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Persistence and Multilocation in Spacetime

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Abstract

The paper attempts to make the distinctions among the three modes of persistence—endurance, perdurance and exdurance—precise, starting with a limited set of notions. I begin by situating the distinctions in a generic spacetime framework. This requires, among other things, replacement of classical notions such as ‘temporal part’, ‘spatial part’, ‘moment of time’ and the like with their more appropriate spacetime counterparts. I then adapt the general definitions to Galilean and Minkowski spacetime and consider some illustrations. Finally, I respond to an objection to the way in which my generic spacetime framework is applied to the case of Minkowski spacetime.

1. Introduction. Enduring, Perduring and Exduring Objects in Spacetime

How do physical objects—atoms and molecules, tables and chairs, cats and amoebas, and human persons—persist through time and survive change? This question is presently a hot issue on the metaphysical market. Things were very different some forty years ago, when most philosophers did not recognize the question as an interesting one to ask. And when they did, the issue would quickly get boiled down to some combination of older themes. Here is a cat, and there it is again. It changed in-between (from being calm to being agitated, say); but what is a big deal? Things change all the time without becoming distinct from themselves (as long as they do not lose any of their essential properties, some would add). What else is there to say?

Today we know that there is much more to say. The problem of persistence has become, in the first place, a problem in *mereology*, a general theory of parts and wholes.[1] It has also become an issue in a theory of *location*.[2] These two topics continue to drive the debate, especially when it comes to situating the rival accounts of persistence in the "eternalist" spacetime framework. There is a sense in which enduring objects are three-dimensional and multilocated in spacetime whereas perduring objects are four-dimensional and singly located. They are extended in space and time and have both spatial and temporal parts.[3] The latter is strictly denied by endurantists.[4] It is also clear

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[1] For an authoritative exposition of classical mereology, see Simons 1987.

[2] For an authoritative and systematic treatment of theories of spatial location, see Casati and Varzi 1999.

[3] Persisting by being singly or multilocated in spacetime and persisting by having or lacking temporal parts are, arguably, two distinct issues. The distinction is made clear by the conceptual possibility of temporally extended simples (Parsons 2000) and instantaneous statues (Sider 2001: 64–65). For the most part I abstract from such possibilities in what follows (but see note 27). For a detailed discussion of the two issues and the resulting four-fold classification of the views of persistence, see Gilmore 2006.

that in view of multilocation in spacetime, the possession of momentary properties and spatial parts by enduring objects must be relativized to time, one way or another.[5] Even in the absence of precise definitions of ‘endurance’ and ‘perdurance’,[6] the contrast between these views is very lucid. Indeed, the contrast shows up in the labels which are often used to refer to these views: ‘three-dimensionalism’ and ‘four-dimensionalism’.

For quite some time four-dimensionalism had been taken to entail perdurantism, the doctrine that ordinary continuants (rocks, tables, cats, and persons) are temporally extended and persist over time much like roads and rivers persist through space. Recently, however, a different variety of “four-dimensionalism” has emerged as a leading contender in the persistence debate. According to *stage* theory, ordinary continuants are instantaneous stages rather than temporally extended perduring “worms”. Such entities persist by *exduring* (the term due to Haslanger 2003)—by having temporal counterparts at different moments. The distinction between perdurance and exdurance is evident (even though the misleading umbrella title ‘four-dimensionalism’ gets in the way): perduring and exduring objects have different numbers of dimensions (assuming that exduring object stages are temporally unextended).

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[4] Except in certain exotic cases, such as those briefly considered at the end of Section 2.

[5] Ways in which this can be done have been discussed, among many others, by Lewis 1986: 202–204, Rea 1998, Hudson 2001 and 2006, Sider 2001, Hawley 2001, and Haslanger 2003. I revisit the issue in Sections 3 and 4.

[6] Much effort has gone recently into defining ‘endurance’ and ‘perdurance’, as well as the underlying notion of *being wholly present* at a time. See e.g., Merricks 1999, Sider 2001: Chapter 3, Hawley 2001: Chapters 1 and 2, McKinnon 2002, Crisp and Smith 2005, Gilmore 2006, Sattig 2006, and references therein. Some authors are skeptical of the prospect of providing fully satisfactory such definitions that would be acceptable to all parties. See, especially, Sider 2001: 63–68. For a recent attempt to define ‘wholly present’ in a universally acceptable way, see Crisp and Smith 2005. Even if perfect definitions are not forthcoming, all parties agree that the views in question are transparent enough to debate their merits.

On the other hand, the distinction between endurance and exdurance is less clear. Exduring objects lack temporal extension, are three-dimensional, and there is a sense in which they are wholly present at multiple instants. But the same is true of enduring objects. Indeed, the features just mentioned—the lack of temporal extension and multilocation in spacetime—are widely believed to be the distinguishing marks of endurance. How then is exdurance different from endurance?

To be sure, there is a sense in which an exduring object is *not* multiply located. But this is not a sense that can be adopted by someone who wants to regard exdurance as a species of *persistence*, for on that sense, exduring objects do not persist. Something persists only if it exists at more than one moment,[7] and an instantaneous object stage, strictly speaking, does not. One could, of course, choose to accept this consequence and agree that exduring objects do not persist. That, however, would undermine the claim of the advocates of stage theory that theirs is the best unified account of *persistence*.[8]

The friends of this account should therefore be sufficiently broad about ways in which an object can be said to be wholly present, or located, at a time. The sense in which this is true of an exduring object is similar to the sense in which an object such as David Lewis is present, located or exists at multiple possible worlds of modal realism. Lewis can be said to exist at world *w* just in case he has a (modal) counterpart in that world. Similarly, an exduring object can be said to be located (in the requisite broad sense) at *t* just in case it has a (non-modal) counterpart located (in the strict and narrow sense) at *t*. This is the only sense in which an exduring object can be said to persist. But as just indicated, on that sense, exduring objects are located at multiple times and share this property with enduring objects. This raises the problem of

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[7] This is widely accepted as a necessary condition of persistence. The locus classicus is probably Lewis 1986: 202: “”Something *persists* iff, somehow or other, it exists at various times.”

[8] See Sider 2001: 188–208, Hawley 2001: Chapters 2 and 6, and Varzi 2003.

defining exdurance as a mode of persistence that is different from endurance, as well as perdurance.

Below I attempt to make the distinctions among the three modes of persistence more precise, starting with a limited set of notions. I begin (Section 2) by situating the distinctions in a generic spacetime framework.[9] This requires, among other things, replacement of classical notions such as 'temporal part', 'spatial part', 'moment of time' and the like with their more appropriate spacetime counterparts. I then adapt the general definitions to Galilean (Section 3) and Minkowski (Section 4) spacetime (which is my real target) and consider some illustrations. In Section 5 I focus on an objection to the way in which the generic spacetime strategy of Section 2 is applied to the case of Minkowski spacetime (in Section 4). The objection is due to Ian Gibson and Oliver Pooley (2006) and raises some broader issues of philosophical methodology, which are also discussed in Section 5.[10]

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[9] The generic spacetime approach of Section 2 has much in common with the strategies developed in Rea 1998, Balashov 2000b, Sider 2001: 79–87, Hudson 2001 and 2006, Gilmore 2004, 2006, Crisp and Smith 2005, and Sattig 2006. Some of my terminology and basic notions come from Gilmore 2004. Some of the material of Section 2 is based, with modifications and corrections, on an earlier short note (Balashov 2007) published in *Philosophical Studies* and is used here with kind permission of Springer Science and Business Media. After the publication of Balashov 2007 (and when a draft of the present paper was finished) I became aware of Thomas Bittner and Maureen Donnelly's paper (Bittner and Donnelly 2004), which develops a rigorous axiomatic approach to explicating the mereological and locational notions central to the debate about persistence. The approach is set in a broadly classical context but could, I think, be usefully extended to the genetic spacetime framework.

[10] Gibson and Pooley use their objection as a springboard for a sustained criticism of my older arguments (Balashov 1999, 2000a) in favor of a particular view of persistence (viz., perdurance) over its rivals (i.e., endurance and exdurance) in the context of special relativity (Gibson and Oliver 2006, Sections 3 and 6). My response to that criticism will have to await another occasion.

