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ARTICLE

Four Degrees of Temporal Becoming

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Abstract
The block universe theory of time is commonly held to be incompatible with temporal becoming. This confuses Maudlin who upholds both eternalism and passage. The aim of this paper is to answer Maudlin's plea for clarification by distinguishing four degrees of temporal becoming: (1) absolute becoming, (2) relational becoming, (3) presentist becoming, and (4) dynamic becoming. After discussing their respective compatibility with the block universe, I argue that Maudlin subscribes to a much more deflated form of temporal becoming as compared to most philosophers of time. Consequently, his form of becoming is compatible with the block universe, whereas the stronger forms of becoming are not.

Keywords Temporal becoming · Block universe · Passage of time · Absolute becoming · Relational becoming · Dynamic becoming

The Moving Finger writes; and, having writ,
Moves on: nor all thy Piety nor Wit
Shall lure it back to cancel half a Line,
Nor all thy Tears wash out a Word of it.
— The Rubáiyát, Omar Khayyám
(Quoted from E. FitzGerald 2009, 41).

1 Introduction

An invitation for clarification. In a recent book symposium on Bradford Skow's *Objective Becoming* (Skow 2015), Tim Maudlin (2018) distinguishes the philosophers of time (such as Skow) from the philosophers of physics (such as Maudlin himself). According to him, both groups have deep interests in the nature of time, but their lingo only partly overlaps. Philosophers of time write about 'tensed' and 'tenseless' theories of time, and about 'A-theories' and "B-theories", whereas philosophers of physics do not.

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"I am not a philosopher of time", confesses Maudlin (2018, 1807). "And for the life of me, I still don't know whether the views I hold [⋯] constitute a 'tensed' or 'tenseless' view; an 'A-theory' or a 'B-theory' " (Maudlin 2018, 1808).[1] Another terminological source of confusion to Maudlin is Skow's use of the terms 'anemic' and 'robust' when discussing change and passage.

Perhaps most troublesome to Maudlin is the alleged *incompatibility* between the block universe (BU) theory of time and robust passage.[2] Indeed, most philosophers of time seem to agree that if the BU theory holds true, then time does not pass. Maudlin, on the other hand, believes he is committed to both the BU theory of time *and* passage, and does not see the problem with that.[3]

The aim of Maudlin's book review, therefore, is twofold: first, to critically comment on Skow's *Objective Becoming* (and in particular, on his use of the terms 'anemic' and 'robust'); secondly, and perhaps more importantly, to ask Skow and the other philosophers of time for clarification. "I just want to know where [my views] fit in the usual set of distinctions", writes Maudlin (2018, 1808)—hoping that such an elucidation will help to reunite both camps. " 'Tis a consummation devoutly to be wished", he concludes (Maudlin 2018, 1814).

Four degrees of temporal becoming. The goal of the present paper is to answer—at least in part—Maudlin's plea for clarification by distinguishing *four degrees of temporal becoming*: (1) absolute becoming, (2) relational becoming, (3) presentist becoming and (4) dynamic becoming.[4] The higher the degree, the stronger the form of becoming and, I argue, the less compatible with the BU ontology.

I will show that Maudlin's view on the passage of time corresponds to a form of relational becoming, whereas Skow's view on robust passage corresponds to a form of dynamic becoming. Maudlin thus subscribes to a strongly deflated form of becoming as compared to Skow's robust becoming. This, I contend, explains why Maudlin maintains the passage of time to be compatible with the BU, while Skow does not.

Outline. My paper is divided into two parts. In the first part (Sect. 2), I offer a tentative characterisation of the notion of temporal becoming. I use it to distinguish four degrees of temporal becoming and subsequently take a closer look at each form of becoming (Sects. 2.1, 2.2, 2.3 and 2.4).

In the second part (Sect. 3), I briefly discuss the compatibility of each form of becoming with the BU. I show that absolute becoming is the only form of becoming which is truly compatible with the BU. But I argue that this form is too deflated to be worthy of the name 'becoming'. Indeed, as far as I know, no-one actually subscribes to this view. Presentist becoming and dynamic becoming, on the other hand, are clearly incompatible with the BU. The situation, I conclude, is much less clear when it comes to relational becoming.

[1] In his reply to Maudlin, Skow (2018a) briefly addresses this issue, but Skow seems to be as confused about Maudlin's views of time as Maudlin is about Skow's.

[2] Maudlin (2018, 1809) thus writes: "when Skow frames the debate as between 'the block universe and robust passage' I am again stymied".

[3] The views of Skow and Maudlin actually do not seem to diverge that much. Skow (2018a, 1822), for one, admits that: "I accept the block universe theory, and I also think that time passes".

[4] The four degrees of temporal becoming, to be outlined in this paper, are not related to the four kinds of temporal becoming as outlined in Fitzgerald (1985).

2 Four Degrees of Becoming

Time's wingèd chariot. Everyone is familiar with time's transitory character. We all share the impression that time *flows* or *passes*. But does it really? Is the flow of time—or *temporal becoming* as philosophers like to call it—an objective feature of reality, or is it (merely) a subjective feature of human experience? Does temporal becoming belong to physics or to psychology? Is it part and parcel of the scientific image or of the manifest image?

In this paper I will entertain the former position. In accordance with Norton (2010, 24), I will treat our sense of temporal passage as reflecting "a fact about the way time truly is, objectively". That is, even if we were not around to experience it, the passage of time would still obtain.

A first question then is: What exactly does the passage of time consist in? According to Pooley (2013, 321), "time's alleged passage is notoriously difficult to pin down". Humankind has used all kinds of metaphors to capture time's transitory aspect. Omar Khayyám's quatrain at the beginning of this paper is but one poetic attempt at capturing time's relentless march from past to future. The romantic poet Charles Cowden Clarke in his 1875 sonnet *The Course of Time* referred to "the vast wheel of time, That round and round still turns with onward might", whereas George Santayana (1938, 85) compared "the essence of nowness" to fire running "along the fuse of time".

Making sense of passage. Unfortunately, all of these metaphors remain vague and incomplete at best, or downright wrong and misleading at worst. So how is one to characterise the passage of time in non-metaphorical terms? Here is a recent attempt by Norton (2010, 24):

> Time passes. Nothing fancy is meant by that. It is just the mundane fact known to all of us that future events will become present and then drift off into the past.

Smart (1949, 483) likewise said that events "approach from the future, are momentarily in the present, and then recede further and further into the past". As time passes, in other words, the history of our world unfolds. To many, this strongly suggests there being a unique set of global NOWS successively coming into being. The passage of time then refers to the movement of this objectively privileged present along the temporal dimension (more on this in Sects. 2.3 and 2.4).

Three paths to passage. On the basis of this (admittedly still rough) characterisation of temporal becoming, Price (2011, 210) has identified three paths to passage—three requirements that should be satisfied if we are to fully capture our intuitive notion of the passage of time:

(1) *Temporal orientation:* The view that time has an objective *direction*; that it is an objective matter which of two non-simultaneous events is the *earlier* and which the *later*;
(2) *Distinguished present:* The view that the *present moment* is objectively distinguished;
(3) *Dynamic flow:* The view that there is something objectively *dynamic*, flux-like, or 'flow-like' about time.

Four degrees of temporal becoming. In what follows, I will speak of *dynamic becoming* (or *dynamic passage*) when all of Price's requirements are met. It should be clear, however, that weaker (deflated) notions of becoming can be obtained by satisfying only one or two of the above requirements.

One could, for instance, endow the spacetime under consideration with a temporal orientation and an objectively privileged present, without making that present move—thereby meeting requirements (1) and (2), but not (3). Or one could introduce a temporal orientation, and leave it at that—satisfying requirement (1), but not (2) and (3). Some even claim that sense can be made of temporal becoming without meeting any of the above requirements.

Clearly then, four kinds of temporal becoming can be distinguished (Table 1). A precise definition of each kind of temporal becoming will be provided further on. For the moment, suffice it to say that as you go down the list, more requirements are met, resulting in stronger kinds of becoming. We thus obtain a hierarchy of forms—or degrees—of temporal becoming, with absolute becoming the weakest, and dynamic becoming the strongest form of temporal becoming.

Each kind of temporal becoming presupposes the previous kinds. That is, relational becoming presupposes absolute becoming; presentist becoming presupposes relational becoming; and dynamic becoming presupposes presentist becoming.

