THE RIETDIJK–PUTNAM–MAXWELL ARGUMENT

CONTENTS

ABSTRACT

This chapter provides a detailed overview and critical analysis of the philosophical literature on the Rietdijk–Putnam–Maxwell argument for the four-dimensionality of the world. After briefly introducing the debate on the dimensionality of the world, I present the arguments by Rietdijk, Putnam and Maxwell, and highlight the differences between them. I subsequently raise a total of eleven objections against it, and conclude that the validity of the Rietdijk–Putnam–Maxwell argument is underdetermined by the formalism of special relativity.

1 INTRODUCTION

One of the central questions in the philosophy of time could be called the *reality question*: which spatiotemporal events are to be considered real? Are only present events real (*presentism*)? Or are past and future events equally real (*eternalism*)? Or are past and present events real, but not future events (*possibilism*)? That is, what is the temporal and ontic structure of the world?[1] Intimately related with this question is the *dimensionality question*: is the world fundamentally zero-, one-, three-, four- or higher-dimensional?

Markosian (2004) calls presentism the "common sense" view of time; Putnam (1967, 240) calls it the view of "the man on the street." Presentism derives its appeal from our intuition that past events were real, but no longer are, and that future events will come to be real, but are not yet. Some claim possibilism to be even closer to our intuitions about time, as it captures the fact that past and present events seem fixed and determinate, whereas future events are open and indeterminate (Savitt, 2014). Presentism and possibilism certainly appear more natural than their rival, eternalism, which seems furthest removed from our common sense. Common sense also takes the world to be fundamentally three-, and not four-dimensional.

But with the advent of special relativity (SR), a major paradigm shift was set in motion with regard to our understanding of time and simultaneity. The relativity of simultaneity, in particular, challenged our presentist intuitions and seemed to imply an eternalist picture of time instead — suggesting that we live in a fundamentally four-dimensional world, or block universe, where past, present and future events exist on an equal footing. As a result, the eternalist view of time has become the favoured position among philosophers of time (Savitt, 2014).

THE RPM ARGUMENT. The most careful formulation for the four-dimensionality of the world and eternalism was independently put forward by the Dutch physicist Cornelis Willem Rietdijk in 1966 and by the American philosopher Hilary Putnam in 1967, more than fifty years ago.[2] Seemingly unaware of this, the British philosopher Nicholas Maxwell published a similar argument in 1985.[3]

---

1 When I say that past and future events are real, I do not intend to say that they are real *now*, which is obviously false. I wish to say that they are real *simpliciter*. That is, I take my claim to quantify unrestrictedly, over the entire spatiotemporal manifold.

2 Although Putnam's paper appeared in print later, Putnam did present his paper at a meeting of the American Physical Society on January 27, 1966.

3 See Rietdijk (1966), Putnam (1967) and Maxwell (1985). Both Rietdijk and Maxwell further developped their ideas in Rietdijk (1976), Rietdijk (2007), Maxwell (1988) and Maxwell (1993).

Since there is a common core to all these arguments, they warrant unification and are commonly referred to as the Rietdijk–Putnam–Maxwell argument, or RPM argument.[4] This being said, there are important differences in style and content between the arguments by Rietdijk, Putnam and Maxwell (see §3).[5]

RPM were not the first to argue for eternalism on the basis of SR. Einstein, Minkowski, Weyl, Eddington, Cassirer, Jeans and Gödel all flirted with an eternalist worldview (see the introduction). But RPM were the first to explicitly write down an argument.[6]

STATUS QUO. The RPM argument has been highly influential in the philosophical literature on SR.[7] Callender (2000) thus confesses that "some quibbles aside, I've always found Putnam et al.'s argument eminently sensible" (p. S592).[8] Dorato (2008, 57) calls it "simple but brilliant".

Stein (1968), however, deems the RPM argument to be "seriously misapplied" (p. 5) and to lack "internal clarity" (p. 22). In his view, the entire argument is "incorrect" (p. 14) and the "asserted conclusions do not follow" (p. 5).[9] Sklar (1981, 129), too, finds Rietdijk's argument "replete with infelicities of expression and formulation".[10]

Indeed, despite its lasting popularity, a plethora of objections have been raised against RPM, exposing different flaws and fallacies in their argument. Yet most, if not all, of these objections have been met with counterobjections. This leaves us with the question as to the actual strenghth, validity and soundness of the RPM argument.