2. Persistence and Multilocation in Generic Spacetime

The task of this section is to develop a framework for describing various modes of persistence in spacetime that would be sufficiently broad to accommodate classical as well as relativistic structures. This requires generalizing some notions that figure centrally in the debate about persistence and, as a prerequisite, introducing some underlying spacetime concepts.

2.1. *Absolute chronological precedence*. We shall take the relation of *absolute chronological precedence* ($\lessdot$) as undefined. Informally, spacetime point p_1 stands in this relation to p_2 ($p_1 \lessdot p_2$) just in case p_1 is earlier than p_2 in every (inertial) reference frame.[11] It is natural to assume that absolute chronological precedence is asymmetrical ($p_1 \lessdot p_2 \rightarrow \neg p_2 \lessdot p_1$) and, hence, irreflexive ($\neg p \lessdot p$).

2.2. *Achronal regions*. Next we define the notion of an *achronal spacetime region*. A spacetime region (i.e., a set of spacetime points) is achronal iff no point in it absolute-chronologically precedes any other point.

(D1) Spacetime region R is *achronal* $=_{df}$ $\forall p_1,p_2\ (p_1,p_2 \in R \rightarrow \neg p_1 \lessdot p_2)$.

Achronal regions are three-dimensional "slices" through spacetime that generalize the classical notion of a moment of time. In fact, a moment of time could be defined as a *maximal* achronal region of spacetime with a certain property:

(D2) R is a *moment of time* $=_{df}$

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[11] As one would expect (see Sections 3 and 4 below), in classical spacetime absolute chronological precedence can be taken literally to mean precedence in the absolute time while in the special relativistic framework absolute chronological precedence is equivalent to the frame-invariant relation in which two points stand just in case they are either (i) timelike separated or (ii) lightlike (null) separated while being distinct.

> [(i) R is a maximal achronal region of spacetime; (ii) R is Ω] $=_{\mathrm{df}}$
> $[(\forall p_1,p_2)\ [p_1,p_2\in R \rightarrow \neg p_1\leqslant p_2] \wedge (\forall p)\ ((\forall p_1,p_2)\ [p_1,p_2\in R\cup\{p\} \rightarrow \neg p_1\leqslant p_2] \rightarrow p\in R) \wedge R \text{ is } \Omega]$.

Clause (ii) is needed because nothing in the above definition requires an achronal region to be a *flat* 3D hypersurface in spacetime. But it is natural to suppose that no achronal hypersurface can represent a moment of time in the classical or special relativistic setting unless it is flat. In these settings, 'Ω' could be taken to be synonymous with 'flat', where flatness is defined in the usual metric way.[12]

The significance of flat achronal hypersurfaces in special relativistic spacetime and their relation to the notion of time are issues that require more discussion and I shall return to them in Section 5. But they do not play any part in the general definitions of the different modes of persistence provided later in this section. What does play a central role in them is the notion of achronality (and the underlying relation of absolute chronological precedence). My approach takes the second notion as a starting point to allow maximum generality. But in familiar contexts, it bears close relationship to other widely used concepts. Thus in many applications, a maximal achronal region is none other than a Cauchy surface—a spacelike hypersurface that intersects every unbounded timelike curve at exactly one point. But there is no need to invoke additional notions, such as 'spacelike' and 'timelike', in a generic context where all the useful work could be done by 'achronal'.

We need, however, make a brief digression to note a familiar problem with the concepts of 'absolute chronological precedence' and 'achronal', which is brought to light by considering peculiar

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[12] What about general relativity? Although it goes beyond the scope of this paper, it is worth noting that, except in very special cases (e.g., certain idealized cosmological models), the notion of a moment of time lacks any meaning in general relativistic spacetime.

spacetimes possessing closed or “almost closed” timelike curves. For the purpose of this informal consideration, ‘timelike’ could be taken to be synonymous with ‘non-achronal’. Closed timelike curves exist, for example, in Gödelian cosmological models of general relativity, but a flat “cylindrical” spacetime could serve as a useful toy model.[13] It is easy to see that there is a sense in which two “nearby” points p_1 and p_2 can stand in the relation of absolute chronological precedence ($p_1 \lessdot p_2$)—the sense obtained by tracing a non-achronal curve from p_1 to p_2 around the “cylinder”. But there is also a sense in which they are not ($\neg p_1 \lessdot p_2$)—the sense obtained by tracing an achronal curve from p_1 to p_2 along a generatrix of the “cylinder”. Accordingly, a certain region containing both p_1 and p_2 might be classified by (D1) as being both achronal and non-achronal. Situations of this sort figure prominently in the literature on time travel.[14]

Another problem arises in spacetimes having a “trouser” topology.[15] Points p_1 and p_2 belonging to different legs of the “trousers” do not bear any well-defined metrical relations to each other and, hence, are not related by $\lessdot$. But if p_1 precedes the merger by just a few seconds but p_2 is thousands of years away from it, there is some inclination to say that p_2 chronologically precedes p_1 (in the sense associated with ‘$\lessdot$’).

Both problems could perhaps be alleviated by making the definition of ‘achronal region’ in the relevant sense *local*[16] and thus consistent with closed or “almost closed” timelike curves, and with the “trouser” topology. We shall abstract from such situations in what follows. This limitation is quite tangential to the main task of the paper—to capture the distinctive features of the various modes of persistence in a spacetime setting by using an economical

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[13] Cf. Gilmore 2007, where a similar toy model is used to investigate the implications of time travel scenarios for the issue of persistence.

[14] For recent discussions, see Gilmore 2006 and 2007 and Gibson and Pooley 2006: Section 5.

[15] See Gilmore 2006: 204, notes 19 and 20, who refers in this connection to Sklar 1974: 306–307.

[16] See Gilmore 2006: 209, note 19 for one attempt to do it.

set of primitive notions. We shall assume, accordingly, that global maximal achronal regions are always available.

2.3. *LOCATION*. Persisting objects are located at regions of spacetime. For our purposes, 'located at' means *exactly located*. The guiding idea here is that the region at which an object is exactly located is the region into which the object exactly fits and which has exactly the same size, shape, and position as the object itself.[17]

I take 'located at R' to mean the same as 'wholly present at R', but I put aside the question of whether the latter notion can be rigorously defined for objects having (achronal) parts.[18] Providing such a definition is one of the most intensely debated problems nowadays.[19] My concerns here are, however, rather orthogonal to it, for I am interested in the underlying sense of 'located at R' applicable to (achronally) composite and non-composite objects alike, which any such definition must take as a starting point.

What is essential to my task is that there be a common notion of location—call it 'LOCATION'—which is broad enough to incorporate the modes in which both enduring and exduring objects are capable of multilocation. To repeat, the sense in which an exduring object accomplishes this feat is similar to the sense in which a worldbound individual of the Lewisian pluriverse can nonetheless be said to exist at multiple worlds. To make the notion of LOCATION precise, let us start with (non-modal) counterparthood and stipulate that every object (enduring, perduring, or exduring) is a (non-modal) counterpart of itself. This is a natural assumption that does not impose any undue commitments on endurantism or perdurantism. The advocates of

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[17] This notion of exact location is similar to Gilmore's notion of *occupation* (Gilmore 2006), Hudson's notion of *exact occupation* (Hudson 2001), Bittner and Donnelly's notion of *exact location* (Bittner and Donnelly 2004), and other equivalents found in the recent literature. But see Parsons 2007 for a very different notion of 'exactly located'.

[18] See the definition of *achronal part* below (D6).

[19] See Rea 1998, Sider 2001: 63–68, McKinnon 2002, Crisp and Smith 2005, Parsons 2007 and references therein.

both theories could agree that every persisting object has an "improper" non-modal counterpart: itself—multiply located in the case of endurantism, and singly located in the case of perdurantism.[20] 'LOCATED at R' could then be defined as follows:

(D3) *o* is (exactly) *LOCATED* at R $=_{\text{df}}$ one of *o*'s (non-modal) counterparts is (exactly) located at R.

The following definitions (adapted from Gilmore 2004: chapter 2 and 2006: 204ff) help to align LOCATION more precisely with the notion of persistence.[21]

(D4) Spacetime region $\mathbb{O}$ is the *path* of object *o* $=_{\text{df}}$ $\mathbb{O}$ is the union of the spacetime region or regions at which *o* is LOCATED.

(D5) *o persists* $=_{\text{df}}$ *o*'s path is non-achronal.

