CONTINUANTS AND TEMPORAL PARTS

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The fourdimensional view of material objects and the idea of temporal parts are considered as two sides of the same coin known as worm theory. As it is argued, objects extended in space have spatial parts while temporally extended objects have temporal parts. The aim of the paper is to show that the notion of temporal part is frame-relative and that its role in the ontology of fourdimensional objects is often overestimated and misconceived by the defenders of fourdimensionalism.

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1. Temporal parts. One of the major theories of material continuants in today's analytic metaphysics is the so-called "worm theory". It is based on several assumptions: (a) material objects are fourdimensional, extended in three spatial dimensions and one temporal, (b) the temporal dimension is fixed and every instant of time objectively exists, and (c) fourdimensional objects persist by having temporal parts at different temporal locations.[1] Let us define the notion of temporal part as follows: x is a temporal part of y if and only if there is a period of time T such that x and y both exist throughout T, and no part of x exists at any time outside T, and at every instant during T, x occupies a subregion of the region of space occupied by y.[2] For instance, your body occupies a range of spatial locations at a given instant of time, and the chunks of the body occupying these locations are your spatial parts. Your body doesn't have spatial parts only in one instant (present), but in every moment of its existence (past, present and future). And the chunks of your body that exist at different temporal moments are your temporal parts: you exist at t_1 (be it past, present or future temporal moment) and so there is your t_1 temporal part; you exist at the time interval $t_2 – t_7$ and so there is your $t_2 – t_7$ temporal part, and so forth. An aggregate of such parts constitutes a spacetime worm – a fourdimensional continuant.[3]

Nevertheless, the notions of temporal part and fourdimensional object are the sub-

[1] Fourdimensionalism – a view according to which the world is a fourdimensional manifold – is presumed in (a), (b) expresses a static view of time, and (c) perdurantist theory of persistence. See also Rea's conceptual and terminological introduction to fourdimensionalism (Rea 2003, 247).

[2] I thank the anonymous reviewer for suggesting this definition.

[3] The main competitors to worm theory are threedimensionalism and stage theory. Threedimensionalism denies temporal parts and believes that objects persist as wholes (Rea 2003, 247; Sider 2001, 53, 64). The stage theory (Sider 2001, 191) admits temporal parts but undermines their aggregates (spacetime worms).

jects of various ontological interpretations. There is an important debate whether temporal parts are temporally extended. According to one view, they are instantaneous entities with zero temporal extension – three dimensional, spatially extended cross-sections of fourdimensional continuants, e. g. your t_1 temporal part (Howley 2001, 48-9; Sider 2001, 59). On the other hand, some defenders of temporal part ontology admit temporal parts with a non-zero temporal dimension. Within this framework, temporal parts are fourdimensional segments of larger, fourdimensional wholes, e. g. your $t_2 - t_7$ temporal part (Sider 2001, 60). Still, both parties to the disagreement believe that any temporal part of yours is shorter-lived than you (Sider 2001, 2). It isn't our aim to solve this dispute here, because our conclusions don't depend upon this discussion. Nonetheless, in order to bring the exposition as close to ordinary material continuants as possible, I have decided to prefer temporally extended temporal parts because of certain psychological prejudices against the notion of instantaneity.

By ordinary material continuant we will mean an impenetrable particular with a definite mass and a definite spatiotemporal location.[4] This sort of entity is depicted either as a worldline or as a worldtube in spacetime diagrams. The worldlines represent paths of entities with zero spatial dimension in spacetime (point-like objects), but our interest focuses on continuants with a non-zero spatial dimension. Spatially extended bodies, unlike point-like objects, are closer to our intuitive understanding of ordinary material continuants. Let O be such an entity:

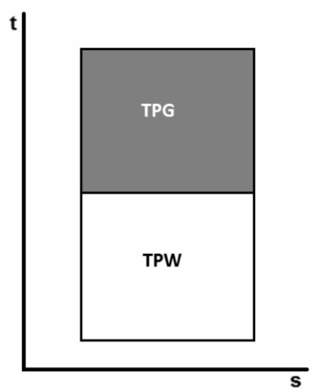

Fig. 1. Object O and its white and grey temporal parts in (s,t) reference frame.