A detailed review and critical analysis of the philosophical literature on the RPM argument is presently non-existent, and long overdue. This chapter aspires to fill this gap. My aim is threefold. First and foremost, I hope to offer some clarity to a muddled debate by

---

4 The RPM argument is also called the *block universe* argument because it establishes that reality is a four-dimensional block, where past, present and future events exist on a par.

5 Another well-known variation on the RPM theme is the *Andromeda paradox*, which was put forward by Penrose (1989, 392-394).

6 More recently, Calosi (2014) has offered a generalized argument against presentism on the basis of SR, which he claims to remain untouched by some of the objections directed at the RPM argument, to be developped in §4.

7 A citation count in Google Scholar on February 13, 2020 reveals that Putnam (1967) has been cited 485 times, Rietdijk (1966) 229 times, and Maxwell (1985) 139 times (as indexed by Google Scholar in February 2020).

8 In his recent book *What Makes Time Special?*, Callender (2017, 53) echoes his previous verdict: "[RPM] has been controversial for over forty years. Yet with a few i's dotted, it is utterly convincing."

9 Stein (1968, 20) furthermore laments the "*prevalent* laxness [and] lowering of critical standards in philosophical discourse [which] precludes understanding and is the death of philosophy" (emphasis in original).

10 Sklar, however, admits that the argument by Putnam (1967) is "framed with greater philosophical sophistication."

bringing together the scattered, disparate and frequently contradictory literature of the last fifty years.

Second, although I realise it is practically impossible to add something truly novel or substantial to an already saturated literature, I do have a number of important remarks to make which should foster the presentism–eternalism debate.

And finally, while any attempt at an exhaustive bibliography is destined to fail, the bibliography at the end of this chapter should be ambitious enough to help the reader find her way in the vast and ever-growing literature on the philosophy of SR.

OUTLINE. The outline of my chapter is as follows. I start with a brief introduction to the reality and dimensionality question (§2). Drawing on the work of Callender (2000) and Peterson and Silberstein (2010), I introduce the notion of a reality field, and its associated reality values and relations, to denote the ontological status of spacetime events.

I continue with a careful presentation of the arguments by Rietdijk, Putnam and Maxwell from SR in favour of eternalism and the four-dimensionality of the world (§3). Building on Dickson (1998), I suggest that there are not one but four distinct arguments being made here: (1) the reality argument, (2) the truth argument, (3) the determinism argument and (4) the becoming argument. Whilst they are all similar in flavour, there are important differences nonetheless, and the conclusions drawn are of differing plausibility.

After discussing the relative merit of each of these arguments, I finally turn to the objections that have been raised against the RPM argument (§4). I distinguish a total of eleven objections, and conclude by arguing that the validity of the RPM argument is underdetermined by the formalism of SR (§5).

2 WHAT IS REAL?

My focus in this chapter is on the presentism–eternalism debate, and RPM's role in it. Let me therefore start by briefly characterising the presentist and eternalist position. Although possibilism will surface here and there as a conceivable intermediate position, it is not my aim here to gauge the prospects for this metaphysical view.

In what follows, I take Minkowski spacetime as common ground for all participants in the debate. That is, I consider the debate from the point of view of SR, despite some excursions to general relativity and quantum mechanics.

PRESENTISM. Presentism is an umbrella term, covering a wide range of different views. Depending on which spatiotemporal shape

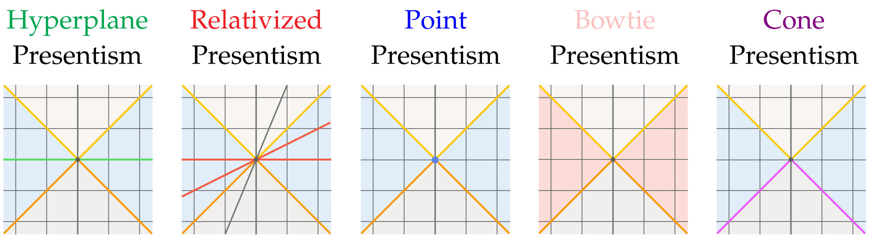

Figure 1: Different flavours of presentism.

the present takes on, for instance, different flavours of presentism can be distinguished (Figure 1). On some accounts the present is reduced to a point; on others, the present is bowtie- or cone-shaped. Some of these flavours will be discussed further on. For the moment, however, I want to keep the discussion focussed, and will take the present to be a three-dimensional Cauchy hyperplane, spanning the entire spatial extent of the world. Call this the *hyperplane present*. With that in place, let me briefly unpack the standard presentist position.