The advantage of (D1) and (D3)–(D5) lies in their ability to offer a *unified* account of persistence and multilocation, on which (i) enduring, perduring and exduring objects persist in the same sense, and (ii) enduring and exduring objects are multilocated in the same sense. All parties can agree that endurance, perdurance, and exdurance are *bona fide* modes of persistence and, in particular, that exdurance is not a second-class citizen: exduring

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[20] For those who may be inclined to resist this usage of 'counterpart' as too stretched, a somewhat less elegant equivalent of (D3) is readily available:

(D3′) *o* is (exactly) *LOCATED* at R $=_{\text{df}}$ *o* is exactly located at R or one of *o*'s (non-modal) counterparts is (exactly) located at R.

[21] But Gilmore might object to combining his definition of 'persists' with the broad sense of 'LOCATED at'. On his official view, as far as I can see, exduring objects do not persist. See, however, Gilmore 2006: 230, note 21, where he suggests a rather innocuous modification to his approach that would accommodate exdurance.

objects persist in the same robust sense as enduring objects do. This allows one to focus on the important question of how they manage to do so.

2.4. *Achronal and diachronic parts*. Next we need generalizations of the concepts of spatial and temporal part. We shall take a three-place relation '*p* is a part of *o* at achronal region R'—as a primitive.[22] The intuitive ancestor of this relation is the familiar time-relativized sense in which certain cells are part of me at one time but not at another. Where *p*, *o* and R stand in this relation, we shall say that *p* is an *achronal part* of *o* at achronal region R and denote it with the subscript '$_\perp$':

(D6) $p_\perp$ is an *achronal part* of *o* at achronal spacetime region R $=_{\text{df}}$ $p_\perp$ is a part of *o* at R.

Diachronic parthood could then be defined as follows:

(D7) $p_{\|}$ is a *diachronic part* of *o* at achronal spacetime region R $=_{\text{df}}$ (i) $p_{\|}$ is located at R but only at R, (ii) $p_{\|}$ is a part of *o* at R, and (iii) $p_{\|}$ overlaps at R everything that is a part of *o* at R.

Note that neither *p* nor *o* need be "as large as" the achronal region R, in order to stand in the relation '*p* is a part of *o* at R'. All that could reasonably be required of the achronal extents of *o* and *p* at R, is that the intersection of *p*'s path with R be "within" the intersection of *o*'s path with R:

(WITHIN) *p* is a part of *o* at achronal region R → $\mathbb{p}\cap\mathrm{R} \subseteq \mathbb{o}\cap\mathrm{R}$.

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[22] This relation is similar to that used by Hudson (2001) in developing his Partist view of persistence but more restrictive than the latter (and thus closer to the familiar concept of temporary parthood), in that Hudson's notion relativizes parthood to arbitrary regions of spacetime whereas mine is limited to achronal regions.

This, of course, entails that both $p \cap R$ and $o \cap R$ are "within" R. Thus my hand is a part of me at a certain momentary location of my hand, at a momentary location of my body, and at a momentary location of the Solar system. Furthermore, if I am an exduring object my hand is a part of me at an achronal region at which neither I nor my hand are even "sub-located"—say, a region at which I *was* located at some moment 10 years ago. In this case the job of grounding R-relativized parthood is done by the non-modal counterparts of the relevant objects. Finally, assuming perdurance, one of my cells at *t* (i.e., a global moment of time) is a part of me at my momentary location at *t* (i.e., at the location of my momentary *t*-part), but also a part of me at the momentary location of the Solar system at *t*.[23]

In contrast, the notion of diachronic parthood is more restrictive: if $p_{\|}$ is a diachronic part of *o* at achronal region R then $p_{\|}$ must "fit into" R exactly, although *o* may "overfill" R in virtue of having parts (both achronal and diachronic) at superregions of R.

In the subsequent discussion the generic relations of achronal and diachronic parthood, explicated in (D6) and (D7), are restricted to distinguished achronal regions—those "containing" (in a relevant sense) the objects involved in the relation. Such regions are *achronal slices* of the objects' paths.

(D8) $R_{\perp}$ is an *achronal slice* of R $=_{df}$ $R_{\perp}$ is a non-empty intersection of a maximal achronal 3D region with R $=_{df}$ $(\exists R^*)\ [(\forall p_1,p_2)\ (p_1,p_2 \in R^* \rightarrow \neg p_1 \leqslant p_2) \wedge (\forall p)\ ((\forall p_1,p_2)$

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[23] One counterintuitive consequence of R-relativized parthood thus understood must be noted: *p* may be a part of *o* at an achronal region "not large enough" for *o*, provided that it is "large enough" for *p*. For example, (WITHIN), as stated above, does not preclude me from being a part of my hand at a momentary location of my hand. A fully axiomatic treatment of R-relativized parthood would probably need to rule out such cases, perhaps by modifying (WITHIN). This would lead to complications that are best avoided in the present context.

$[p_1,p_2 \in R^* \cup \{p\} \rightarrow \neg p_1 < p_2] \rightarrow p \in R^*) \wedge R_\perp = R \cap R^* \wedge$
$(\exists p)\, p \in R_\perp]$

More comments are in order.

(i) As defined by (D6) and (D7), achronal and diachronic parthood are not mutually exclusive. Indeed, diachronic parthood is just a special case of achronal parthood. In the case of both perdurance and exdurance, the diachronic part of any object at a *t*-slice of its path is equally its achronal part at that slice.

(ii) However, there is a sense in which *proper* achronal and diachronic parthood are exclusive. If *proper parthood at achronal region R* is defined as *asymmetrical* achronal parthood at R:

(D9) $p_\perp$ is a *proper achronal part* of *o* at achronal region R $=_{df}$ (i) $p_\perp$ is an achronal part of *o* at R, (ii) *o* is not an achronal part of $p_\perp$ at R,

then, if $p_\perp$ is a proper achronal part of *o* at some achronal slice $\mathbb{O}_\perp$ of its path then $p_\perp$ is not a diachronic part of *o* at $\mathbb{O}_\perp$, proper or not. The reason, roughly, is that $p_\perp$ is “smaller” than *o* at $\mathbb{O}_\perp$ and thus cannot be a diachronic part of *o* at $\mathbb{O}_\perp$.

And if *proper diachronic parthood* is defined as *asymmetrical* diachronic parthood:

(D10) $p_{||}$ is a *proper diachronic part* of *o* at achronal region R $=_{df}$ (i) $p_{||}$ is a diachronic part of *o* at R, (ii) *o* is not a diachronic part of $p_{||}$ at R,

then, if $p_{||}$ is a proper diachronic part of *o* at some achronal slice $\mathbb{O}_\perp$ of its path then $p_{||}$ is not a proper achronal part of *o* at $\mathbb{O}_\perp$. The reason, roughly, is that being a diachronic part of *o* at $\mathbb{O}_\perp$, proper or not, makes $p_{||}$ “as large as” *o* at $\mathbb{O}_\perp$ and, hence, not a proper achronal part of it at $\mathbb{O}_\perp$. However, $p_{||}$ and *o* will in general be *improper* achronal parts of each other at $\mathbb{O}_\perp$.

On the other hand, if proper achronal and diachronic parthood at achronal region R are understood as follows:

(D9′) $p_\perp$ is a *proper achronal part* of *o* at achronal region R $=_{df}$ (i) $p_\perp$ is an achronal part of *o* at R, (ii) $p_\perp \neq o$;

(D10′) $p_{||}$ is a *proper diachronic part* of *o* at achronal region R $=_{df}$ (i) $p_{||}$ is a diachronic part of *o* at R, (ii) $p_{||} \neq o$,

then one object could be both a proper achronal and a proper diachronic part of another object at some achronal region. Consider a perduring or exduring statue and the piece of clay of which it is composed. Some would argue that the statue (and, hence its *t*-part) is not identical with the piece of clay (and its corresponding *t*-part). If so then the statue and the piece of clay are both proper achronal and proper diachronic parts of each other at the *t*-slice of the path of both objects.

(D9), (D10), (D9′) and (D10′) raise an interesting question of how to develop general R-relativized mereology.