The distinction between absolute and relational becoming was first made by Dorato (2006).[5] Both absolute and relational becoming are examples of what I will call *tenseless* becoming, or B-series becoming. Presentist becoming and dynamic becoming, on the other hand, are examples of *tensed* becoming, or A-series becoming. Absolute, relational and presentist becoming are *static* (Parmenidean) forms of becoming, whereas dynamic becoming is obviously *dynamic* (Heraclitean).[6] Once again, what Price (2011) calls real, objective becoming corresponds here to dynamic becoming.

Unfortunately, these four kinds of becoming are often conflated in the philosophical literature. As a result, many philosophers of time and physics talk past each other, muddling an already muddled debate.[7] In what follows, I critically discuss each kind of temporal becoming (Sects. 2.1, 2.2, 2.3 and 2.4), before gauging their compatibility with the BU theory of time (Sect. 3).

One last remark: in order to keep the discussion focused, I will limit myself to a study of temporal becoming in a (special or general) relativistic setting. That is, I will not analyse the nature of becoming in quantum mechanics, quantum field theory or theories of quantum gravity.

2.1 Absolute Becoming

The notion of absolute becoming has been independently defended by Savitt (2002), Dorato (2002, 2006), and Dieks (2006) in an attempt to make room for temporal becoming in the BU. Compared to the other kinds of becoming, this is by far the most *deflated* form. The coming into being of an event, on this account, is nothing but its happening. "Events come into being by occurring, by happening", holds Dieks (2006, 170), "what other coming into being could there be?" Here then is my definition of absolute becoming (see also Dorato 2006):

[5] Note that this distinction is completely unrelated to the debate on whether space and time are absolute or relational in character.

[6] These notions will be further explained in the Sects. 2.1, 2.2, 2.3 and 2.4 to come.

[7] Price (2011, 210) concurs that his three paths to passage—and, by extension, my four degrees of becoming—"have not been sufficiently distinguished, either by defenders or critics of the notion of objective passage—a fact which has allowed the two sides to talk past one another, in various ways".

Table 1 Four degrees of temporal becoming

Kind of becoming	Temporal orientation	Distinguished present	Dynamic flow	Tensed becoming	Dynamic becoming
Absolute	No	No	No	No	No
Relational	Yes	No	No	No	No
Presentist	Yes	Yes	No	Yes	No
Dynamic	Yes	Yes	Yes	Yes	Yes

Definition 1 *Absolute becoming*: Let $\langle \mathcal{M}, g_{ab} \rangle$ be a relativistic spacetime, and consider an event $a \in \mathcal{M}$.[8] To say that *a becomes* (or comes into being) at that spacetime point means that *a* occurs or happens at that point.

The doctrine of the manifold. The notion of absolute becoming is certainly not new. It originated in Broad's careful analysis of McTaggart's argument for the unreality of time (Broad 1938). Indeed, it was Broad who coined the term 'absolute becoming' to convey the idea that "to 'become present' is, in fact, just to 'become', in an absolute sense [⋯] or, most simply, to 'happen'".

A few years later, Williams, in his paper *The Myth of Passage* (1951),[9] similarly maintained that "taking place is not a formality to which an event incidentally submits—it is the event's very being" (Williams 1951, 464). Hence, according to Williams, "there is passage, but it is nothing extra. It is the mere happening of things" (Williams 1951, 463). "World history", for Williams, "consists of actual concrete happenings", and that is all there is to the matter (Williams 1951, 464).

The quest for anything extra that would capture the *true* passage of time—whether that be something active or moving, a dynamic essence, a transitory aspect, or some other ingredient—would be an "altogether false start", according to Williams (Williams 1951, 102). There simply is nothing over and above "the spread of events in space-time" (Williams 1951, 153)—nothing dynamic, nothing transitory, and nothing flux- or flow-like. Williams called this "the doctrine of the manifold".[10]

Thin and yawn-inducing. Far from everyone is convinced by this deflationary analysis of temporal becoming. In a recent paper, Leininger (2018, 109) wrote that "this kind of passage is no more than a clock showing different times at different moments". According to Earman (2008, 159), absolute becoming is at best "a thin and yawn-inducing" sense of

[8] A general relativistic spacetime is an ordered pair $\langle \mathcal{M}, g_{ab} \rangle$ where $\mathcal{M}$ is a smooth, connected, n-dimensional manifold ($n \geq 2$, usually $n = 4$) and g_{ab} is a smooth Lorentzian metric on all of $\mathcal{M}$. Each element a of $\mathcal{M}$ represents a spacetime point or event. Two remarks are in order. First, we are treating events in an idealised way by restricting our attention to point-events which happen at a spacetime *point* rather than at a spacetime *region*, and thus have no spatial extension nor temporal duration. Examples of such idealised point-events include the collision of two particles, the lighting of a firecracker, the decay of an elementary particle, or an instant in the history of a photon. Second, it is useful to distinguish between *spacetime points* and *point-events*: spacetime points belong to the manifold $\mathcal{M}$, whereas point-events are what potentially happens at those points. A point-event, such as the collision of two particles, can of course occur at different spacetime points.

[9] *The Myth of Passage* was later reprinted, with minor modifications, in Gale (1968).

[10] For more on Broad's and Williams' conception of absolute becoming, see Savitt (2002).

becoming. Finally, in the words of Pooley (2013, 326), the "advocates [of absolute becoming] seem to be making heavy weather of facts that (almost) no one has ever denied". What is worse, they divert the "attention from the key challenge [⋯], namely, that of providing [an] explanation of why we are inclined to take the 'becoming more past' of events as an objective feature of reality" (Pooley 2013, 326).

From absolute to relational. Let me stress that as long as we consider absolute becoming, "we are abstracting from the spatial and temporal relations that an event e bears to other events" (Dorato 2006, 563). As Dorato argues, even in a universe consisting of a single event, there would be absolute becoming. But as soon as more than one event is present, we can study the spatiotemporal relations between them. This brings me to the second degree of temporal becoming—relational becoming.

2.2 Relational Becoming

The proponents of absolute becoming (referred to above), I maintain, do not actually endorse the admittedly bare and absolute notion of becoming, as given in Definition 1. Instead, they all go further by advocating a slightly stronger (but importantly different) notion of temporal becoming which I claim is more appropriately classified as relational becoming.

According to Dieks (2006, 171; emphasis added), for example, "becoming is nothing but the happening of events, *in their temporal order*". Savitt (2002, 157; emphasis added) also maintains that "true and literal passage is the *ordered* occurrence of [⋯] events in the manifold". Williams (1951, 464; emphasis added), finally, concurs that the passage of time "consists of actual concrete happenings *in a temporal sequence*".[11]

A network of happenings. Clearly then, the idea behind all this is that spacetime is not a structureless set of unrelated events, but a spatiotemporal "network of happenings" (Dieks 2006, 173). Indeed, the spacetime manifold has topological structure, affine structure and metric structure. It is in virtue of this added structure that events can be temporally related to one another, such that some events are simultaneous, some are earlier and some later (and some perhaps unrelated)—yielding a temporally ordered web of events.

The temporal ordering of events is carried out via an asymmetric, transitive, binary relation such as the earlier-than relation E or the later-than relation L. Of course, the order thus obtained need not be *total*. Classical Newtonian spacetime can be foliated into simultaneity hypersurfaces that are totally ordered. But in special and general relativity, the lightcone structure only imposes a *partial* order on all events, such that for any event $a \in \mathcal{M}$, all events p in its past lightcone are earlier than a (pEa), all events f in its future lightcone are later than a (aEf), and all events o outside the two lightcones are not temporally ordered with respect to a.

[11] Most proponents of absolute becoming fail to distinguish absolute from relational becoming, in the way Dorato (2006) has done, and I do here. For them, relational becoming is part of the definition of absolute becoming. Consider, for instance, Savitt (2002, 160; emphasis added) who maintains that "absolute becoming is the *ordered* occurrence of [⋯] events". The accounts of absolute becoming, advocated by Dieks, Savitt and Williams, thus fall under the category of relational becoming, which seems to suggest that no one actually defends bare absolute becoming.

For the proponents of relational becoming, this is all we need to make sense of the passage of time. Those events which are earlier than a have already become; those which are later than a have not yet become. Here then is my definition of relational becoming (see also Dorato 2006)[12]:

Definition 2 Relational becoming: Let $\langle \mathcal{M}, g_{ab} \rangle$ be a relativistic spacetime, and consider a pair of events $a, b \in \mathcal{M}$. Let B be a two-place relation of becoming. To say that a has become for b means that a and b are related by B such that aBb.

Typically, the becoming relation B is taken to be the earlier-than relation E. That is, a has become for b iff a is earlier than b: $aBb \iff aEb$.