O is extended in both spatial (s-axis) and temporal (t-axis) dimensions – O is fourdimensional.[5] At a certain moment in time, it suddenly changes colour from white to grey. TPW denotes O before the change and TPG after the change. Hence Fig. 1 depicts

[4] Thus the paper doesn't touch massless objects with indefinite locations in spacetime, such as quantum particles.

[5] The two-dimensionality of the picture forces us to suppress two spatial dimensions in Fig. 1.

a worldtube consisting of two segments, two temporal parts. TPW stands for the O's white temporal part, TPG for its grey part. It should be stressed that O in Fig. 1 is depicted from the perspective of the (s,t) reference frame, according to which it is stationary. Hyperplanes of simultaneity are orthogonal to the t-axis, and so is the black line that separates TPG from TPW. Consider, however, a different frame according to which O is in relative motion.[6] The simultaneity planes have changed their positions, and events that were simultaneous in the previous frame become non-simultaneous in the new one:

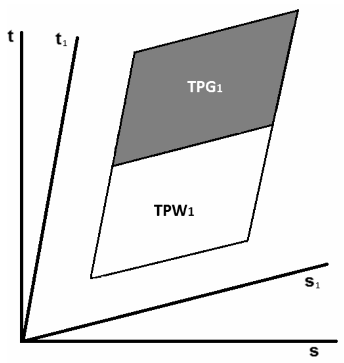

Fig. 2. O's colour change from the (s_1,t_1) reference frame.

The temporal parts of O have changed their shapes and positions. O's lower and upper horizontal boundaries are not parallel to the s-axis, and the same holds for the line separating O's white and grey temporal parts. Its vertical lines lean to the right (run parallel to the t_1- axis) as a result of O being in relative motion. Our plan is twofold: Demonstrate that TPW and TPW_1 (and TPG with TPG_1) are not the *same* temporal parts in different frames, but *distinct* temporal parts, and demonstrate that the difference between them is not perspectival, but thoroughly ontological. If that is the case, then it is easy to argue that worm theory, which bases the ontology of continuants on temporal parts, precludes the existence of frame-invariant material bodies. A worldtube which is nothing over and above its frame-relative temporal parts is frame relative as well. As a result, O in one reference frame necessarily differs from O in the other frame, which is a serious ontological consequence. The question is whether the friends of worm theory are willing to pay its price.

2. Temporal parts in different frames of reference. There is an unquestionable assumption that two objects with different shapes occupying different areas of spacetime are qualitatively and numerically distinct entities. As will be argued, this assumption is applicable to the temporal parts of O in different frames of reference. Observers from different

[6] A systematic exposition of temporal parts within the relativistic framework can be found in Balashov's and Gilmour's papers (Balashov 2000, Gilmour 2006).

frames view the colour distributions, shapes and positions of O's temporal parts differently.[7] We will consider the worldtube of O in the (s,t) reference frame and see how its grey temporal part is projected in the (s_1,t_1) frame.

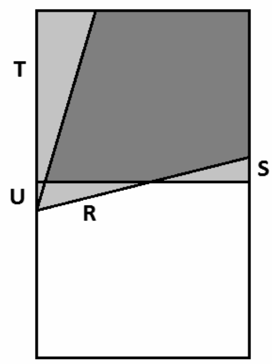

Fig. 3. The grey temporal part of O in the (s,t) reference frame and how it is projected in the (s_1,t_1) frame.