(iii) As defined, achronal and diachronic parts are achronal, that is, diachronically (or "temporally", where this designation is appropriate) non-extended. In this I deviate from the authors who explicitly allow temporally extended temporal parts and make them do some useful work.[24]

2.5. *Achronal Universalism*. Finally, we assume the thesis of Achronal Universalism:

(Achronal Universalism)
(i) Any enduring object is located at every achronal slice of its path;
(ii) any perduring object has a diachronic part at every achronal slice of its path;

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[24] See, in particular, Heller 1990, Zimmerman 1996, Butterfield 2006 and note 28 below.

(iii) any exduring object is LOCATED at every achronal slice of its path.

Thus in the context of this general consideration, which is not specific to any particular type of spacetime, we impose no restriction whatsoever on which of the achronal slices of an object's path contain that object or one of its diachronic parts. Nothing of substance turns on this simplifying assumption for the purpose of this section. The situation will change when we turn to adapting the generic definitions to particular spacetime structures in later sections. At that point, the statement of Achronal Universalism appropriate to a given such structure will become a more controversial matter.

2.6. *'Endurance', 'perdurance' and 'exdurance' defined*. The following definitions capture the important distinctions among the three modes of persistence.

(D11) *o endures* $=_{\mathrm{df}}$ (i) *o* persists, (ii) *o* is located at every achronal slice of its path, (iii) *o* is LOCATED only at achronal slices of its path.

(D12) *o perdures* $=_{\mathrm{df}}$ (i) *o* persists, (ii) *o* is LOCATED only at its path, (iii) the object located at any achronal slice $\mathbb{O}_{\perp}$ of *o*'s path is a proper diachronic part of *o* at $\mathbb{O}_{\perp}$.

(D13) *o exdures* $=_{\mathrm{df}}$ (i) *o* persists, (ii) *o* is located at exactly one region, which is an achronal slice of its path, (iii) *o* is LOCATED at every achronal slice of its path,

On these definitions, the difference between endurance and perdurance is as expected: (i) enduring but not perduring objects are multilocated (and, hence, multiLOCATED) in spacetime; (ii) perduring but not enduring objects have diachronic parts.[25]

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[25] Barring certain exotic exceptions; see note 27.

More importantly, the definitions also bring out the crucial distinction between perdurance and exdurance: (a) exduring but not perduring objects are multiLOCATED in spacetime; (b) while both perduring and exduring objects have diachronic parts, perduring objects have only *proper* diachronic parts. That exduring objects have improper diachronic parts follows from clauses (ii) and (iii) of (D13) and the definition of 'diachronic part', which together entail that the object located at every achronal slice of an exduring object's path is a diachronic part, at that slice, of some object: namely, itself.[26]

Finally, the definitions pinpoint the difference between exdurance and endurance: while both exduring and enduring objects are multiLOCATED, only the former (again, barring some exotic cases; see below) have diachronic parts at every region at which they are LOCATED. Indeed, clause (ii) of (D11) generally

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[26] This does not imply that exduring objects have *only* improper diachronic parts. It depends on how proper diachronic parthood at R is defined—the issue already considered above. In any case, the stage theorist should, of course, deny that an exduring object o is strictly identical with its t_1-stage, p_1, as well as with its distinct t_2-stage, p_2. If so, then under the aforementioned definition (D10′) of R-relativized proper diachronic parthood:

(D10′) $p_{\|}$ is a *proper diachronic part* of o at achronal region R $=_{\mathrm{df}}$ (i) $p_{\|}$ is an diachronic part of o at R, (ii) $p_{\|} \neq o$,

at least one of p_1 and p_2 is a proper diachronic part of o (at t_1- or t_2-slice of o's path). On the other hand, if proper parthood at R is defined as *asymmetrical parthood* at R:

(D10) $p_{\|}$ is a *proper diachronic part* of o at achronal region R $=_{\mathrm{df}}$ (i) $p_{\|}$ is an diachronic part of o at R, (ii) o is not a diachronic part of $p_{\|}$ at R,

then both p_1 and p_2 are improper parts of o, at different t-slices of its path. This, of course, does not entail that $p_1=p_2$.

prevents an enduring object from having a diachronic part at any achronal slice of its path.[27]

(D11)–(D13) thus delineate the important contrasts among the three modes of persistence.[28]

3. Persistence and Multilocation in Galilean Spacetime

In this Section I adapt the generic framework introduced above to Galilean spacetime. This task is relatively straightforward. The relation of absolute chronological precedence ($\lessdot$) in Galilean spacetime (ST^G) coincides with the relation of absolute temporal precedence: $p_1 \lessdot p_2 \leftrightarrow t_1 < t_2$, where (x_1, y_1, z_1, t_1) and (x_2, y_2, z_2, t_2) are the coordinates of p_1 and p_2 in any Cartesian coordinate system associated with any inertial frame of reference. Accordingly, a region R of Galilean spacetime is achronal iff it is a subregion of an absolute time hyperplane. That is:

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[27] But here (finally!) is an exotic exception. Consider an enduring lump of clay that becomes a statue for only an instant (Sider 2001: 64–65). On (D7), the statue is a diachronic part of the lump at that instant.

[28] At the same time, it should be emphasized that these definitions are not watertight, and I did not strive to make them so. In fact, one may doubt that watertight definitions are even possible, especially in the case of endurance (see note 6). Apart from Sider's instantaneous statue (note 27), (D11)–(D13) give intuitively wrong results in other exotic cases. Consider an organism composed of perduring cells and stipulate that the cells and their diachronic parts are the *only* proper parts of the organism (Merricks 1999: 431). By clause (iii) of (D12), the organism itself does not perdure. Another exotic case (suggested by a referee of Balashov 2007) includes an object satisfying (D11) but having "finitely extended diachronic parts." It is unclear whether such an object could be regarded as enduring. Relatedly, there could be an object satisfying clauses (i) and (ii) of (D12) but having only "finitely extended proper diachronic parts." On (D12), such an object does not perdure, an intuitively wrong result. To handle possibilities of this sort, one would need to make full use of the appropriately defined notion of a "diachronically extended diachronic part," which lies outside the scope of this project. See also note 24. Fortunately, cases of this sort are too remote to bear on the agenda of this paper and we can safely ignore them. For our purposes, (D11)–(D13) provide good working accounts of the three modes of persistence.

(D1^{G}) Region R of ST^{G} is *achronal* $=_{df} \forall p_1, p_2 \, (p_1, p_2 \in R \rightarrow t_1 = t_2)$.

And a moment of time (= a maximal achronal region) is simply a time hyperplane in ST^{G}:

(D2^{G}) R is a *moment of time* in ST^{G} $=_{df}$ R is a time hyperplane in ST^{G}.

We take the definitions of *LOCATION* and *path* directly from Section 2.

(D3^{G}) *o* is (exactly) *LOCATED* at R in ST^{G} $=_{df}$ one of *o*'s (non-modal) counterparts is (exactly) located at R.[29]

(D4^{G}) Spacetime region $\varnothing$ is the *path* of object *o* in ST^{G} $=_{df}$ $\varnothing$ is the union of the spacetime region or regions at which *o* is LOCATED.

According to our older generic definition (D5), *o persists* just in case *o*'s path is non-achronal. Adapted to Galilean spacetime, this boils down to the requirement that *o*'s path intersect at least two distinct moments of time.

(D5^{G}) *o* persists in ST^{G} $=_{df} \exists p_1, p_2 \in \varnothing, t_1 \neq t_2$.

The earlier generic definitions of 'achronal part of *o* at achronal region R' (D6) and 'diachronic part of *o* at achronal region R' (D7)

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[29] As before, those who are dissatisfied with the broad sense of 'counterpart' at work in (D3^{G}), may choose a less elegant equivalent of (D3^{G}):

(D3$^{G\prime}$) *o* is (exactly) *LOCATED* at region R of ST^{G} $=_{df}$ *o* is exactly located at R or one of *o*'s (non-modal) counterparts is (exactly) located at R.

generalized the concepts of spatial part and instantaneous temporal part to the spacetime framework. In Galilean spacetime, however, all and only achronal regions are moments of absolute time. This effectively reduces some of the generic notions of Section 2 to their more familiar classical predecessors. In particular, an achronal slice $R_\perp$ of R in ST^G is simply the intersection of R with a moment of time:

(D8^G) $R_\perp$ is an *achronal slice* of R in $ST^G =_{df} R_\perp$ is a non-empty intersection of a moment of time (i.e., a time hyperplane) with R.