Where is the whiz and go? Before we continue, let us briefly take stock of what we have seen so far by considering the pair of events $a, b \in \mathcal{M}$ in Fig. 1. Absolute becoming says that:

1. Since a occurs at τ_0, it becomes at τ_0;
2. Since b occurs at τ_1, it becomes at τ_1.

Relational becoming (of the B-theoretic type) additionally says that

3. Since $\tau_0 < \tau_1$, a occurs before b; hence, a has become for b.

In short, $aEb \implies aBb$. All of these facts can of course be represented in a traditional spacetime diagram, such as Fig. 1.

To most proponents of temporal becoming, however, the above account is still too modest and weak. Where, they will ask, is "the whiz and go" (Savitt 2002, 162)? How can a static representation, such as Fig. 1, capture the dynamic unfolding of our world?

Savitt (2002, 163) responded (correctly in my opinion) that one should not confuse a "static representation with a representation of stasis". That is, "we do not need an animated picture to have a picture of animation". Dieks (2006, 172) concurs that "the fact that the block diagram [⋯] does not 'flow' is irrelevant for the status of what is being depicted". Maudlin (2007, 140), finally, joins forces in noting that "mathematical objects are, in their own nature, 'static'". Hence, it is only natural that we find them inadequate to represent the passage of time, but in Maudlin's opinion this "apparent inadequacy must be an illusion" (Maudlin 2007, 142).

Does a stack of papers become? The worry nonetheless remains that the mere presence of a temporally ordered set of events is not sufficient to capture the passage of time. After all, a stack of papers can be ordered too (e.g. a book with pages running from 1 to some higher number), but surely, dixit Dieks (2006, 170), "the papers do not come into successive existence by virtue of this". Likewise, events can be spatially ordered,

[12] Note that what Skow (2015) calls 'anemic' passage is actually very close (if not identical) to relational becoming as defined here (see also Leininger 2018). Indeed, Skow (2018a, 1823) subscribes to the definition of anemic passage as given in Deasy (2018) according to which "the passage of time is anemic iff the following is true: if there is a time later than this one, then in virtue of this fact time is passing".

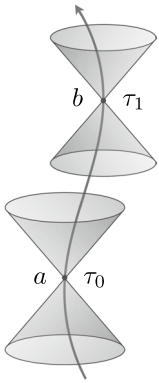

Fig. 1 Diagram of time-oriented Minkowski spacetime $\langle \mathcal{M}, \eta_{ab}, \uparrow \rangle$ with two events $a, b \in \mathcal{M}$ and their respective lightcones

but this does not seem sufficient to justify the existence of spatial becoming (or the 'flow' of space).

So, how is a temporally ordered set of events different from a spatially ordered one, or from a linearly ordered stack of papers? Here, the answers by the advocates of relational becoming diverge. For Dieks (2006), the answer lies in the fundamental difference between space and time. Even in relativity theory, where "space by itself, and time by itself, are doomed to fade away into mere shadows" (Lorentz et al. 1952, 75), the three spatial dimensions remain distinct from the temporal one. This is made explicit, for instance, in the $(-,+,+,+)$ signature of the metric tensor which assigns a $+$ to the three spatial coordinates and a $-$ to the temporal coordinate.[13] Dieks' earlier quote thus misses the mark: a stack of papers does not become because they are stacked in space; a temporally ordered set of events, in contrast, *does* become because they are 'stacked' in time.

Maudlin (2007, 109; emphasis added) likewise concedes that "the passage of time connotes *more* than just an intrinsic asymmetry". There is more to the passage of time, in Maudlin's view, than the mere presence of a temporal orientation. For Maudlin (2007, 110), there is the additional aspect of "one state 'coming out of' or 'being produced from' another". Earlier states produce later ones; not the other way round. There is, in other words, an important asymmetry in our explanatory scheme (Maudlin 2007, 133; emphasis in the original):

> The [⋯] final state is accounted for as the *product of an evolution from a* [⋯] *initial state* in a way that the initial state cannot be explained as a product of evolution from a [⋯] final state.

Those who remain unconvinced that relational becoming fully captures the transitory aspects of time should look for ways to expand the notion. This will lead to the next two degrees of temporal becoming: presentist becoming (Sect. 2.3) and dynamic becoming (Sect. 2.4). Before I look at these forms of becoming, however, let me conclude this section by considering two examples of relational becoming. The first one was proposed, a long time ago, by Stein (1991) and will be discussed in Sect. 2.2.1, the second one is currently endorsed by Maudlin (2002; 2007) and will be discussed in Sect. 2.2.2.

[13] Alternatively, one might choose to use a metric whose signature is $(+,-,-,-)$. Which signature is selected, is a matter of convention. What is important is that in both cases the signature clearly differentiates the spacelike from the timelike directions.

2.2.1 Steinian Becoming

At first sight, the theory of special relativity seems rather hostile to the idea of temporal becoming. Indeed, Gödel (1949) famously argued *against* temporal becoming on the basis of the relativity of simultaneity (see also Sect. 2.3). Rietdijk (1966), Putnam (1967) and Maxwell (1985) independently reached much the same conclusion. Call this the RPM argument *against* becoming.[14] An important counterargument, however, was developed by Stein (1968; 1991), and was further generalised by Clifton and Hogarth (1995).[15] Call this the SCH argument *for* becoming.

The SCH argument. In essence, RPM argue for the BU theory of time, according to which the future is ontologically determinate (fixed, actualised); SCH argue that the future is ontologically indeterminate (open, potential). Since the passage of time supposedly turns an indeterminate future into a determinate present, temporal becoming requires an open future. Hence, RPM (indirectly) argue *against* temporal becoming, whereas SCH argue *for* temporal becoming. To be specific, SCH showed that time-oriented Minkowski spacetime *is* compatible with an objective notion of becoming.

The becoming relation. Stein considers the beefed-up structure of *time-oriented* Minkowski spacetime, denoted $\mathcal{M} = \langle \mathbb{R}^4, \eta_{ab}, \uparrow \rangle$, with $\uparrow$ the temporal orientation. He then introduces a binary (two-place) relation B among the elements of $\mathcal{M}$, where B stands for 'has become for'. Then aBb is shorthand for 'event a has become for event b'. Stein furthermore requires B to satisfy five (natural) assumptions, which he deems necessary for a notion of objective becoming:

1. B is definable from time-oriented metrical relations;
2. B is reflexive, i.e. a has already become for a (aBa);
3. B is transitive, i.e. $aBb \wedge bBc \implies aBc$;
4. B is non-universal, i.e. for any point b, there is a point a such that $\neg aBb$;
5. aBb holds whenever a is in the causal past of b, i.e. $aJ^-b \implies aBb$.[16]

Remarks Requirement 1 ensures the objectivity of the becoming relation by demanding that B remains invariant under all automorphisms of $\mathcal{M}$ preserving the temporal orientation $\uparrow$. Requirements 2 and 3 should be self-explanatory. Requirement 4 demands that B be different from the universal relation U. After all, the idea of becoming is that for any event b, some events have become (constituting the determinate past), whereas other events have not yet become (constituting the indeterminate future). Since U holds between any pair of events, no event would be indeterminate for b; there would be no open future, and thus no becoming. Hence, by requiring B to be non-universal, Stein's theorem does not actually *prove* that there is temporal becoming; it merely shows temporal becoming to be *compatible* with Minkowski spacetime (Dorato 1996). Requirement 5, finally, can be rewritten in terms of the relation of past causal connectibility κ_p, such that $a\kappa_p b \implies aBb$.

[14] For a detailed overview and critical analysis of the philosophical literature on the RPM argument, see Thyssen (2020, Chapter 1).

[15] Stein (1968) was a direct response to Rietdijk (1966) and Putnam (1967), whereas Stein (1991) was provoked by Maxwell (1985).

[16] $J^+(p)$ and $J^-(p)$ denote the causal future and past of an event $p \in \mathcal{M}$.