The regions R, S, T and U are subject to disagreements between the observers from the (s,t) frame of reference (Observer A) and the (s_1,t_1) frame (Observer B). Observer A would claim that regions R and U in Fig. 2 are parts of O's white temporal part, while Observer B would disagree. From the perspective of the B observer, region R is grey and regions U and T are neither white nor grey because they are not even occupied by O from the perspective of (s_1,t_1). Region S is grey for observer A, while it is white for the B observer. According to relativity theory, both parties to the dispute are correct. The fact that different shapes imply different exact locations is trivial in everyday experience, yet important in our context. TPW and TPW_1 have different shapes formed by relativistic differences in the distribution of white and grey colours on object O, which implies that their exact locations must differ as well. The same conclusions apply to TPG in relation to TPG_1. It is obviously true that objects with different shapes must occupy different areas of spacetime.[8] We can demonstrate this argument by drawing lines separating O's temporal parts in different frames:

[7] One is inclined to say that O itself changes. Its colours, shapes and positions are distinct in different frames of reference too. This conclusion, however, holds only if O is nothing over and above its temporal parts, which is a principle to be rejected in the next part of the paper.

[8] However, partial colocation is admittable. This is explained soon below.

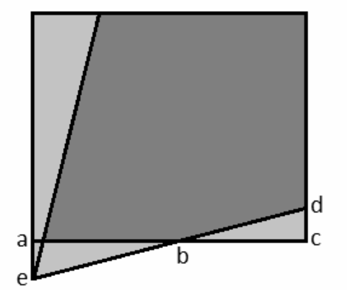

Fig. 4. Lines separating O's temporal parts in the (s,t) and (s_1,t_1) reference frames.

The line between the points **a** and **b** lies in the absolute future of the line connecting **e** with **b**. This means that events on the first line have no actual or potential influence on events lying on the second.[9] The lines are simply two distinct cross-sections of the worldtube. The same holds true for the line between **b** and **d** in its relation to the line connecting **b** with **c**. The relation of "being in the absolute future of" is frame invariant according to relativity theory, and so every observer would regard the considered lines as distinct. Thus the borderlines dividing O into its temporal parts are, in different frames of reference, distinct entities – distinct sets of point-like events.[10] If the borderline between O's temporal parts is not frame invariant, then the overall shape of the temporal part is not invariant either. TPW and TPW_1 along with TPG and TPG_1 are qualitatively distinct segments of O. Similar relativistic shifts in positions and locations concern other boundary lines of O's temporal parts, which fosters the argument about their frame-dependent nature.

As has been stressed several times, different shapes correspond to incompatible spatiotemporal locations. The spacetime region occupied by TPW is not identical to the region occupied by TPW_1, i.e. it doesn't exactly match the region occupied by TPW_1. The same holds for TPG in relation to TPG_1, although partial colocation is natural. It is natural because, as will be explained in the next part of the paper, they are ontologically dependent parts of a larger physical system – the worldtube of O. The differences between O's temporal parts in various frames of reference are not, however, restricted to their shapes and locations. There are also differences in causality, which is another reason to consider O's temporal parts as frame dependent. Observer A sees O's colour change, in her reference frame, as sudden, whereas events on the line between TPW_1 and TPG_1 constitute, from the perspective of (s,t), a temporally extended process of gradual colour change. Surprisingly, the colour change of O is also sudden for the B observer in her frame of reference, and the B observer would report that the events on the line separating TPW and TPG represent (contrary to the A observer) a gradual process of O's colour change.

[9] This idea is borrowed from Gilmore (Gilmore 2006, 215-216).

[10] Every point of the spatiotemporal diagram is either an actual or a potential point-like event (due its zero spatial extension), and so it is natural to consider a line as a series of point-like events.

Therefore different observers may even ascribe different causal profiles to O's temporal parts, caused by the distinctions between their reference frames.[11]

What should one say about two bodies with qualitative differences occupying distinct areas of spacetime? The answer is obvious: they must be distinct. As has been indicated, our proposal is that the difference between temporal parts in distinct frames of reference is not merely perspectival, but deeply ontological.