Accordingly, I shall refer to the achronal slice of R at *t* in ST^G simply as '*t*-slice of R' or '$R_{\perp t}$'. This brings the concepts of achronal and diachronic parthood at achronal region R closer to the older concepts of *temporal part at t* and *spatial part at t*. In what follows I shall sometimes use such simpler notions, where context makes it clear that '*t*' refers not to an entire hyperplane of absolute simultaneity but to a rather small subregion of it: $\mathbb{O}_{\perp t}$.

As before, we assume Achronal Universalism:

(Achronal Universalism^G)
  (i) Any enduring object is located at every *t*-slice of its path (in Galilean spacetime);
  (ii) any perduring object has a *t*-part at every *t*-slice of its path;
  (iii) any exduring object is LOCATED at every *t*-slice of its path.

On this assumption, endurance, perdurance and exdurance in Galilean spacetime can be defined as follows:

(D11^G) *o endures* in $ST^G =_{df}$ (i) *o* persists, (ii) *o* is located at every *t*-slice of its path, (iii) *o* is LOCATED only at *t*-slices of its path.

(D12^G) *o perdures* in ST^G $=_{df}$ (i) *o* persists, (ii) *o* is LOCATED only at its path, (iii) the object located at any *t*-slice of *o*'s path is a proper *t*-part of *o*.

(D13^G) *o exdures* in ST^G $=_{df}$ (i) *o* persists, (ii) *o* is located at exactly one region, which is a *t*-slice of its path, (iii) *o* is LOCATED at every *t*-slice of its path,

As noted in Section 2, these definitions are not watertight, but they bring out all the essential differences among the three modes of persistence in Galilean spacetime.

Multilocation has a familiar consequence for the analysis of temporal predication. Galilean spacetime provides a convenient framework for discussing this issue. To say what properties (and spatial parts) an object has at *t*, the endurantist who subscribes to spacetime realism must relativize possession of temporary properties (and spatial parts) to time. She cannot say that a certain poker is hot and stop here, because the selfsame poker is also cold, when it is wholly present at a different time.[30] Time must somehow be worked into the picture. One has to explain how time interacts with predication and what makes statements attributing temporary properties to objects true. There are several ways of doing it, which bring with them somewhat distinct semantics and metaphysics of temporal modification.[31]

In discussions that abstract from spacetime considerations such schemes are often looked upon as providing a semantic regimentation for simple expressions of the form '*o* has Φ at *t*'. In a more systematic treatment, ascription of properties must be relativized to achronal regions of spacetime, namely, to achronal slices of *o*'s path. However, since in ST^G all the achronal regions

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[30] This is often referred to as the "problem of temporary intrinsics" or the "problem of change."

[31] The general strategy of relativizing temporary properties to times was sketched by Lewis 1986: 202–204. It was then implemented in a great number of works and in many different forms. For recent contributions and references see MacBride 2001, Haslanger 2003.

of interest can (in ordinary cases) be indexed by moments of absolute time, we can, for the purpose of illustration, keep the simple form.

The following is a brief summary of the analyses of temporal predication in the competing views of persistence, beginning with endurance, which allows three somewhat different schemes:[32]

(EndST^G-1: Rel) Enduring object *o* has Φ at *t* in Galilean spacetime$=_{df}$ *o* bears Φ-at to *t*.

(EndST^G-2: Ind) Enduring object *o* has Φ at *t* in Galilean spacetime $=_{df}$ *o* has Φ-at-*t*.

(EndST^G-3: Adv) Enduring object *o* has Φ at *t* in Galilean spacetime $=_{df}$ *o* has_t Φ.

Perdurance and exdurance, on the other hand, naturally go along with the following canonical accounts of temporal predication in Galilean spacetime:

(PerST^G) Perduring object *o* has Φ at *t* in Galilean spacetime $=_{df}$ *o*'s *t*-part has Φ.

(ExdST^G) Exduring object *o* has Φ at *t* in Galilean spacetime $=_{df}$ *o*'s *t*-counterpart has Φ.

To illustrate these ideas further, consider a 10 meter-long pole in Galilean spacetime. At a certain moment, it starts to contract until its length is reduced to 5 meters. On endurantism, the pole is a 3D entity extended in space but not in time. It is located at all *t*-slices of its path and any such intersection features the full set of

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[32] In the text below 'Rel' stands for "Relationalism" (not to be confused with spacetime Relationism), 'Ind' for "Indexicalism", and 'Adv' for "Adverbialism". None of these terms is universally accepted, but all are widely used (and sometimes confused with each other) in the literature.

properties the pole has at a corresponding time, including its length. Some of these properties are apparently incompatible, such as being 10 meters long and being 5 meters long. How can the self-same object exhibit incompatible properties? Part of the controversy about persistence arises from taking this question seriously. But given multilocation of enduring entities in (Galilean) spacetime, the answers are readily available. On Relationalism, the pole comes to have the property of being 5 meters long at t_1 and 10 meters long at t_2 by bearing the relation *5-meter-long-at* to t_1 and *10-meter-long-at* to t_2.[33] On Indexicalism, the pole accomplishes the same feat by exemplifying two time-indexed properties, *5-meter-long-at-*t_1 and *10-meter-long-at-*t_2. On Adverbialism, the pole possesses the simple property *5-meter-long* in the t_1-ly way, and another property, *10-meter-long*, in a different, t_2-ly way.

On perdurantism, on the other hand, the pole is a 4D entity extended both in space and time. It persists by having distinct momentary *t*-parts at each *t*-slice through its path. When we say that the pole is 10 meters long at t_1 and 5 meters long at t_2, what we really mean is that the pole's t_1-part has the former property and its t_2-part the latter. The sense in which the properties of the pole's *t*-parts can be attributed to the 4D whole is, in many ways, similar to the sense in which the properties of the spatial parts of an extended object are sometimes attributed to the whole. When we say that the oil pipe is hot in the vicinity of the pump and cold elsewhere, we really mean that the pipe has, among its spatial parts, a part in the vicinity of the pump, which is hot, and an elsewhere part, which is cold. Just as the pipe (and entire thing) *changes* from being hot to being cold, the pole (the entire perduring object) changes from being long to being short.

On exdurantism, the pole is a 3D entity LOCATED at multiple *t*-slices through its path, thanks to having distinct *t*-counterparts at each such slice. The pole comes to be 10 meters long at t_1 and 5

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[33] As noted above, in simple contexts 't_1' and 't_1' come in handy as useful shorthand for '$\mathbb{O}_{\perp t_1}$' and '$\mathbb{O}_{\perp t_2}$

meters long at t_2 by having a t_1-counterpart and a t_2-counterpart, which have these respective lengths *simpliciter*. (Remember that the *t*-counterpart relation is reflexive.)

Persistence and temporal predication in Galilean spacetime are straightforward.

4. Persistence and Multilocation in Minkowski Spacetime

Minkowski spacetime (ST^M) brings novel and interesting features. In ST^M absolute chronological precedence is the frame-invariant relation in which two points stand just in case they are either timelike separated or lightlike separated while being distinct: $p_1 \lessdot p_2 \leftrightarrow I(p_1,p_2) \geq 0 \wedge p_1 \neq p_2$, where $I(p_1,p_2) \equiv c^2(t_2 - t_1)^2 - (\mathbf{x}_2 - \mathbf{x}_1)^2$ is the relativistic interval. Accordingly, any spacelike hypersurface[34] counts as an achronal region of ST^M:

(D1^M) Region R of ST^M is *achronal* $=_{df} \forall p_1,p_2\ (p_1,p_2 \in R \rightarrow I(p_1,p_2) < 0)$.

But only a subset of them—those that are *flat*—represent legitimate perspectives: moments of time in inertial reference frames, $\{t^F\}$:

(D2^M) R is a *moment of time* in ST^M $=_{df}$ R is a spacelike hyperplane in ST^M.

It is therefore appropriate to index LOCATION of persisting objects and their parts in ST^M to t^F.[35] And it is convenient to treat 't^F' as a two-parameter index, assuming that the choice of a

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[34] A hypersurface is spacelike just in case any two points on it are spacelike separated.

[35] The appropriateness of restricting "legitimate perspectives" and LOCATIONS of persisting objects and their parts to moments of time in inertial reference frames in ST^M has been criticized by Gibson and Pooley 2006, 159–165. I discuss and respond to their criticism in the next section.

particular coordinate system adapted to a given inertial reference frame can somehow be fixed.