Stein's theorem. On the basis of this, Stein (1991) proceeds to prove the uniqueness of the becoming relation B. To be specific, Stein shows that if B satisfies all of the constraints above, then B reduces to (is co-extensional with) the relation of past causal connectibility κ_p. This, then, is Stein's theorem:

Theorem 1 *Let B be a binary relation among the elements of time-oriented Minkowski spacetime $\mathcal{M} = \langle \mathbb{R}^4, \eta_{ab}, \uparrow \rangle$, where B stands for 'has become for', and where B satisfies the constraints* 1 *to* 5 *above. Then for any pair of events a and b in $\mathcal{M}$, the following holds*:

$$aBb \iff a\kappa_p b.$$

That is, a has become for b iff a is in the causal past of b. □

This shows, contra RPM, that "at each stage, the entire history of the world is separated into a part that has already become [⋯] and a part that is not yet settled" (Stein 1991, 148). Indeed, according to theorem 1, all events in and on the past lightcone of b have become for b and are therefore fixed and determinate; all events outside the past lightcone of b have not yet become for b and are therefore open and indeterminate (Fig. 2).

Challenging the status quo. According to Clifton and Hogarth (1995, 356), "Stein's proof has settled the issue [⋯] in favour of the possibility of objective becoming" in a special relativistic setting. Indeed, "the idea that Stein conclusively refuted Putnam et al. [⋯] seems to have achieved the status of conventional wisdom", writes Callender (2000, S592). These statements have to be tempered in two respects.

First, Stein's notion of objective becoming aspires to be a form of relational becoming. The becoming relation B, after all, fails to meet requirements 2 and 3 referred to in Sect. 2. That is, Stein's becoming relation fails to pick out a distinguished present. For any arbitrary spacetime point $b \in \mathcal{M}$, Stein's relation tells you which events have become relative to b, and which have not. But it does not tell you which event is present NOW. Second, there is nothing dynamic or flow-like in Stein's account of becoming. In sum, to the extent that Stein indeed proved 'the possibility of objective becoming', this only applies to relational becoming, *not* to the stronger forms of presentist and dynamic becoming.

Second, even as a form of relational becoming, Stein's becoming relation is problematical for various reasons. Callender (2000; 2017) and Bigaj (2008) have raised important objections, and I will draw the reader's attention to yet another one in Sect. 3.2.

2.2.2 Maudlinian Becoming

In his book review of Skow's *Objective Becoming*, Maudlin (2018, 1813) admits regarding himself (and being regarded by others) "as holding an extremely strong view about [⋯] the passing of time". "I think that time passes", he writes (Maudlin 2018, 1808). "I think that the passage of time is a fundamental characteristic of it: if something does not pass, then that thing is not time".[17]

The question of interest here, however, is *which* form of temporal becoming Maudlin has in mind when speaking of the passage of time. For Maudlin (2007, 109), "the passage

[17] Maudlin (2018, 1809) regards the passage of time as *criterial* of time: "time is exactly that aspect of physical reality that passes".

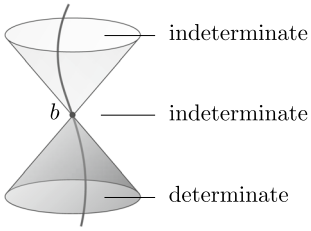

Fig. 2 The past, present and future for b according to Steinian becoming

of time is deeply connected to the problem of the direction of time, or time's arrow". When speaking of the direction of time, Maudlin (2007, 109) means "an irreducible intrinsic asymmetry in the temporal structure of the universe". Indeed, according to Maudlin (2017, 78):

> The essence of time is successiveness, one thing happening after another in a fixed order. Newton took the ordered entities to be moments of universal time, each one spread out over all of space. Relativity takes them instead to be events, and the order to be a partial order. But the primary notion of successiveness and asymmetrical ordering remains.

I think this quite clearly puts Maudlin in the camp of relational becoming. In a special relativistic setting, events occur in successive order along timelike worldlines. For Maudlin (2017, 78-79) the passage of time does not get more dynamical than this: "The temporal aspect of space-time is dynamical: events along a single worldline occur in successive temporal order. Even in relativity, time passes".

Nowhere does Maudlin mention a distinguished present ("I'm sure I'm no sort of presentist!" exclaims Maudlin 2018, 1809), which suggests he does not subscribe to presentist becoming. Maudlin (2018, 1811) is also very sceptical about the possibility of a temporal flow or flux of time (and rightly so, I think) as this would require the introduction of a *second-order time* or *metatime* (see Sect. 2.4): "to attribute [a flow or flux] to time is to force the postulation of the second-order time". But such a notion would quickly lead to vicious circularity or vicious regress. Hence, Maudlin (2018, 1808) concludes: "I do not believe in any meta-time or hyper-time or second-order time". This suggests he does not subscribe to a form of dynamic becoming either.

2.3 Presentist Becoming

At the beginning of Sect. 2, I outlined three requirements for a full-blown account of objective becoming. The more requirements are met, the stronger the resulting form of becoming. So far, I only introduced the first requirement, namely the presence of a temporal orientation. The second requirement is the presence of an objectively distinguished present. I will speak of *presentist becoming* when such a present exists.

Definition 3 *Presentist becoming*: Let $\langle \mathcal{M}, g_{ab} \rangle$ be a relativistic spacetime. To say that there is *presentist becoming* means that $\langle \mathcal{M}, g_{ab} \rangle$ is endowed with a temporal orientation, and that there is an objectively distinguished present.

According to Leininger (2018, 111), it is the postulation of a NOW that differentiates A-theories from B-theories. Hence, since both absolute becoming and relational becoming lack

an objectively privileged NOW, they are B-theories. Presentist becoming, on the other hand, is an A-theory, since it postulates the existence of one, and only one, moment that is privileged as being the present moment or NOW. Leininger (2018, 111) calls this the *A-Present Thesis*. According to presentist becoming, reality is tensed in the sense that each event is either past, present or future. Hence, any description of reality will remain incomplete, on this view, as long as we fail to specify which time is present.

Parmenidean presentism. By far the most popular account of presentist becoming is *presentism*. On this (ontologically austere) view, only those events constituting the present moment are singled out as being real. Past events were real but are no longer; future events will become real but are not yet. The presentist, as a consequence, takes the world to be three-dimensional. Some prominent advocates of presentism are John Bigelow, Thomas Crisp, Peter Ludlow, Ned Markosian, Trenton Merricks, Arthur Prior and Dean ~~Zimmerman~~ (Sullivan 2012).

Usually, on such presentist accounts, time is assumed to pass: as future events come into existence, present events disappear into the past, leading to a succession of present moments or a moving NOW. However, this is a separate claim, not logically entailed by the belief in an objective present. Leininger (2018, 111), for instance, refers to this as the *A-Change Thesis*, to draw the contrast with the *A-Present Thesis* referred to above.

Here, I do not (yet) want to assume this dynamic aspect of time. After all, as soon as we set the NOW in motion, we are no longer dealing with *presentist* becoming, but with *dynamic becoming*, to be discussed in the next section. For the moment, then, I will assume the present to be static. That is, I will assume that the state of the world does not change with time. Or, to put it yet differently, I will assume that the *A-Present Thesis* obtains, but not the *A-Change Thesis*. Price (2011, 211) refers to this position as *presentism-without-change*. Monton (2006, 264) calls it *Parmenidean presentism*, contrasting it with (the more natural) *Heraclitean presentism*.

The stationary spotlight. But Parmenidean presentism is not the only possible account of presentist becoming. Another example of presentist becoming (albeit a less popular one) can be found in a particular version of the *moving spotlight* (MS) theory of time.[18]

The MS theory of time combines ideas from both the BU theory and the A-theories of time. Like the BU theory, it holds that all past, present and future events are real. The world, as a consequence, is four-dimensional. This view is called *eternalism* and finds a natural representation in the BU. Unlike the BU theory, these events do not coexist on an equal ontological footing. The present moment "glows with a special metaphysical status" (Skow 2009, 666), as if being illuminated by a spotlight.

Usually, the spotlight is assumed to move from earlier to later times, such that which moment is being illuminated changes. Broad (1923, 59) likened it to the spotlight "from a policeman's bulls-eye traversing the fronts of the houses in a street". But here again, I do not (yet) want to assume this dynamic aspect. Our focus here, then, is on the *stationary spotlight* (SS) theory, not on the *moving spotlight* theory (Wilson 2018). Price (2011, 212) calls this *frozen-block presentism*.

[18] The *growing block* theory of time provides yet another account of presentist becoming, but will not be discussed in this paper. Advocates of the growing block theory include Robert Adams, C. D. Broad, Peter Forrest, and Michael Tooley (Sullivan 2012).

Global becoming. How plausible are Parmenidean presentism and the stationary spotlight theory of time? For a start, neither theory has ever been seriously entertained. Two problems might explain this fact:

1. The problem of how to identify the present moment;
2. The problem of keeping the present moment stationary.

Let us tackle these in turn, starting with the first problem. The flow of time has typically been associated with a succession of global NOWS. Each such cosmic NOW extends across the entire Universe, and groups all simultaneous events into one global hypersurface of simultaneity.

