On this point we agree, and he approvingly cites Savitt (2002) as a recent proponent of this view.

as any two distinct points along the world line λ--are timelike separated.

The Shimony/Dieks view does call one's attention to the importance of timelike curves, along which we characterize transience. But this new focus in turn calls up the third reservation one might have about my proposal (in fact, about mine and the Shimony/Dieks proposal as well).

My notion of transience is local and metaphysically very austere. It may avoid the sorts of objection that are brought against metaphysically stronger (or, as I would say, more baroque) conceptions of passage, but it might be that in order to avoid these objections it falls foul of a problem at the other extreme. The problem is that one could parameterize a spacelike curve with, say, proper length. Is my notion of transience not so weak that I am, then, committed to a parallel notion of spatial becoming, change of length along a spacelike curve? And is this not a *reductio*? There is no spatial becoming. Space does not pass, and in this way space differs from time.

Before I try my hand at a rejoinder, I'd like to point to a line of thought that doesn't do the trick. It is simply to emphasize that the timelike curves along which Alexandroff presents occur successively are *time*like. Therefore, one might think, change in this dimension is trivially change (or passage) of time. But thus far, the 'time' part of timelike has not been given any *temporal* content. Timelike vectors are distinguished in §4 in the usual purely formal way in terms of the metric, and timelike curves are those that have timelike tangent vectors. It's true that the signature of the metric is (1,3) and so has one distinguished dimension, but it is difficult to see how pointing to this fact will help with objection raised here.

Nevertheless, I do think there is a cogent response, and I was led to it by thinking about closing the circle—about finding a connection between our experience of time (as crude clocks) and timelike worldlines. The connection is typically left implicit in discussions of special relativity, but it is explicitly stated in mathematically complete characterizations of the theory. It is the clock hypothesis, and one can find it stated in Naber (1998, 52):

> If α: [a,b] → $\mathcal{M}$ is a timelike worldline in $\mathcal{M}$, then L(α) [my τ_{AB} above] is interpreted as the time lapse between the events α (a) and α(b) as measured by an ideal standard clock carried along by the particle whose world line is represented by α.

These standard clocks are ideal in that they continue to register proper time even though accelerated and hence subject to forces.[10] But these clocks are idealizations of the clocks around us and, even more so, of ourselves, since we are crude clocks (as any of us who have traveled across more than two time zones have been made aware). It is through clocks, and as clocks, that we experience time. Timelike curves are connected to ideal clocks via the clock hypothesis, and ideal clocks are an idealization of real clocks. These connections show why timelike lines are indeed *time*like and why the succession of nows along a timelike curve should count as an idealized version of the passage of *time*.

There is no similar spatial phenomenon (as the objector noted above) and so no connection from spacelike curves to it through any parallel or analogous hypothesis. That is why there is no spatial

[10] Herein could lie a long and fascinating digression. See §6.2.1 of Brown (2005).

becoming, no transient *here*, even though spacelike curves can be parameterized too.

Another (fourth) problem that is often raised to accounts of transience is this: if time is supposed to "pass", then it must make sense to ask how quickly it passes. Yet, it is objected, there is no sensible answer to this question. Consider, for example, Huw Price's presentation (1996, 13) of this "stock objection" to the so-called "block universe" view of time:

> [T]he stock objection is that if it made sense to say that time flows then it would make sense to ask how fast it flows, which doesn't seem to be a sensible question. Some people reply that time flows at one second per second, but even if we could live with the lack of other possibilities, this answer misses the more basic aspect of the objection. A rate of seconds per second is not a rate at all in physical terms. It is a dimensionless quantity, rather than a rate of any sort. (We might just as well say that the ratio of the circumference of a circle to its diameter flows at π seconds per second!)