Two related facts about frame-relative moments of time in ST^M are worth noting:

(i) Any two distinct moments of time $t^F{}_1$ and $t^F{}_2$, $t^F{}_1 \neq t^F{}_2$, in a single frame F are parallel and, therefore, do not overlap. In this respect, moments of time in a given frame are similar to absolute moments of time in ST^G.

(ii) Any two moments of time in distinct frames, $t^{F_1}{}_1$ and $t^{F_2}{}_2$, $F_1 \neq F_2$, overlap. In this respect, moments of time in distinct frames in ST^M are very different from absolute moments of time in ST^G.

LOCATION and *path* in ST^M can then be defined.

($D3^M$) *o* is (exactly) *LOCATED* at region R of $ST^M =_{df}$ one of *o*’s (non-modal) counterparts is (exactly) located at R.[36]

($D4^M$) Spacetime region $\varnothing$ is the *path* of object *o* in $ST^M =_{df} \varnothing$ is the union of the spacetime region or regions at which *o* is LOCATED.

On the generic definition of persistence (D5), *o persists* just in case *o*’s path is non-achronal. In Minkowski spacetime, this is equivalent to the requirement that *o*’s path intersect at least two distinct moments of time in a single frame or, alternatively, that *o*’s path contain two non-spacelike separated points.

($D5^M$) *o* persists in ST^M $=_{df} \exists p_1, p_2 \in \varnothing \; \exists F \; t^F{}_1 \neq t^F{}_2$

$=_{df} \exists p_1, p_2 \in \varnothing \; (p_1 \neq p_2 \wedge I(p_1, p_2) \geq 0)$.

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[36] Alternatively:

($D3^{M\prime}$) *o* is (exactly) *LOCATED* at region R of $ST^M =_{df}$ *o* is exactly located at R or one of *o*’s (non-modal) counterparts is (exactly) located at R.

As before, $(\mathbf{x}^F{}_1, t^F{}_1)$ and $(\mathbf{x}^F{}_2, t^F{}_2)$ are the coordinates of p_1 and p_2 in a Cartesian coordinate system adapted to the inertial frame of reference F.

An achronal slice $R_\perp$ of R in ST^M is the intersection of R with a moment of time in some inertial frame:

(D8^M) $R_\perp$ is an *achronal slice* of R in $ST^M =_{df} R_\perp$ is a non-empty intersection of a moment of time (i.e., a time hyperplane) with R.

We shall refer to the achronal slice of R at t^F in ST^M as 't^F-slice of R' or "$R_{\perp t^F}$". And we shall allow such expressions as 'achronal part of *o* at t^F', 'diachronic part of *o* at t^F' and '*o*'s t^F-part' to go proxy for their more complex equivalents, such as 'achronal part of *o* at t^F-slice $\mathbb{O}_{\perp t^F}$ of *o*'s path $\mathbb{O}$' and so forth. Moreover, we shall allow ourselves the liberty to speak of "spatial parts" of persisting objects in Minkowski spacetime when it is clear what reference frame is under consideration.

As before, we adopt a version of Achronal Universalism, appropriate for ST^M:

(Achronal Universalism^M)

(i) Any enduring object is located at every t^F-slice of its path (in ST^M);

(ii) any perduring object has a t^F-part at every t^F-slice of its path;

(iii) any exduring object is LOCATED at every t^F-slice of its path.

Given Achronal Universalism^M, the definitions of the three basic modes of persistence in Minkowski spacetime are rather simple.

(D11^M) *o endures* in $ST^M =_{df}$ (i) *o* persists, (ii) *o* is located at every t^F-slice of its path, (iii) *o* is LOCATED only at t^F-slices of its path

(D12$^{\mathrm{M}}$) *o perdures* in ST$^{\mathrm{M}}$ $=_{\mathrm{df}}$ (i) *o* persists, (ii) *o* is LOCATED only at its path, (iii) the object located at any t^{F}-slice of *o*'s path is a proper t^{F}-part of *o*.

(D13$^{\mathrm{M}}$) *o exdures* in ST$^{\mathrm{M}}$ $=_{\mathrm{df}}$ (i) *o* persists, (ii) *o* is located at exactly one region, which is a t^{F}-slice of its path, (iii) *o* is LOCATED at every t^{F}-slice of its path,

The analysandum of the predication schemes characteristic of endurance, perdurance and exdurance in ST$^{\mathrm{M}}$ is an expression of the form '*o* has Φ at t^{F}' (where, as before, 't^{F}' is a simplified index for what, in a more systematic treatment, would be '$\mathbb{O}_{\perp t^{\mathrm{F}}}$').

(EndST$^{\mathrm{M}}$-1: Rel) Enduring object *o* has Φ at t^{F} in Minkowski spacetime $=_{\mathrm{df}}$ *o* bears Φ-at to t^{F}.

(EndST$^{\mathrm{M}}$-2: Ind) Enduring object *o* has Φ at t^{F} in Minkowski spacetime $=_{\mathrm{df}}$ *o* has Φ-at-t^{F}.

(EndST$^{\mathrm{M}}$-3: Avd) Enduring object *o* has Φ at t^{F} in Minkowski spacetime $=_{\mathrm{df}}$ *o* has$_{t^{\mathrm{F}}}$ Φ.

(PerST$^{\mathrm{M}}$) Perduring object *o* has Φ at t^{F} in Minkowski spacetime $=_{\mathrm{df}}$ *o*'s t^{F}-part has Φ.

(ExdST$^{\mathrm{M}}$) Exduring object *o* has Φ at t^{F} in Minkowski spacetime $=_{\mathrm{df}}$ *o*'s t^{F}-counterpart has Φ.

To illustrate, consider the path of a 10-meter pole in Minkowski spacetime. In the rest frame of the pole F_0 its length is 10 meters, the pole's *proper* length. In the reference frame F, uniformly moving in the direction of the pole, this length is Lorentz-contracted to 5 meters. This effect is a spacetime not a dynamic phenomenon and is explained by making precise what is involved in attributing length to an extended object, such as our pole, in a given perspective, or reference frame. Clearly, it involves taking the difference of the pole's ends' coordinates in that frame. These coordinates must obviously refer to the *same* time. Put another way, the events of taking the measurements of these coordinates must be simultaneous and, hence, belong to the same time hyperplane in the reference frame under consideration. Geometrically, the sought-for length is just the length of the t^F-slice through the pole's path. Not surprisingly, it turns out to be different from the proper length of the pole. Ascription of length and of many other physical properties to objects must therefore be relativized to the two-parameter index 't^F'. The endurantist, the perdurantist and the exdurantist discharge this task in their characteristic ways.

On endurantism, the pole is a 3D entity multilocated at all t^F-slices of its path and any such intersection features the full set of properties the pole has at a corresponding time in a given frame, including its length. On (Minkowskian) Relationalism, the pole comes to have the property of being 5 meters long at t^F and 10 meters long at t^{F_0} by bearing the relation *5-meter-long-at* to t^F and *10-meter-long-at* to t^{F_0}.[37] On (Minkowskian) Indexicalism, the pole accomplishes the same task by exemplifying two time-indexed properties, *5-meter-long-at-*t^F and *10-meter-long-at-*t^{F_0}. On (Minkowskian) Adverbialism, the pole possesses the simple property *5-meter-long* in the t^F-ly way, and another such property, *10-meter-long*, in the t^{F_0}-ly way.

On perdurantism, the pole is a 4D entity located at its path and having a distinct momentary t^F-part at each t^F-slice through its path. Saying that the pole is 10 meters long at t^{F_0} and 5 meters long at t^F is made true by the pole's t^{F_0}-part having the former property and its t^F-part having the latter one simpliciter.

On exdurantism, the pole is a 3D entity multiLOCATED at t^F-slices through its path, in virtue of having a t^F-counterpart at each such slice. The pole is 10 meters long at t^{F_0} and 5 meters long at t^F

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[37] Or, in a more precise analysis, to '$\mathbb{O}_{\perp t^{F}}$' and '$\mathbb{O}_{\perp t^{F0}}$'.

courtesy of its t^{F_0}- and t^{F}-counterparts, which have these respective lengths simpliciter.