However, in view of the *relativity of simultaneity*, observers moving with different (uniform) velocities relative to one another, each have their own set of universal NOWS. Given the principle of relativity, no observer is privileged. Hence, there is no objectively preferred way of foliating spacetime into spacelike hypersurfaces. Gödel (1949, 558) notoriously argued along these lines:

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

Gödel's problem is only aggravated by the conventionality thesis of simultaneity, according to which the notion of distant simultaneity loses its objective meaning even for one and the same observer (Thyssen 2019). That is, which spacelike separated events an observer deems to be simultaneous with her HERE and NOW depends on a *convention* (such as the choice of the Reichenbach synchronisation parameter ϵ, with $0 < \epsilon < 1$).

As if the situation is not already bleak enough, there is the additional fact that certain relativistic spacetimes (such as Gödel's infamous rotating Universe) do not even admit a foliation into spacelike hypersurfaces. This then is the final nail in the coffin of an already floundering attempt at establishing global becoming.

Local becoming. One way out of this problem is by giving up the notion of global becoming altogether, and postulating a form of *local becoming* to make it compatible with relativity theory.[19] This view has been developed by Dieks (1988, 2006) in particular. The trouble with global becoming is that it relies on a preferred foliation, which yields a *total* temporal order, as in classical Newtonian (or neo-Newtonian) spacetime. But in relativistic spacetimes, the temporal order is only *partial*.

[19] There are other ways out. First, as to Gödel's rotating Universe, one might hold that such exotic spacetimes are logically and mathematically possible, but not physically. Second, even though Minkowski spacetime does not posit a preferred foliation, there are (highly symmetric) general relativistic spacetimes which do admit a natural foliation. Third, in quantum mechanics a folitation seems required in order to account for the observed violations of Bell's inequality. Finally, a notion of absolute simultaneity might be added to special relativity, as in the neo-Lorentzian interpretation.

Dieks's proposal then is to reformulate the notion of becoming in a way that does not make reference to a universal NOW. This can be done, in a first step, by restricting our attention to the history of a single particle along its worldline. The proper time imposes a total order among the events on this worldline. By singling out one event as NOW, the history of the particle is thus divided in a past, present and future part. This assignment of a local NOW should now be carried out for every particle in the Universe, taking care however that the NOW of one particle is never inside the past lightcone of any other particle.

One problem remains though. According to Dieks (1988, 459), "it is not possible to single out any particular moment as the 'now' on the basis of the laws of physics". Notice that this problem also applies to global becoming. Even if we could agree on a preferred foliation, the question remains how to single out one of these hyperplanes as representing the NOW.

Trouble in Broad Street. The problems keep piling up. Supposing for a moment we successfully generalised the pre-relativistic notion of a universal NOW to properly apply in a relativistic setting, and assuming that we found a way to single out the distinguished NOW in an objective way, yet another problem remains.

Both the stationary spotlight theory and Parmenidean presentism postulate a stationary present. But in doing so, we seem to have "thrown out not just the baby, but almost the entire bathroom", writes Price (2011, 212). "It is as if we've built just one house in 'Broad Street'". That is, "we seem to have lost the materials for a realist view of passage, change, or temporal transition." (Price 2011, 212). What is missing here, in other words, is an element of flux; we want the NOW to move from one instant to another. But for this we have to climb yet another rung up the temporal becoming ladder.

2.4 Dynamic Becoming

According to most proponents of robust becoming, one crucial element is still missing, namely Price's third requirement that there be "something objectively *dynamic*, flux-like, or 'flow-like' about time" (see Sect. 2). Adding such an element to our account of temporal becoming yields *dynamic becoming*.

Definition 4 *Dynamic becoming*: Let $\langle \mathcal{M}, g_{ab} \rangle$ be a relativistic spacetime. To say that there is *dynamic becoming* means that $\langle \mathcal{M}, g_{ab} \rangle$ is endowed with a temporal orientation, a distinguished present, and a dynamic flow.

In dynamic becoming, both the *A-Present Thesis* and the *A-Change Thesis*, referred to in Sect. 2.3, obtain. That is, not only is there a distinguished present or NOW, but what moment is NOW changes, leading to a succession of NOWS. It is this changing NOW, above anything else, that is supposed to capture the fact (referred to at the start of Sect. 2) that events become ever more past. Allow me to reiterate the point that this change in NOW is not perspectival; it is not a consequence of our own subjective perspective. Rather, as Norton (2010, 24) stresses, "the fact of passage obtains independently of us;" it is a mind-independent process.

Heraclitean presentism. The account of dynamic becoming preferred by most is *Heraclitean presentism*. Like its stationary analogue, Parmenidean presentism, it holds that only present events are real. Unlike Parmenidean presentism, it maintains that the present does not abide, but constantly shifts, leading to a succession of presents. This is in line with the Heraclitean aphorism πανta ρει, *everything flows*. Or in the words of Heraclitus himself (as translated by Wheelwright 1959, 29):

> "Everything flows and nothing abides; everything gives way and nothing stays fixed. You cannot step twice into the same river, for other waters are continually flowing on".

The moving spotlight. The *moving spotlight* (MS) theory of time was first articulated by Broad (1923), and is considered one of the most obscure accounts of dynamic becoming, combining (as we saw in Sect. 2.3) elements from both the A- and B-theories of time.[20] As the spotlight moves, different regions of the spacetime manifold light up and become present. However, unlike Heraclitean presentism, the change in what time is present is not accompanied by a change in what exists (on the eternalist MS view, after all, all events exist). My aim here is not to enter into any more detail with regard to either presentism or the MS theory of time, except to briefly raise two (familiar) worries with respect to the moving NOW conception.

One second per second. The first worry is about the rate at which the NOW moves. It seems that time passes at a rate of one second per second (or one hour per hour, or one year per year). To some, such as Price (1996) and Tallant (2016), this answer in nonsensical; to others, such as Maudlin (2007; 2017), there is nothing objectionable about this answer.[21]

Metatime. The second worry is the notorious 'two times' objection (Pooley 2013). Ordinary movement is defined as change in spatial position with respect to time. But for time itself to move, it seems there should be some second-order time (or *metatime*, or *hypertime*) with respect to which we could measure its movement. On the MS view, for instance, which moment in ordinary time is being illuminated by the spotlight, depends on which metatime it is. That is, at each point T of metatime, only one time t is NOW. Furthermore, at later metatimes $T' > T$, the NOW will have moved to later times $t' > t$.[22]

Whether or not one is prepared to bite the bullet and postulate a second temporal dimension, the worry remains that "the multiplication of times will not stop at two" (Maudlin 2018, 1811). After all, in asking ourselves how fast metatime flows, one might be forced to postulate a third temporal dimension (a *metametatime*). But this of course threatens to generate an infinite regress, without an obvious way of halting it.

[20] Skow's *Objective Becoming* takes the MS theory as its focus, see Skow (2015). For another book-length treatise on the MS theory, see Cameron (2015).

[21] See Prosser (2016) for more references on this topic.

[22] Notice that one is forced to assume metatime to be temporally oriented as well.

3 Block Universe Compatibility

Some, if not most, assume the BU theory of time to be incompatible with temporal becoming. The static block, it is said, fails to capture the dynamic passage of time (Earman 2008). Others, such as Maudlin, do not see such problem. Still others have attempted to make the block compatible with becoming, in a variety of ways. The goal of this section is to offer some clarification by gauging the compatibility of the BU with each of the four degrees of temporal becoming discussed in Sects. 2.1, 2.2, 2.3 and 2.4. Two forms of compatibility need to be considered here:

1. Compatibility of becoming with the BU ontology as such;
2. Compatibility of becoming with a broadened BU ontology.

In the former case, the BU ontology comes built-in with some form of becoming. That is, the BU package (and the spatiotemporal structure posited by it) already contains becoming as an ingredient. In the latter case, the BU ontology is too thin to account for becoming. Here, the BU package first has to be expanded before room can be made for becoming. For lack of better terms, I will henceforth speak of becoming being (respectively) BU-compatible and BU^+-compatible.