On the presentist view, the present is singled out as a uniquely special moment we call NOW. Only those events that constitute the present moment are real. Past events are no longer real and future events are not yet real. According to hyperplane presentism, the world, as a consequence, is three-dimensional.[11]

Notice also that presentism is a realist thesis (Saunders, 2002): there is an objective, universal fact of the matter as to which events constitute the present moment, whether or not we have epistemic access to it. That is, the presentist thesis makes an *ontic* claim about the nature of time, not an *epistemic* one.

In presentism, time is usually assumed to pass: present events disappear into the past as future events come into existence, leading to a succession of presents or a moving NOW. This dynamic aspect of time is referred to as the *passage of time* or *temporal becoming*. Change and temporal becoming are thus taken to be fundamental aspects of reality. The passage of time, however, is not logically entailed by the belief that only the present exists (see Monton, 2006 and Chapter 2). In any case, our focus here is on the reality of events and on the dimensionality of the world, not on becoming.[12]

ETERNALISM. On the eternalist view, all past, present, and future events are real and determinate. No special status is accorded to the present moment.[13] The world, as a consequence, is four-dimensional.

11 Not all presentists would agree on this: according to the point presentist, the world is zero-dimensional; for the bowtie and cone presentists, the world is four-dimensional.
12 For the prospects of temporal becoming in the block universe, see Chapter 2.
13 Just as the Eiffel Tower is considered real, despite being spatially removed from me *here* in Leuven, so dinosaurs and super-intelligent robots are to be considered real, despite being temporally removed from me *now* anno 2020.

The eternalist account of time finds a natural representation in the so-called *block universe*, where all events coexist on an equal footing. From a God's eye point of view — or what Price (1996) calls the view from nowhen — every moment of the universe's history is set out, and time no longer flows. Reality, in the words of Black (1962, 181), is "a timeless web of 'world-lines' in a four-dimensional space."

WHAT IS REAL? The difference between presentism and eternalism is thus cashed out in terms of which events are real. For the presentist, the events simultaneous with the here-and-now are real. For the eternalist, all events are real, whether or not they are simultaneous with the here-and-now.

But what exactly does it mean to say that a particular event is *real*? This question has remained largely untouched in the philosophical literature. Two exceptions are Callender (2000) and Peterson and Silberstein (2010). Callender asks us to consider a four-dimensional manifold of events, where each event carries a lightbulb that can be ON or OFF. When a lightbulb is ON, the corresponding event is real; when the lightbulb is OFF, the event is not real. Presentism, on this view, holds that only present lights are ON, whereas eternalism maintains that all lights are ON (Figure 2).[14]

REALITY VALUES AND RELATIONS. Instead of associating a lightbulb with each event, Peterson and Silberstein (2010) introduce a *reality field* $\mathcal{R}$ on the set $\mathcal{M}$ of spacetime events $a, b, c, \ldots$ The reality field denotes the ontic status of each event by assigning it a dimensionless *reality value* or *$\mathcal{R}$-value*:

$$\begin{aligned} \mathcal{R}: \quad \mathcal{M} &\longrightarrow \{0,1\} \\ a \in \mathcal{M} &\longmapsto \mathcal{R}(a) \end{aligned} \tag{1}$$

The reality field is assumed to be a scalar field; all observers therefore agree on the value of the reality field at a particular point of spacetime. Every event, in other words, has a unique, observer-independent $\mathcal{R}$-value, with $\mathcal{R} = 1$ denoting a real event, and $\mathcal{R} = 0$ an unreal event (Figure 3). This is called the *uniqueness criterion*.

Peterson and Silberstein next introduce a binary *reality relation* R which holds between any two events having the same $\mathcal{R}$-value. For instance, if $a, b \in \mathcal{M}$ share the same $\mathcal{R}$-value, then they are said to be *equally real*.[15] This is written as aRb (read: 'event a and event b are equally real' or 'event a is real for event b'). Due to the uniqueness criterion, the relation R is:

14 Possibilism is an intermediate position between presentism and eternalism, arguing that only past and present lights are ON.