5. Flat and Curved Achronal Regions in Minkowski Spacetime

In the generic spacetime framework introduced in Section 2, LOCATIONS of persisting objects were indexed to arbitrary achronal regions. The adaptation of the general definitions of the different modes of persistence (and of other important principles, such as Achronal Universalism) to Minkowski spacetime in Section 4 was based on the assumption[38] that persisting objects and their parts are LOCATED (and, consequently, have properties) at *flat* achronal regions representing, in special relativity, moments of time in inertial reference frames. Let us explicitly refer to this assumption as FLAT:

> (FLAT) In the context of discussing persistence in Minkowski spacetime it is appropriate to restrict the LOCATIONS of persisting objects and their parts to flat achronal regions representing subsets of moments of time in inertial reference frames.

Initially one might be inclined to reject FLAT on rather general metaphysical grounds. Consider a *non*-flat achronal slice $\mathbb{O}_{\perp}$ of object *o*'s path in Minkowski spacetime. How could *o* (if *o* endures or exdures), or one of *o*'s diachronic parts (if *o* perdures), *fail* to be LOCATED at $\mathbb{O}_{\perp}$? In other words, how could $\mathbb{O}_{\perp}$ fail to "contain" *o* (or one of *o*'s diachronic parts)? After all, $\mathbb{O}_{\perp}$ is an achronal slice of *o*'s path and is matter-filled; therefore it must

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[38] Shared by a number of other writers; see, in particular, Sider 2001: 59, 84–86, Rea 1998, Sattig 2006: Sections 1.6 and 5.4. Gilmore, who held this assumption in his earlier work (Gilmore 2004), appears to have abandoned it later (see, in particular, Gilmore 2006). Unlike Gibson and Pooley (2006), however, he does not offer any specific criticism of the assumption.

contain *something*! And what could this "something" be except *o* or one of *o*'s diachronic parts?

This general line of thought should be resisted (cf. Gilmore 2006: 210–211), because in turns on conflating the notion of an achronal region's being a LOCATION of *o* (or one of its achronal parts) with the notion of an achronal region's being "filled with achronal material components of *o*." A region may satisfy the latter property without satisfying the former. Imagine Unicolor, a persisting object one of whose essential properties is to be *uniformly colored*. Suppose further that Unicolor uniformly changes its color with time in a certain inertial reference frame F. Consider an achronal slice of Unicolor's path, flat or not, that crisscrosses hyperplanes of simultaneity in F. Whatever (if anything) is LOCATED at such a slice is not uniformly colored and, hence, must be distinct from Unicolor, even though it is filled with the (differently colored) achronal material components of Unicolor.

This shows that general metaphysical considerations are not sufficient to reject FLAT. But notice that the property of being *uniformly colored* used in the above example is itself grounded in a prior concept of spatial or achronal *uniformity*, which, in turn, presupposes that flat achronal regions of Minkowski ST are somehow physically privileged in the context of SR. In a recent work Gibson and Pooley (2006: 160–165) have argued that they are not, thereby presenting a more pointed objection to FLAT. Their objection also raises important methodological questions about the relationship between physics and metaphysics. Below I consider and respond to Gibson and Pooley's objection and, in the course of doing it, address the methodological concerns brought to light in their critique of FLAT.

In Gibson and Pooley's view, the tendency to "frame-relativize" in the manner of FLAT and other similar assumptions, which is adopted unreflectively by several authors discussing persistence in the context of Minkowski spacetime (see note 38), represents a relic of the classical worldview and stands in the way of taking relativity seriously. While inertial frames of reference (i.e., spacetime coordinate systems adapted to them) are geometrically privileged and, therefore, especially convenient for describing spatiotemporal relations in Minkowski spacetime, this does not give them any distinguished metaphysical status. Accordingly (and contrary to FLAT), no such status should be granted to flat achronal regions in Minkowski spacetime. Thus Gibson and Pooley:

> From the physicist's perspective, the content of spacetime is as it is. One can choose to describe this content from the perspective of a particular inertial frame of reference (i.e., to describe it relative to some standard of rest and some standard of distant simultaneity that are optimally adapted to the geometry of spacetime but are otherwise arbitrary). But one can equally choose to describe the content of spacetime with respect to some frame that is not so optimally adapted to the geometric structure of spacetime, or indeed, choose to describe it in some entirely frame-independent manner (Gibson and Pooley 2006, 162).
>
> …
>
> More significantly, one surely wants a definition [of a notion relevant to characterizing a particular mode of persistence in spacetime—Y.B.] applicable in the context of our best theory of space and time, general relativity. While this theory allows spacetimes containing flat spacelike regions, generic matter-filled worldtubes will have *no* flat maximal spacelike subregions. The obvious emendation, therefore, is simply to drop clause (iv) [i.e., FLAT or some analogous assumption—Y.B.] (Ibid., 163).

These remarks contain two distinct points, and both raise important questions. The first point—that inertial reference frames and flat regions in Minkowski spacetime are privileged only geometrically and not physically and, therefore, do not warrant ascribing to them any metaphysical significance in the context of questions about persistence—appears to derive its force from a crucial lesson of the contemporary methodology of spacetime theories: that the choice of a local coordinate system is completely arbitrary and has no bearing whatsoever on the content of a particular spacetime theory.[39] Any such theory—Newtonian mechanics, classical electrodynamics or special relativity—can be formulated in any coordinate system. Moreover, such a formulation can always be made covariant with respect to arbitrary local coordinate transformations, at the cost of making it less elegant. For example, Newtonian mechanics of free particles in Galilean spacetime can be stated in terms of a set of geometrical objects on the manifold:[40] an affine connection *D*, a covariant vector field *dt*, and a two-rank symmetric tensor *h*, satisfying the following field equations:

$$R^{\mu}{}_{\nu\lambda\kappa} = 0\,,\ t_{\mu;\nu} = 0\,,\ h^{\mu\nu}{}_{;\lambda} = 0\,,\ h^{\mu\nu}t_{\mu} = 0$$

and the equations of motion:

$$\frac{d^2x_\mu}{du^2} + \Gamma^{\mu}_{\lambda\kappa}\frac{dx_\lambda}{du}\frac{dx_\kappa}{du} = 0\,,$$

where *u* is a real-valued parameter and ‘;’ denotes covariant differentiation. The above represents the statement of the theory in arbitrary local coordinate systems. As Gibson and Pooley note, a spacetime theory such as Newtonian mechanics can also be given a coordinate-free formulation:

$$K = 0\,,\ \overline{D}(dt) = 0\,,\ \overline{D}(h) = 0\,,\ h(dt, w) = 0$$

where *w* is a covariant real vector field in the cotangent space defined at a given spacetime point.

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[39] See, for example, Friedman 1983: Section II.2.

[40] My outline of this example follows Friedman 1983: 87–94.

It turns out that there is a special sub-class of *inertial* coordinate systems—defined locally by $\Gamma^{\mu}_{\lambda\kappa} = 0$, $t_{\mu} = (1,0,0,0)$, and $h^{\mu\nu} = \delta^{\mu\nu}$ for all μ and ν except $\mu = \nu$ = 0, while $h^{00} = 0$—in which the equation of motion takes the familiar form of Newton's First Law:

$$\frac{d^2 x_{\mu}}{dt^2} = 0 .$$

Although this fact obviously has enormous practical significance: it allows us to use a simple expression of Newton's First Law in a great variety of practical applications, the fact that such frames exist has no physical importance. Indeed, suppose a certain particle performs a non-inertial motion. One could then associate with it a series of instantaneous rigid Euclidean systems, for which $\Gamma^{\mu}_{\lambda\kappa}$ will not vanish, and recover the equation of motion (Friedman 1983: 83):

$$\frac{d^2 x_{\mu}}{dt^2} + a^{\mu} + 2\Omega^{\mu}_{\nu} \frac{dx_{\nu}}{dt} = 0 ,$$

where $x_{\mu}(t) \equiv x_{\mu} \circ \sigma(t)$ is a family of continuous and differentiable real functions of the time-parameter *t*, $a^{\mu} \equiv \dfrac{d^2 x_{\mu}}{dt^2} + \Gamma^{\mu}_{\lambda\kappa} \dfrac{dx_{\lambda}}{dt} \dfrac{dx_{\kappa}}{dt}$ is the acceleration and $\Omega^{\mu}_{\nu} \equiv \Gamma^{\mu}_{0\nu} = \Gamma^{\mu}_{\nu 0}$ is an antisymmetric rotation matrix. This equation of motion features the inertial force a^{μ} associated with the acceleration of the rest frame of the particle and the Coriolis force $2\Omega^{\mu}_{\nu} \dfrac{dx_{\nu}}{dt}$ associated with its rotation.