The BU ontology. As a first step, then, let us briefly unpack the BU ontology. The BU ontology posits a four-dimensional manifold $\mathcal{M}$ of events, along with a spatiotemporal metric g_{ab}, resulting in the relativistic spacetime $\langle \mathcal{M}, g_{ab} \rangle$. In the case of special relativity, for instance, $\mathcal{M} = \mathbb{R}^4$ and $g_{ab} = \eta_{ab}$, the Minkowski metric. All spacetime events in the block are ontologically on a par; no time is metaphysically privileged. In particular, there is no distinguished present or NOW, let alone an additional time dimension. With that in place, we can finally gauge the compatibility of the BU ontology with each of the four degrees of temporal becoming, starting with absolute becoming.

3.1 Absolute Becoming

Given its deflationary character, it should come as no surprise that absolute becoming is BU-compatible. After all, the proposal is to equate the coming into being of an event with its happening. Hence, argues Dieks (2006, 170), "since everything that happens is recorded in the block universe diagram, 'coming into being' is also fully represented. There is no need to augment the block universe in any way". Indeed, "the four-dimensional picture *already contains* becoming" (Dieks 2006, 174; emphasis in original).

One important caveat is to be noted though. As I have argued in Sect. 2.2, what Dieks and others have in mind when discussing the relative merits of absolute becoming, is actually a form of relational becoming. And while Dieks is perfectly right to maintain the BU-compatibility of absolute becoming, this need not necessarily hold true for relational becoming too.

3.2 Relational Becoming

In Maudlin's opinion, there is no question about the BU-compatibility of relational becoming. "I believe in a block universe", writes Maudlin (2007, 109). "But I also believe that

time passes, and see no contradiction or tension between these views". For Maudlin "the four-dimensional universe is a single entity of which the *passage* of time [⋯] is an ingredient" (Maudlin 2007, 109; emphasis in original).[23] Stein (1991, 148) similarly concurs that "a notion of 'real [i.e. relational] becoming' can be coherently formulated in terms of the structure of Einstein-Minkowski spacetime". Stein (1991, 147) thus regards his becoming relation B as "uniquely appropriate to the special theory of relativity".

Temporal orientation. However, recall that the becoming relation B is typically taken to be the earlier-than relation E (or a closely related notion, such as Stein's relation of past causal connectibility κ_p, see Sect. 2.2.1). But in order for the earlier-than relation E to exist, and to be used to temporally relate the web of events, the spacetime under consideration must be *temporally oriented*. That is to say, at every point of spacetime, the past-to-future direction has to be specified. If this were not the case, then there would be no way to tell for any pair of timelike separated events $a, b \in \mathcal{M}$ whether aEb or bEa. That is, without a temporal orientation, a and b cannot be temporally ordered.[24]

B- and C-theoretic becoming. In short, since relational becoming assumes there to be a temporal order, it must assume spacetime to be temporally oriented. Nothing new is being said here. Yet, it is surprising how little attention this well-known fact has received in the philosophical literature. One exception is Maudlin, who has emphasised the importance of a temporal orientation for relational becoming by highlighting the contrast between the B- and C-series of McTaggart (1908).[25]

In the A-series, it will be recalled, events are ordered as past, present and future.[26] In the B-series, events are ordered as earlier-than, later-than and simultaneous-with.[27] In the C-series, finally, no such temporal asymmetry is posited, and events are ordered via a ternary betweenness relation, rather than via the binary earlier-than or later-than relation. Hence, what makes the C-series fundamentally unlike the A- and B-series is that it lacks a temporal orientation.[28] Hence, in developing his account of relational becoming, Maudlin (2007, 126) argues:

> The theory of time's passage I defend focuses on the B-series: all events are ordered by a transitive, asymmetrical relation of earlier and later. [⋯] Any theory that denies a fundamental asymmetric relation of earlier than (or later than), and hence denies an intrinsic direction of time, ought not to be called a B-series theory but rather a C-series theory. So I am not arguing for an A-series theory over a B-series theory, I am arguing for a B-series theory over a C-series theory.

[23] Or again: "The belief that time passes, in this [relational] sense", writes Maudlin (2007, 108), "has no bearing on the question of the 'reality' of the past or the future".

[24] Without an orientation, one could, at most, say that a and b are timelike, rather than spacelike or lightlike, separated.

[25] McTaggart's paper *The Unreality of Time* later reappeared as Chapter 33, *Time*, in his 1927 volume *The Nature of Existence* (McTaggart 1927).

[26] Events are said to possess intrinsic, monadic temporal properties of being present, or being past or future to differing degrees.

[27] Whereas the A-properties are constantly changing (at least on the standard view), the B-relations are eternal.

[28] To put it differently, whereas the B-series is *anisotropic,* the C-series is *isotropic*. The former represents a *directed* order; the latter only a *serial* order (Reichenbach 1956, 26-7).

Two types of relational becoming can thus be distinguished: *B-theoretic* versus *C-theoretic* relational becoming. Whereas C-theoretic relational becoming requires spacetime to be temporally *orientable*, B-theoretic relational becoming requires the spacetime to be temporally *oriented*.

To the best of my knowledge, no one currently advocates the C-theoretic version.[29] Even the advocates of absolute becoming (Dieks, Savitt and Williams) assume spacetime to be temporally oriented, as argued above (see also Sect. 2.2 and footnote 11). So if no one actually subscribes to either absolute becoming or C-theoretic relational becoming, then B-theoretic relational becoming would seem to be the weakest form of temporal becoming currently taken seriously in the literature.

Added structure. One precondition for the existence of a *temporal orientation* (and, by extension, for B-theoretic relational becoming) is that the relativistic spacetime under consideration be *temporally orientable*.[30] But although the temporal orientability of a relativistic spacetime $\langle \mathcal{M}, g_{ab} \rangle$ is a *necessary* condition for that spacetime to be temporally oriented, it is not a *sufficient* condition (Price 2011). It is not because a spacetime is temporally orientable, in other words, that it automatically comes equipped with a temporal orientation. For example, although the BU is temporally orientable, it remains an open question whether it also has a temporal orientation.

A temporally orientable spacetime $\langle \mathcal{M}, g_{ab} \rangle$, after all, can always be oriented in one of two ways. Neither of these orientations is objectively right or wrong. Indeed, since the metric g_{ab} cannot distinguish between future-directed and past-directed timelike 4-vectors, the choice of a temporal orientation amounts to the addition of *extra structure* to the relativistic spacetime under consideration. I have made this notationally explicit in this paper by denoting a non-temporally oriented relativistic spacetime as $\langle \mathcal{M}, g_{ab} \rangle$ and a temporally oriented one as $\langle \mathcal{M}, g_{ab}, \uparrow \rangle$ or $\langle \mathcal{M}, g_{ab}, \downarrow \rangle$ (see also the Appendix).

Yet, all too often, and particularly in the debate on temporal becoming, this extra structure is merely postulated without explaining where it comes from. In a recent paper defending the objectivity of temporal becoming, for example, Savitt (2018, 2) acknowledges the "radical difference between the past and the future" as a basic feature of the passage of time. But Savitt has "little to say about this feature" (Savitt 2018, 2). He thus simply assumes that the spacetime under consideration "is represented by an orientable manifold and that *this manifold has, somehow, acquired an orientation*" (Savitt 2018, 2; emphasis added). Again, in an attempt to explain the passage of time from a B-theoretical perspective, Dieks (2012, 112) just accepts the temporal "asymmetry [between the past and the future] as given". Finally, in his *Precis of Objective Becoming*, Skow (2018b, 1788) writes that according to the BU theory, "at the very least some spacetime points are later than others, so that among the relations spacetime points bear to each other are temporal relations".

Notice that in their study of relativistic becoming, Stein, Clifton and Hogarth similarly *assume* the BU to be temporally oriented (Sect. 2.2.1). That is, instead of working with

[29] That is not to say that there are no philosophers of time who have defended a C-series theory of time. Price (1996), Farr (2012), and Kajimoto et al. (2021), for example, have all endorsed a version of the C-theory in spelling out their directional eliminativist positions. However, precisely because of their C-theoretic views on time, none of them have advocated C-theoretic *becoming*. To these authors, temporal becoming is an illusion. I thank one of the reviewers for bringing this to my attention.

[30] The distinction between the notions of temporal orientability versus temporal orientation is a crucial one, and is explained in some more detail in the Appendix. Readers already familiar with this distinction can safely skip the Appendix, and continue reading.

Minkowski spacetime $\langle \mathbb{R}^4, \eta_{ab} \rangle$ as such, SCH consider the beefed-up structure $\langle \mathbb{R}^4, \eta_{ab}, \uparrow \rangle$. After all, argue Clifton and Hogarth (1995, 359), a "minimal distinction between the past and the future is needed before one has any hope of driving an ontological wedge between them". Stein (1991, 148; emphasis in original) similarly maintains that "since our issue is the coherence of a notion of *becoming*, we must, of course, postulate a distinguished *time-orientation*".