15 Notice that a and b can be equally real in virtue of both being unreal (*i.e.* in virtue of both having an $\mathcal{R}$-value of 0).

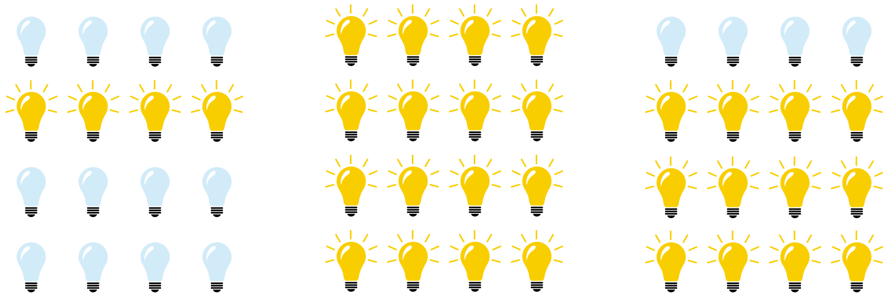

Figure 2: Which lightbulbs are ON?

0 0 0 0	1 1 1 1	0 0 0 0
1 1 1 1	1 1 1 1	1 1 1 1
0 0 0 0	1 1 1 1	1 1 1 1
0 0 0 0	1 1 1 1	1 1 1 1
Presentism	Eternalism	Possibilism

Figure 3: Reality values.

1. *Reflexive*: aRa is true (since a has a unique $\mathcal{R}$-value);
2. *Symmetric*: if aRb is true, then bRa is true (since a and b share the same $\mathcal{R}$-value);
3. *Transitive*: if aRb is true, and bRc is true, then aRc is true (since a and c share the same $\mathcal{R}$-value).

This turns R into an equivalence relation. R thus provides a partition of the underlying set $\mathcal{M}$ into two disjoint equivalence classes: the class of real events and the class of unreal events.

The reality relation R not only allows a proper distinction between presentism and eternalism, it will also enable us to make the structure of the RPM argument more explicit, which in turn should help us to expose the different assumptions that go into the argument (§3).

THE PRESENTIST CREDO. With this in place, let us rewrite the presentist credo that all (and only) present events are real more explicitly. Let $\mathcal{M}$ be the set of all spacetime events $a, b, \ldots$, and S the relation of simultaneity among the elements of $\mathcal{M}$. Then aSb is shorthand for 'event a is simultaneous with event b'. If b represents the here-and-now, b is real.[16] That is, $\mathcal{R}(b) = 1$. The present for b consists of all events simultaneous with b. Hence, if aSb holds true, then a is

16 This is also the first assumption in Putnam (1967), who phrases it as follows: "I-now am real" (p. 240).

present for b. Following the presentist credo, a is therefore real for b:

$$aSb \implies aRb, \tag{2}$$

with $\mathcal{R}(a) = \mathcal{R}(b) = 1$. Call this the thesis of *hyperplane presentism*.

3 THE RIETDIJK–PUTNAM–MAXWELL ARGUMENT

REDUCTIO AD ABSURDUM. One of the best-known arguments from SR in favour of eternalism and the four-dimensionality of the world is the Rietdijk–Putnam–Maxwell argument. The RPM argument is a *reductio ad absurdum* (but see Stein, 1968, 17). As with all apagogical arguments, the purpose of the RPM argument is to establish a claim (eternalism) by showing that the opposite scenario (presentism) leads to a ridiculous, absurd or contradictory conclusion. That is, RPM start from the presentist doctrine according to which all (and only) present events are real and determinate (future and past events being unreal and indeterminate) and proceed to show the untenability of this position in light of SR.

The argument relies on the well-known relativity of simultaneity: for any event that is future with respect to one observer, there always is a second observer (simultaneous with the first) for whom that event is present and hence (following the presentist credo) real. But surely — the argument continues — if an event is real for one observer, it has to be real for all observers. Thus, Putnam (1967, 242, emphasis in original) concludes: "*future* things (or events) are already real!"[17] The same can of course be said for past events, implying that future and past events are real after all. This refutes presentism, and confirms eternalism.