3. Temporal parts and worldtubes. Are TPW and TPG taken together identical to the worldtube of object O? If O is a mere composite of its temporal parts (Haslanger 2003, 318), then O should be nothing over and above TPW and TPG. But this is obviously false because in the (s_1,t_1) frame of reference, O is composed of distinct temporal parts: TPW_1 and TPG_1. Nevertheless, according to the composition as identity principle (CI), the whole is identical to its parts (Wallace 2011, 804) in at least two different senses. Strong CI implies numerical identity between parts and the whole, whereas weak CI only implies qualitative similarity (Wallace 2011, 806). Frame-relative temporal parts, as building blocks of spacetime worms, exclude strong CI. Worldtube O can't be numerically identical to two different sets of temporal parts – TPW+TPG and TPW_1+TPG_1. On the other hand, O is qualitatively similar both to TPW+TPG and TPW_1+TPG_1. Worldtube O is partly white because TPW and TPW_1 are white and partly grey because TPG and TPG_1 are grey. Wallace draws attention to Butler's distinction between strict and loose identity (Wallace 2011, 801), suggesting that the distinction is similar to the distinction between strong and weak CI. Strong CI implies strict identity and weak CI loose. If what has been said is true, then aggregates of temporal parts imply only loose identity conditions on the spacetime tubes they belong to. What else then contributes to the identity conditions of the worldtubes?

This question has been discussed for decades in physics. The situation was complicated enormously by the arrival of quantum particles, whose worldlines can collocate, intersect and whose locations in spacetime can be indefinite and occurrence probabilistic. Nonetheless, we have avoided these difficulties by considering worldtubes of classical impenetrable material bodies with exact spatiotemporal positions. Howard, following Einstein, proposes spatiotemporal separability as a fundamental attribute that lies behind identity and individuation in modern physics: *Separability seems to be necessary for the purpose of dividing the world up into parts, this being necessary in order for us to be able to make statements about the parts. We need some conventional specification of what is to count as a system, and Einstein can see no objective way to do this other than via the scheme of individuation implicit in the separability principle* (Howard 1997, 122).

Two physical systems are separated if they are spatiotemporally distinct – if the spatiotemporal interval between them has a non-zero quantity. Einstein applied this principle to spacetime events and Howard ascribes it to worldlines and worldtubes. Worldtubes of

[11] This is not surprising. As electromagnetism proves, some causal relations do vary depending on the perspective. One and the same physical process can be associated with distinct forces (magnetism or electric force) due differences between reference frames.

two physical systems separated by a non-zero spatiotemporal interval in their causal pasts remain individuated unless the worldtubes intersect in their causal futures (Howard 1997, 132–33).[12] As a matter of fact, the spacetime interval between TPW and TPG (and also between TPW_1 and TPG_1) in Fig. 1 is zero, and so, according to the separability principle, they are not individuals but parts of a larger system. The larger system, in their case, is the worldtube of O. Following Einstein and Howard, individuality and individuation is applicable only to separate systems, which disqualifies inseparable temporal parts from being genuine individuals. This conclusion will be given a more precise interpretation, but before doing so, here is a complete list of the conclusions we have reached thus far:

1. Worldtubes of impenetrable material objects are not mere constructs of temporal parts.
2. Temporal parts impose only loose identity conditions on worldtubes.
3. Temporal parts are frame relative.
4. Temporal parts are not genuine individuals.

Depriving temporal parts of individuality is the most controversial claim. I suggest reading the phrase "not a genuine individual" in the sense that temporal parts lack *intrinsic* identity conditions. This doesn't mean that they can't be individuated at all. Esfeld deploys the notion of relational (extrinsic, contextual) identity as opposed to intrinsic (Esfeld 2009, 180). This means that objects are individuated due to the positions and roles they play as constituents of larger physical systems. Esfeld and Lam show us an example of spacetime points that can't be individuated independently of the metrical relations in which they stand (Esfeld and Lam 2008, 37-38), and a similar strategy can be used in the case of temporal parts and worldtubes. Howard's separation principle is implicitly also contextual, because the identity conditions of a worldtube can't be set independently of its relations to other worldtubes and worldlines. Remember, separation (individuation) is violated if two worldtubes intersect, but this relationalism is a part of definition, not of reality. It merely helps us to determine what it is to be an individuated worldtube, whereas the identity of temporal parts is relational in a stronger sense. The identity of a temporal part depends on two factors: worldtubes and reference frames. In order to individuate a particular temporal part, we need to know of a worldtube it is part of and a reference frame that "carved it out" of that worldtube (Balashov 2000, 333). A worldtube, unlike a temporal part, has an invariant shape (Balashov 2000, 333) and a definite position in spacetime, which is presupposed by the separation principle. Moreover, ontological dependence of temporal parts on worldtubes is accompanied by explanatory dependence: *Hence the properties of its 3D parts are directly inherited from the properties of the 4D whole: the latter bear an ancestral relation to the former. The explanatory power of this account rests on the fact that four-dimensional space-time entities are relativistically*