I think there are two ways of meeting this objection. The first is a "bite the bullet" strategy. One of the things we learn from the four-vector formulation of special relativity, as we saw above in §IV, is that all massive objects move through spacetime with speed 1. That is, the velocity four-vector $\mathbf{u}$ of all such objects has length −1, and the absolute value of this length is a speed.[11] This result holds for an object in its rest frame, when it is not moving through space at all. There is only one dimension left in which it has this speed, then, the temporal dimension. If these objects move through time with speed 1, however, then our anti-Dobsonian argument ensures that we can equally well say that, for these objects, time passes with speed 1.

[11] See §5.2 of Hartle (2003).

Does this make sense? Maudlin (2002) has a heroic argument that it does. Consider by way of analogy, he says, exchange rates. The exchange rate for the U. S. dollar might be (say) $1.10 Canadian dollars per U. S. dollar but only .7 Euros. What is the exchange rate for the U. S. dollar itself? One U. S. dollar per U. S. dollar, of course. Isn't this limiting rate a valid exchange rate? The why isn't one second per second a valid "flow" rate?

In addition, one can point out that in many standard presentations of the special theory, time is given by *ct*, a distance. Speeds are dimensionless when time is indicated this way, and this result has not been perceived as problematic.

There is another, and perhaps subtler, way to look at this matter. N. David Mermin deduces from the invariance of the spacetime interval that for any massive object[12]

$$(T_0/T)^2 + v^2 = 1, \qquad (8)$$

where T_0 is proper time, T is coordinate time in a fixed frame, and v^2 is velocity squared. Then he comments:

> Now a stationary clock moves through time at 1 nanosecond [of proper time] per nanosecond [of frame or coordinate time] and does not move through space at all. But if the clock moves through space—i.e. the larger v is—the slower it moves through time—i.e. the smaller T_0/T is—in such a way as to maintain the sum of the squares of the two at 1. It is as if the clock is always moving through a union of space and time—spacetime—at the speed of light. If the clock is stationary then the motion is entirely through time (at a speed of 1 nanosecond per nanosecond). (2005, 86)

[12] That is, the events for which Mermin considers the interval must be timelike separated, since one clock can be present at each. Mermin has told me that his discussion was inspired by Greene (1999, 47-51).

This second strategy for meeting the objection does provide a genuine ratio of one quantity to another in order to make a rate of transience or passage. In the classical case, this strategy is disastrous. Introducing a second temporal dimension re-raises the question of its “flow” and so leads to an infinite regress of temporal dimensions. The two kinds of time are already in the special theory, however. No new time dimension has to be added in order to solve the problem of transience, nor do both of the time dimensions have to “flow”.

In fact, in my view transience is to be found in proper time, rather than coordinate time, and I would prefer to work with the reciprocal of the ratio in (8). In this case, one would have to think of (coordinate) time as speeding up as an object’s spatial speed increased, and hence as moving clocks running faster. Mermin notes this (2005, 163) but seems to think of coordinate time as that which passes.

The fifth and final reservation is one that is difficult to state and may prove the most difficult to overcome. Our cognitive life seems to be structured in a very deep way around classical Nows, around thinking in terms of the-world-at-an-instant. It is hard to have an intuitively satisfying picture of time, of local transience, of the sort sketched above.

We seem to have evolved to have a false picture of time for the Steinian reason given near the end of the previous section. I note that there are similar but in some odd way dual difficulties in understanding quantum mechanics, where features that we took to be local turn out not to be (instead of a global structure turning out to be, if I am right local). Perhaps these difficulties are in some deep way connected. Perhaps it is no coincidence that a similar picture seems to underlie the following remark of Lee Smolin, a prominent researcher in the field of quantum gravity (2001, 55):

> "A causal universe is not a series of stills following on, one after the other. There is time, but there is not really a notion of a moment of time. There are only processes that follow one another by causal necessity."

A universe with local passing of time is unfamiliar to most of us, puzzling to common sense; but it looks as if this is the picture of time we must learn to live with if we are to understand our universe.

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