THE RPM ARGUMENT. Let us go through the argument in a bit more detail. Consider the set $\mathcal{M}$ of all spacetime events $a, b, \ldots$, and let S and R be the relations of simultaneity and reality as defined above. Now consider two inertial observers $\mathcal{O}_1$ and $\mathcal{O}_2$, with $\mathcal{O}_2$ moving towards $\mathcal{O}_1$ (Figure 4). The spatial axis of $\mathcal{O}_2$ is therefore tilted with respect to $\mathcal{O}_1$'s axis.[18] Next, let a and b be two events on the worldline of $\mathcal{O}_1$ such that a chronologically precedes b. Finally, consider an

17 Putnam's use of the adverb "already" is unfortunate as he thereby mixes a tensed adverb with the tenseless verb "are" (Dorato, 2008, 58).

18 Notice that the spatial axes of $\mathcal{O}_1$ and $\mathcal{O}_2$ partition Minkowski spacetime into a past (all events below the axis), present (all events on the axis) and future (all events above the axis). However, since the spatial axes of $\mathcal{O}_1$ and $\mathcal{O}_2$ differ, $\mathcal{O}_1$ and $\mathcal{O}_2$ will not necessarily agree on what events are past, present and future. This, of course, is a natural consequence of the relativity of simultaneity.

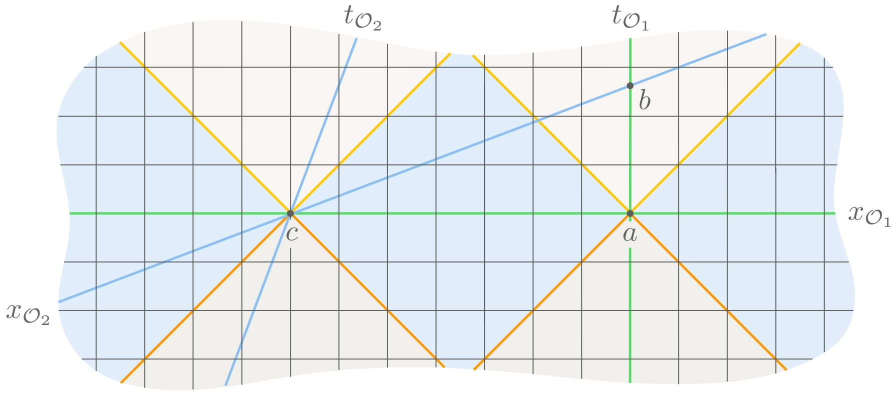

Figure 4: The Rietdijk–Putnam–Maxwell argument.

event c on the worldline of $\mathcal{O}_2$ that is spacelike separated from both a and b, such that:

(i) At a, c is present relative to $\mathcal{O}_1$;

(ii) At c, b is present relative to $\mathcal{O}_2$.

This is taken to be the case despite the fact that a and c (or c and b) are spacelike separated from one another, and hence *epistemically inaccessible*. I will return to this point in §4.1 and §4.3.

According to the presentist credo, as given in Eq. (2), two events are deemed to be co-real when they are co-present.[19] That is, two events are said to co-exist when they co-occur. Hence, we can conclude from (i) and (ii) that:

(iii) At a, c is real for $\mathcal{O}_1$;

(iv) At c, b is real for $\mathcal{O}_2$.

Now according to SR, there are no privileged observers. $\mathcal{O}_1$ must therefore recognize the 'equal authority' of $\mathcal{O}_2$ (Dickson, 1998, 167). Hence, everything $\mathcal{O}_2$ judges to be real, should be real also for $\mathcal{O}_1$. The claim, more precisely, is that whatever is real for $\mathcal{O}_2$, who is real for $\mathcal{O}_1$, should be real for $\mathcal{O}_1$ as well. Putnam (1967, 241) elevated this to a principle, which he dubbed the principle that There Are No Privileged Observers:

> If it is the case that all and only the things that stand in a certain relation R to me-now are real, and you-now are also real, then it is also the case that all and only the things that stand in the relation R to you-now are real.

19 Notice that on this definition, the reality of events is as epistemically inaccessible as their presentness.

The reality relation R, in other words, is *transitive*, as I previously observed in §2. Given that, it follows from (iii) and (iv) that:

(v) At a, b is real for $\mathcal{O}_1$.

But b is in the chronological future of a. Hence, on a presentist reading:

(vi) At a, b is not real for $\mathcal{O}_1$.

A contradiction thus arises between (v) and (vi):

(C) At a, b is real and not real for $\mathcal{O}_1$.