[12] This approach to individuality seems to be confined to the realm of classical physics, which undermines Howard's intention to broaden its application to the quantum world (Jaeger 2010, 1402). If true, then this limitation is a serious problem for Howard, but not for us, because our continuants are defined in terms of classical physics.

invariant: they can objectively stand behind all their 3D parts, much in the way usual three-dimensional objects in space stand behind all their perspectival plane projections (Balashov 2000, 333-334).

Shapes and locations of temporal parts are easily explained by reference to invariant tubes and the ways they decompose in various reference frames in accordance with the principles of relativity theory. If the explanation avoids worldtubes, then it would be a mystery why (a) some fusions of temporal parts comprise "nice" fourdimensional volumes in spacetime (Balashov 2000, 334), (b) why they have the shapes they actually have, and (c) why they are located where they are. With worldtubes and reference frames at hand, the explanations are simple: start with a fourdimensional object and then "slice" it in various ways to produce temporal parts (Balashov 2010, 334) with specific shapes and locations. Slicing is not possible if fourdimensional invariants are not considered, and many facts about temporal parts would remain unexplained. I think this suffices to show that a successful account of fourdimensional material continuants should give ontological and explanatory priority to worldtubes and worldlines instead of temporal parts. Temporal parts are not fundamental building blocks of worm theory, as many fourdimensionalists wrongly assume.

4. Conclusion. Fourdimensionalism is viewed as a naturalistic approach in modern analytic metaphysics that draws serious ontological consequences from current scientific theories. For instance, the static view of time, borrowed from special relativity, fuels some of the main arguments in favour of the objective existence of temporal parts (Rea 2003, 269). However, as we have seen, relativity theory is not a true friend of temporal part ontology because it makes temporal parts frame-relative and thus ontologically dependent on worldtubes and observers. Temporal parts are not fundamental building blocks of fourdimensionalism, and this should force a defender of worm theory to reconsider some of her central beliefs. Perdurantism and genidentity relation are good examples. The perdurantist position according to which objects persist by having different temporal parts at different temporal locations must be relativized to particular frames of reference.[13] This necessary move has some unwelcome consequences. For instance, object O persists differently in every reference frame, which is what, I believe, a defender of perdurantism doesn't want to say. If temporal parts are frame relative, then an account built on them must be, in a certain sense, relativistic too. The non-relativistic persistence of fourdimensional material bodies must differ from perdurantism as we know it now.

Genidentity relation is a relation that is assumed to hold between temporal parts of the same continuant (Armstrong 1980, 68; Sider 2001, 224-225).[14] The relation is needed if too much ontological weight is put on temporal parts. Within this line of thought, the ontology of material continuants begins with temporal parts, followed by a search for the absence or presence of the genidentity relation. Its presence signals that the given tempo-

[13] Since temporal parts can't be properly indexed by times within the relativistic setting, Balashov introduces time-like parts as proper counterparts of pre-relativistic temporal parts (Balashov 2000, 331).

[14] Genidentity is usually reduced to the spatiotemporal continuity of temporal parts, their qualitative similarity or interactions rooted in immanent causation (Armstrong 1980, 74-5; Sider 2001, 225).

ral parts belong to the same fourdimensional worm; its absence means that the temporal parts belong to different continuants. Genidentity relation is supposed to be a necessary ingredient of fourdimensional ontology because it stands (together with temporal parts) behind the identity and persistence of fourdimensional wholes. We have questioned this approach and, instead, based identity and persistence on fourdimensional wholes themselves. The relativistic segments of worldtubes and the relations between them should be rejected as identity-defining features of material bodies. Nevertheless, the non-relativistic versions of perdurantism and genidentity relation require accounts of their own.[15]

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