Is spacetime temporally oriented? The presupposition, however, that all temporally orientable spacetimes are, as a matter of course, temporally oriented, is not as innocent as these authors make it sound. As I have argued above, it is far from clear whether all temporally orientable spacetimes come equipped with a temporal orientation (Earman 1974, 19). That is, while I agree with Maudlin (2007, 118) that "the admission of an orientation to space-time is not, *per se*, wildly at odds with present physical theory", the question is whether such an orientation is built into the BU package, or whether it has to be added to it. That is, the question is whether (B-theoretic) relational becoming is BU- or BU$^+$-compatible.

According to Price (1996), for example, time is not endowed with an intrinsic direction or arrow at all (see also Price 2011). Horwich (1987, 3) likewise maintains that "time *itself* has no intrinsic directionality or asymmetry". The structure of time, for Price and Horwich, is symmetric and isotropic, and thus without privileged orientation or direction.[31] Such a view is of course not new. Boltzmann (1964, 446), in his *Lectures in Gas Theory* of 1896, already played with the idea that "the two directions of time are indistinguishable, just as in space there is no up or down".

The assignment of two different names (past and future) to the two lightcone sheets of a spacetime event is thus purely *conventional*. The two lightcone sheets, after all, are *formally identical*: if one were to interchange both sheets, the entire lightcone would remain unchanged. As Castagnino et al. (2003) remark, the distinction would be *substantial* only if it involved the (conventional) naming of two objects that are *formally distinct*.[32] For Price and Horwich, then, there is no substantial difference between the two temporal directions, and hence no basis for (B-theoretic) relational becoming. Indeed, if time is not intrinsically directed, then "the whole idea that time 'passes' at all" is of course "some sort of illusion" (Maudlin 2012, 168).

The time direction heresy. Maudlin (2002; 2007) holds a minority position in this debate. Contrary to Price and Horwich, Maudlin has championed the view that the past-to-future direction *is* distinguishable from the future-to-past direction, and that this distinction is a substantial one. In order to do so, Maudlin has argued that one should consider this

[31] In order to forestall any immediate objections, the time-symmetric view of Price and Horwich does not imply that they also reject the existence of, say, the thermodynamic or the causal arrow of time. Here, it is important to clearly distinguish between the asymmetry *of* time (the subject of our concern) from the asymmetries *in* time (such as the thermodynamic and causal arrows). The asymmetry *of* time refers to a property of time itself; an asymmetry *in* time refers to a property of the arrangement of things in time (Castagnino et al. 2003). Even a world without intrinsic asymmetry *of* time can thus exhibit various asymmetries *in* time.

[32] The authors offer the following example to clarify their point (Castagnino et. al. 2003, 2489): "the difference between the two poles of [⋯] a magnet is conventional since both poles are formally identical". However, "the difference between the two poles of the Earth is substantial because [at] the north pole there is an ocean and [at] the south pole there is a continent (and the difference between ocean and continent remains substantial even if we conventionally change the names of the poles".

distinction to be *primitive*. That is, according to Maudlin (2007, 109), the direction of time is "an intrinsic asymmetry in the temporal structure of the universe". Importantly, this intrinsic asymmetry is "a fundamental, irreducible fact" (Maudlin 2007, 107).

Spacetime, for Maudlin, comes hardwired with an arrow of time. This makes Maudlin the staunchest promotor of what Earman (1974, 20) has called *The Time Direction ~~Heresy~~*—the view that the "temporal orientation is an intrinsic feature of space-time which does not need to be and cannot be reduced to nontemporal features".

Like Aristotle's unmoved mover, the direction of time is taken to be the ungrounded grounder for all other asymmetric processes in the world. The causal arrow, for example, "is itself parasitic on a fundamental asymmetry of time", dixit Maudlin (2012, 166). The same holds true for the thermodynamic arrow, which according to Maudlin (2012, 167) "presupposes a time direction". In summary, then, for Maudlin the arrow of time is the master arrow which explains all other arrows. It is the asymmetry *of* time that explains the asymmetries *in* time, not the other way round.

Passage. Notice that this also explains why Maudlin is able to subscribe to both a BU ontology and the passage of time. Maudlin, after all, draws on the irreducible character of time's direction to argue for the irreducible character of time's passage. The passage of time, writes Maudlin (2007, 110), is not to be "explicated by means of any other more primitive notion". It is "a metaphysically fundamental characteristic that cannot be further analyzed [⋯] into simpler or more basic components". Temporal becoming, in short, is in no need of further justification or explanation.

Maudlin's primitivist view (when properly adapted to a relativistic setting) is thus no different from Newton's, who claimed that "time, of itself, and from its own nature, flows equably without relation to anything external" (Newton 1934). It also explains why Maudlin can uphold the compatibility between the block universe and temporal passage. "I believe I am committed to both a block universe and robust passage", writes Maudlin (2018, 1809), where 'robust passage' should be interpreted as B-theoretic relational becoming.

3.3 Tensed Becoming

When it comes to the compatibility of presentist and dynamic becoming, both can be treated together. For a start, it should be clear that Parmenidean and Heraclitean presentism are incompatible with the BU, since they postulate a fundamentally different ontology according to which only present events are real, whereas in the BU both past, present and future events are real.

The question, therefore, is whether the stationary and moving spotlight theories of time are compatible with the block. Given that the BU theory does not postulate a distinguished present nor a supertime, both the SS and MS theory are BU-incompatible. Of course, many have claimed that they can be made BU^{+}-compatible, via the addition of, say, a preferred foliation and/or a second-order time, but those are topics for another time.

4 Conclusion

In this paper, I distinguished four degrees or forms of temporal becoming: (1) absolute becoming, (2) relational becoming, (3) presentist becoming and (4) dynamic becoming. The higher the degree, the stronger the form of becoming and, I argued, the less compatible with the BU ontology.

I am of the same mind as Earman (2008, 159), who finds absolute becoming too "thin and yawn-inducing" to be worthy of the name becoming. This fact, I believe, also explains why even the proponents of absolute becoming (such as Dieks, Savitt and Williams) actually endorse a stronger relational form of becoming. When it comes to presentist and dynamic becoming, the barren landscape of absolute becoming makes way for a mine-field of problems, too big in my opinion to be convincingly overcome. In view of all this, the prospects for temporal becoming in a BU ontology are pretty bleak. There remains, after all, only one form of temporal becoming, namely relational becoming.

I showed that relational becoming is either BU- or BU$^+$-compatible, depending on whether the temporal orientation is intrinsically given. According to Maudlin's primitivist approach, the temporal orientation of our world *is* primitive. This renders (B-theoretic) relational becoming BU-compatible, and explains why Maudlin can uphold both the BU theory of time and the passage of time. Skow's view on robust passage, on the other hand, corresponds to a form of dynamic becoming which is clearly BU-incompatible.

Appendix

The aim of this short appendix is to carefully distinguish the notions of temporal orientability versus temporal orientation. Let $\langle \mathcal{M}, g_{ab} \rangle$ be a relativistic spacetime, and consider any point $p \in \mathcal{M}$. The lightcone $\mathcal{L}(p)$ at p is an open submanifold of $\mathcal{M}$, consisting of three parts: the spacetime point p itself, and two connected components or lightcone sheets (see Fig. 3). Let us denote the upper sheet by $\mathcal{L}^{\uparrow}(p)$ and the lower sheet by $\mathcal{L}^{\downarrow}(p)$.

Spacelike, lightlike and timelike. Now consider any 4-vector τ at p. If τ points outside $\mathcal{L}(p)$, then τ is said to be *spacelike*; if it lies on $\mathcal{L}(p)$, it is *null* or *lightlike*, and if τ is inside $\mathcal{L}(p)$, it is *timelike*. The lightcone structure at p thus divides all 4-vectors into three classes. However, there is an important structural difference between these classes of vectors.

Spacelike vectors can be continuously rotated into one another without ever becoming lightlike or timelike. Lightlike and timelike vectors, on the other hand, are further partitioned into two disjoint classes. That is, although any (null or timelike) 'up-pointing' vector can be smoothly transformed into any other (null or timelike) 'up-pointing' vector, an 'up-pointing' vector can never be turned into a 'down-pointing' vector, and *vice versa*, without becoming spacelike at some point. There thus is, in the words of Maudlin (2018, 1810), "a basic distinction between two sorts of timelike directions and two sorts of null directions, and no corresponding distinction among the spacelike directions". This is perhaps one of the most fundamental differences between space and time.