According to RPM, the absurdity of (C) forces us to reject premise (vi). This shows the presentist position to be untenable and establishes an eternalist worldview instead. After all, by allowing $\mathcal{O}_2$ to move at different speeds towards and away from $\mathcal{O}_1$ and by placing $\mathcal{O}_2$ at different distances from $\mathcal{O}_1$, *any* event in the future and past lightcone of a, as well as *any* event in the absolute elsewhere of a can be made real. Putnam (1967, 247) thus concludes that "we live in a four-dimensional and not a three-dimensional world."

SUMMARY. Allow me to write down the RPM argument one last time in shorthand notation for further convenience:

(i) $c\mathsf{S}a$;
(ii) $b\mathsf{S}c$;
(iii) $c\mathsf{S}a \implies c\mathsf{R}a$;
(iv) $b\mathsf{S}c \implies b\mathsf{R}c$;
(v) $b\mathsf{R}c \wedge c\mathsf{R}a \implies b\mathsf{R}a$;
(vi) $\neg b\mathsf{S}a \implies \neg b\mathsf{R}a$;
(C) $b\mathsf{R}a \wedge \neg b\mathsf{R}a$.

FOUR ARGUMENTS. According to Dickson (1998), there are not one, but four distinct arguments being made of differing plausibility: (1) a reality argument, (2) a truth argument, (3) a determinism argument, and (4) a determinateness argument.[20] Each of these arguments relies on the same geometrical features as presented in the Minkowski diagram in Figure 4, but each argument reaches a different conclusion. Dickson's distinction is rarely made by other authors — a fact to be deplored as it has led to unneccessary confusion about what

20 Dickson associates the reality and truth argument with Putnam (1967), the determinism argument with Rietdijk (1966), and the determinateness argument with Maxwell (1985).

exactly the RPM argument is supposed to entail. It will prove worthwhile therefore to follow Dickson and disentangle the four possible readings of the RPM argument.

The determinism and determinateness argument, in particular, are fundamentally similar, but importantly different. In view of their close resemblance, I prefer to discuss both arguments together, under the determinism heading, for reasons that should become clearer further on. I also want to introduce yet another argument that was overlooked by Dickson: the (temporal) becoming argument. I thus distinguish (1) the reality argument, (2) the truth argument, (3) the determinism argument, and (4) the becoming argument.

In what follows, I highlight the differences between the four arguments, and discuss their relative merit. I furthermore argue that there really is but one master argument: the reality argument. The truth argument, determinism argument, and becoming argument are but corollaries to the reality argument.

3.1 The reality argument

According to Dolev (2006), the RPM argument relies on an *ontological assumption*. "The assumption", Dolev explains, "is that the difference between past, present and future, concerns the *ontological status* of events, and that it is to be analyzed in terms of *reality claims*, claims to the effect that events are or are not *real*" (p. 178, emphasis in original).

Putnam's goal, then, is to establish which events are *real* on the basis of SR. Starting from the presentist credo according to which "all (and only) things that exist *now* are real", Putnam (1967) shows this position to be incompatible with SR. Instead, Putnam insists that all past, present and future events are equally real. Call this the *reality argument*. Notice that this is also how I have presented the RPM argument above, by making explicit use of the reality relation R.

3.2 The truth argument

Although the RPM argument is usually read as an *ontic* thesis, it also has *semantic* implications, as emphasized by Putnam (1967, 243). According to Putnam, the theory of SR implies that *all* propositions have a definite truth value, including past and future contingents.[21] Dorato (2008) calls this *semantic determinateness*. Notice that the semantic determinateness of past- and future-tense statements follows directly from the reality argument (§3.1). If past and future events

21 Past and future contigents are statements concerning past or future events that are *contingent*. That is, they are neither necessarily true (like the statement that "$2+2=4$") nor necessarily false (like the statement that "$2+2=5$").

are real, then all statements about past and future events must have definite truth values. Call this the *truth argument*.

ARISTOTLE'S SEA BATTLE. Putnam (1967) was swift at applying the truth argument to the problem of future contingents, as first discussed by Aristotle in book IX of his *De Interpretatione*. Aristotle was an indeterminist; he believed that future contingent statements have *no* truth value. The proposition that "there will be a sea battle tomorrow", for example, is neither true nor false according to Aristotle since the outcome of this future event is not determined at the present time.[22] The proposition will acquire a definite truth value (by becoming true or false) once the event it describes becomes present (by occuring or failing to occur).