The point to note here is that the presence of straight non-achronal "position lines," which allow one to identify spatial positions at different times in perspectives associated with inertial coordinate systems, has no physical consequence. Based on this point, one could argue that position in space, as defined in a *given* inertial frame, is a rather thin notion that hardly bears the weight attributed to it in many metaphysical discussions—even in the context of classical physics.

And things get worse. Even in *that* context, one can choose to "geometrize away" gravitational forces by incorporating the gravitational potential into the affine connection (Friedman 1983: 100):

$$\Gamma^{\mu\,\prime}_{\lambda\kappa} = \Gamma^{\mu}_{\lambda\kappa} + h^{\mu\lambda}\Phi_{;\lambda}t_{\lambda}t_{\kappa}$$

at the cost of making the classical spacetime non-flat (i.e., by making it curved).[41]

This example shows that, *even in the classical context*, the presence of a well-defined family of straight diachronic position lines and the usual assumption that the spacetime as a whole is flat have no physical significance. Does this mean that one should ban familiar notions, such as *same place over time in a given inertial frame*, from philosophical discussions tailored to the classical context, simply because inertial frames and straight achronal lines enjoy no special status at the fundamental level of physical description?

Hardly so. Banning such notions would deprive one of many useful resources in the situation where such resources are *available*. Note that the issue does not concern the retention of the notion of *sameness of place over time*, period (even the classically-minded metaphysician can be convinced that the latter notion *is* meaningless), but only the significance of the notion of sameness of place over time *in an inertial frame*. This notion provides resources for imposing on spacetime a global coordinatization and assigning to such coordinatization various conceptual roles. It would appear that the metaphysician should feel free to make use

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[41] We shall not pursue this further. See Friedman 1983: 95–104 for details.

of the familiar concept of sameness of place across time (against the backdrop of a particular inertial frame)—as long as such a concept is definable—even if physics, in the end, denies distinction to inertial frames.

Two facts seem to be relevant here: (i) that global inertial coordinate systems are *available* (despite the lack of physical importance) and (ii) that their availability allows one to *minimize revision* of the existing ontological vocabulary. The above brief excursus into Newtonian mechanics should serve to support (i). (ii), on the other hand, raises more general considerations having to do with philosophical methodology.

It is a well-known fact that most contemporary discussions in fundamental ontology[42] continue to be rooted in the "manifest image of the world" and ignore important physical developments, which have rendered many common-sense notions untenable and obsolete. Attempts to bring physical considerations to bear on issues in fundamental ontology, such as those discussed in this paper, are still very rare. This persistent self-isolation of contemporary metaphysics from science may prompt at least two different reactions from philosophers who are wary of "armchair philosophical speculation." One may be tempted to reject such speculation, root and branch, and adopt the following attitude: let physics tell us what the world is like and then let the "metaphysical chips" fall where they may. It is unclear whether any part of the contemporary metaphysical agenda would survive such a treatment. But it is equally unclear whether any consistent world view could emerge from it. Science is an open-ended enterprise which is becoming increasingly fragmented. The same is true of any particular scientific discipline, such as physics. The question of what parts of contemporary fundamental physics could contribute safe and reliable components to the foundations of an overall world view is a highly complex question, which may not have a good answer.

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[42] I.e., discussions of such issues as time, persistence, material composition, the nature of fundamental properties and laws, etc.

This suggests a different attitude. One may admit that the prolonged mutual alienation of metaphysics and physics is unfortunate but insist that both have some value in their *current* state, and could therefore benefit from gradual rapprochement. It should be clear that the present paper follows the second course. It should also be clear that this course brings with it certain limitations. One of them has to do with the choice of the physical theory (or theories) under consideration. Given the open-ended nature of physics any physical theory is likely to be false. But one hopes that some theories are good approximations to the truth, and to the extent that they are, adapting existing metaphysical views to them is valuable. The scope of the present consideration does not go beyond special relativity. This represents a particular choice and brings with it quite obvious restrictions.

Even more important, when engaged in extending an existing metaphysical debate to a new physical framework one confronts non-trivial judgment calls at many turns, when it becomes clear that some familiar notions must be abandoned, others modified, while others can be kept more or less intact. Usually there is more than one way to "save the philosophical appearances," but the decision as to what "intuitions" must be retained at the expense of others is difficult because one is now swimming in uncharted waters. In the end, it is the entire resulting systems and their performance across a variety of theoretical tasks that must be compared. I submit that the only reasonable regulative maxim to be imposed on physically-informed metaphysical theorizing should be stated in terms of *Minimizing the Overall Ontological Revision* (MOOR). Vague as it is, its role could be favorably compared to Quine's famous criteria of "conservatism," "the quest for simplicity" and "considerations of equilibrium" affecting the "web of belief as a whole":

(MOOR) In adapting a metaphysical doctrine to a physical theory one should seek to minimize the degree of the overall ontological revision.

As we depart from the "comfort zone" of the classical world view, the degree and extent of the "overall ontological revision" become progressively up for grabs, which makes MOOR increasingly wholesale and non-specific. But as indicated above, any alternative to MOOR would amount to rejecting the entire agenda of contemporary metaphysics. I should emphasize that the latter is not what Gibson and Pooley undertake to do in the above-quoted work (Gibson and Pooley 2006). Having noted that they have "a lot of sympathy" for the view that "the project of reconstructing relativistic version of familiar non-relativistic doctrines [may be] horribly misguided,"[43] they "nonetheless think that it is worthwhile to engage with attempts to square the familiar doctrines with relativity" (ibid.: 157–8). Such attempts, I recommend, must be guided by something like MOOR.

Returning (finally) to FLAT, I contend that it conforms to the spirit of MOOR quite well. Indeed FLAT employs structures (viz., global flat hypersurfaces) that are (i) available in Minkowski spacetime, (ii) widely used in physics, and (iii) are indispensable to extending the important notions of moment of time and momentary location of an object or its part (in a given reference frame) to the special relativistic framework. In this respect, FLAT is on a par with the license to attribute metaphysical importance to a family of straight positions lines in classical spacetime despite the fact that, at bottom, straight diachronic lines do not enjoy (*even* in Galilean spacetime) any physical privilege over curved diachronic lines. The important facts are that (i) straight lines are *definable* in that context and that (ii) without their presence, the notion of "place over time in a given frame" would get completely out of touch with any familiar notions. For similar reasons, global hyperplanes can be assigned important metaphysical roles in Minkowski spacetime. First, they are easily definable as such. Second, if they lose their privilege over arbitrary achronal hypersurfaces vis-à-vis issues of persistence, the notion of *momentary* location of a

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[43] "Should we not start with the relativistic world picture and ask, in that setting and without reference to non-relativistic notions, how things persist?" (Gibson and Pooley 2006: 157–8)

persisting object—and, with it, the host of other notions tied up to momentary location, such as momentary shape, momentary achronal composition, and the like—would lose much of their ground and would be hard to connect to any familiar concepts. They would become too remote to perform any meaningful function in a metaphysical debate.

I conclude that FLAT is justified in the context of Minkowski spacetime. But I fully agree with Gibson and Pooley that it is not appropriate for *general* relativistic spacetime, where matter-filled flat achronal regions are *not available*. Since that context has no place for global "moments" of time and "momentary" locations, the connection with the familiar set of notions is severed anyway and there is no pressure to align other concepts with them. In general relativistic spacetime it is only natural to regard any achronal slice of an object's path as a good candidate for the object's (or its part's) location—if one thinks that the notion of location continues to make any sense there.[44,45]

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[44] My consideration is restricted, for the most part, to Minkowski spacetime of special relativity, which, for the purpose of discussion, is taken to be a good approximation of the spacetime of our real world. Even so, the issue of the status of curved hypersurfaces in Minkowski spacetime is more interesting than it might appear. Some facts about such hypersurfaces are non-trivial and notable in their own right. For discussion of one such fact, see Balashov 2005: Section 9 and Appendix.

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