Temporal orientability. In all relativistic spacetimes that are taken seriously from a physical point of view, the distinction between the two sorts of timelike and null directions is *global*. That is, as soon as you have labelled the lightcone sheets of one event, there is a unique way of labelling the lightcone sheets of all other events.

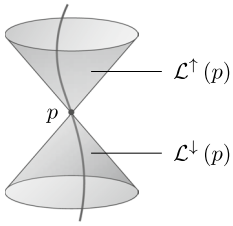

Fig. 3 The lightcone $\mathcal{L}(p)$ of p consists of an upper sheet $\mathcal{L}^{\uparrow}(p)$ and a lower sheet $\mathcal{L}^{\downarrow}(p)$

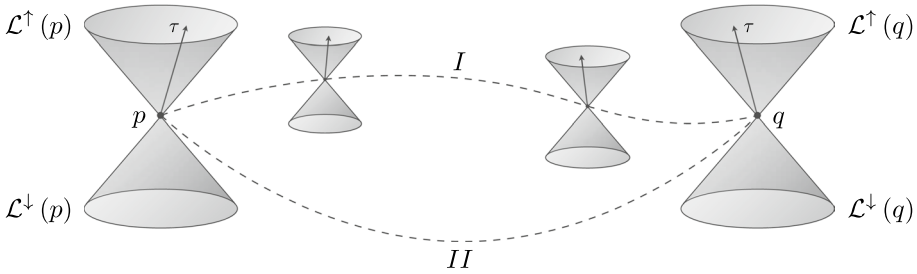

Fig. 4 After arbitrarily labelling the lobes of $\mathcal{L}(p)$, the labelling of the lobes of $\mathcal{L}(q)$ is path-independent. Figure adapted from Weingard (1977, 124)

Consider, by way of example, the three-dimensional Minkowski spacetime $\left\langle \mathbb{R}^3, \eta_{ab} \right\rangle$ in Fig. 4—the arena of special relativity (in three dimensions).[33] Consider any two spacetime points p and q, and start by labelling the two lobes of p's lightcone $\mathcal{L}^{\uparrow}(p)$ and $\mathcal{L}^{\downarrow}(p)$ in an arbitrary way. Now pick a timelike 4-vector τ at p that lies inside $\mathcal{L}^{\uparrow}(p)$, and imagine moving τ from p to q along path I via continuous timelike transport. That is, imagine moving τ in a continuous manner along path I, taking care to keep τ timelike at all times, never allowing it to become lightlike or spacelike. When τ finally arrives at q, it will point in one of the two lobes of $\mathcal{L}(q)$. Call that lobe $\mathcal{L}^{\uparrow}(q)$, and call the other lobe $\mathcal{L}^{\downarrow}(q)$.

It turns out that as long as τ is kept timelike, no matter which path you take from p to q, you will always end up labelling the lobes of $\mathcal{L}(q)$ in the same manner. If, for instance, you had moved τ along path II, the result would have been the same. The labelling of the lobes of $\mathcal{L}(q)$ is thus *path-independent*, and this ensures that the labelling is globally consistent. For this reason, the spacetime is said to be *temporally orientable*. Following the definition by Weingard (1977, 123):

Definition 5 *Temporal orientability*: A relativistic spacetime $\langle \mathcal{M}, g_{ab} \rangle$ is temporally orientable iff the lightcone a timelike vector τ points in after being transported by continuous timelike transport from p to q, is independent of the path of transport between p and q (p and q being arbitrary spacetime points).

Temporal non-orientability. Minkowski spacetime $\langle \mathcal{M}, \eta_{ab} \rangle$, as just explained, is temporally orientable. However, this property need not necessarily carry over to general relativistic spacetimes. Although the metric of a general relativistic spacetime can be

[33] This example comes from Weingard (1977, 123-125).

reduced to the Minkowski metric of special relativity for small regions of spacetime, it is unlikely that the spacetime will be flat on a global scale due to the presence of gravitational effects. As a result, very different topologies are compatible with the Einstein field equations.

Some of these spacetimes are temporally non-orientable and causally pathological. In such spacetimes, a timelike 'up-pointing' vector can be transformed into a 'down-pointing' one by continuous timelike transport (e.g. by following a spacelike path along a Moebius band). Clearly then, the past-future distinction cannot be made on a global scale in such spacetimes, and so a global notion of temporal becoming cannot be introduced. My focus here, however, is on the time orientable Minkowski spacetime of SR, not on the pathological spacetimes of GR.

Co-directionality. If a relativistic spacetime is temporally orientable, then there is a unique and globally consistent way of labelling all the lightcone sheets by moving a timelike vector around via continuous timelike transport.[34] Two lightcone sheets are then said to be *co-directional* when they are both labelled ↑ or both ↓.[35] This relation of co-directionality is reflexive, symmetric and transitive. It is, in other words, an equivalence relation on the set of all lightcone sheets. The quotient set of this relation has two elements, the equivalence classes $\mathcal{L}^{\uparrow}$ and $\mathcal{L}^{\downarrow}$. Each class contains exactly one of the lightcone sheets at every spacetime point:

$$\mathcal{L}^{\uparrow} := \bigcup_{p} \mathcal{L}^{\uparrow}(p), \quad \forall p \in \mathcal{M}; \tag{1a}$$

$$\mathcal{L}^{\downarrow} := \bigcup_{p} \mathcal{L}^{\downarrow}(p), \quad \forall p \in \mathcal{M}. \tag{1b}$$

The lightcone structure $\mathcal{L}$ is thus an open submanifold of $\mathcal{M}$ with two components: $\mathcal{L} = \mathcal{L}^{\uparrow} \cup \mathcal{L}^{\downarrow}$. Or, to put it more simply, the set of all lightcone sheets is divided into two classes, denoted $\mathcal{L}^{\uparrow}$ and $\mathcal{L}^{\downarrow}$.

Temporal orientation. The labelling of one class as future-directed, and the other as past-directed, amounts to choosing a *temporal orientation* or *direction of time*. Suppose, for instance, that we decided (by convention) to label $\mathcal{L}^{\uparrow}$ as future-directed and $\mathcal{L}^{\downarrow}$ as past-directed. Then since this past-future distinction is global, we can use it locally at each spacetime point to define the past and future. After all, for any spacetime point $p \in \mathcal{M}$, $\mathcal{L}^{\uparrow}(p) \subset \mathcal{L}^{\uparrow}$ and $\mathcal{L}^{\downarrow}(p) \subset \mathcal{L}^{\downarrow}$. Hence, $\mathcal{L}^{\uparrow}(p)$ corresponds to the future, and $\mathcal{L}^{\downarrow}(p)$ to the past for p.

Definition 6 *Temporal orientation:* A relativistic spacetime $\langle \mathcal{M}, g_{ab} \rangle$ is *temporally orientable* iff the lightcone structure $\mathcal{L}$ has two components. A relativistic spacetime $\langle \mathcal{M}, g_{ab} \rangle$ is *temporally oriented* iff one component is labelled future-directed and the other past-directed.

[34] Another way of putting this is that there exists a continuous nonvanishing vector field on $\mathcal{M}$ which is timelike with respect to g_{ab} (Earman 1974).

[35] When two lightcone sheets are co-directional, then their set-theoretic intersection is always another lightcone sheet. For example, $\mathcal{L}^{\uparrow}(p) \cap \mathcal{L}^{\uparrow}(q) = \mathcal{L}^{\uparrow}(s)$ with $p, q, s \in \mathcal{M}$.

Notice, however, that a temporally orientable spacetime $\langle \mathcal{M}, g_{ab} \rangle$ can always be oriented in one of two ways. In the above example, for instance, we might just as well have labelled $\mathcal{L}^{\uparrow}$ as past-directed and $\mathcal{L}^{\downarrow}$ as future-directed, in which case the arrow of time would have pointed in the opposite direction. No orientation is objectively right or wrong. To make clear which orientation is chosen, I will denote these temporally oriented spacetimes as $\langle \mathcal{M}, g_{ab}, \uparrow \rangle$ and $\langle \mathcal{M}, g_{ab}, \downarrow \rangle$, respectively, with $\uparrow$ or $\downarrow$ referring to which equivalence class $\mathcal{L}^{\uparrow}$ or $\mathcal{L}^{\downarrow}$ is taken to be future-directed.

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Declarations

Conflict of interest No potential Conflict of interest is reported by the author.

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