According to Putnam (1967, 244), "Aristotle was wrong. At least he was wrong if Relativity is right". Here is what Putnam has in mind. Let event b in Figure 4 represent a sea battle. Then the sea battle is in the future for observer $\mathcal{O}_1$ at a. Following Aristotle, the proposition that "there will be a sea battle tomorrow" has *no* truth value for $\mathcal{O}_1$ at a. But for $\mathcal{O}_2$ at c, the sea battle is in her present, and the proposition therefore *has* a truth value for $\mathcal{O}_2$ at c. And since there are no privileged observers, it must be the case that the proposition also has a truth value for $\mathcal{O}_1$ at a, despite it being a future contingent, and contrary to Aristotle's opinion.[23]

3.3 The determinism argument

According to Rietdijk (1966), the RPM argument does not establish the *reality* of past and future events, or the *truth* of past and future contingents, but *determinism*. Here is what Rietdijk has in mind. Consider event b in the chronological future of a (Figure 4). Assuming $\mathcal{O}_1$ to be a free agent, it seems that $\mathcal{O}_1$ at a can influence b in an arbitrary way. However, according to $\mathcal{O}_2$ at c, b has already occurred, and is therefore fixed. And since $\mathcal{O}_2$ at c is simultaneous with $\mathcal{O}_1$ at a (according to $\mathcal{O}_1$), $\mathcal{O}_1$ is forced to conclude that b is fixed and unalterable. $\mathcal{O}_1$ can "do nothing at all to prevent event [b] in his absolute future" (p. 342). That is, b "is pre-determined from time immemorial", thereby excluding "the possibility of saving freedom of will" (p. 343). Call this the *determinism* (or *relativistic fatalism*) *argument*.

22 Notice that Aristotle's view commits us to a three-valued logic (Tooley, 1999). This goes against the law of bivalence (or the law of the excluded middle, if you like) according to which every proposition p is either true or false (symbolically: $p \vee \neg p$).

23 Miller (2013) raises the same point: "for any future-tensed claim uttered at t, that claim is either true at t, or false at t, and it is determinate, at t, *which* of these truth values it has" (p. 356, emphasis in original).

NOMOLOGICAL VERSUS BLOCK DETERMINISM. It is important not to confuse this form of determinism with the notion of nomological determinism, as traditionally understood. Dieks (2014), for instance, carefully distinguishes *block determinism* from *physical determinism* (see also Dieks, 1991, 2012a, Sklar, 1981/1985 as well as Norton, 2018b).[24] Physical determinism is a doctrine about the *relations* between events at different times; block determinism is a doctrine about the events *themselves* (or, perhaps more correctly, about the events and their one-to-one representation in the block universe).

Physical determinism holds when the boundary conditions at one time (defined via a Cauchy hypersurface) and the laws of nature fully determine the conditions at any other time (both earlier and later). Block determinism, in contrast, holds when "the four-dimensional Minkowski picture of the world is accurate and faithful". In that case, Dieks (2014, 105) continues:

> [H]istory cannot be different from what the representation says it is. The *cannot* here expresses *logical* necessity; [...] There is no connection at all here with physical determinism or causality. The future, and the past, are fixed and determined in the block determinism sense because they cannot be different from what they will actually be (in the case of the future) or from what they actually were (in the case of the past).

Physical determinism and block determinism are thus independent notions. It is not because one holds, that the other necessarily holds too. In particular, it is not because the block universe is block deterministic, that it also has to be physically deterministic. The block universe could just as well be physically indeterministic.

To make this more concrete, consider the following example. Pick a foliation of Minkowski spacetime, and consider the time slice $t = 0$. Suppose you measure the z-spin of an electron that is determinately x-spin up at $t = 1$. Since $|\uparrow\rangle_x = \frac{1}{\sqrt{2}}(|\uparrow\rangle_z + |\downarrow\rangle_z)$, there is an equal chance that the z-spin of the electron will be z-spin up or z-spin down at time $t = 1$. Which outcome will be realized, is physically undetermined, at least on the orthodox (Copenhagen) reading of quantum physics. The situation at time $t = 0$ does not fix or determine the situation at time $t = 1$. And yet, in the block universe, the future time slice at $t = 1$ 'already' exists since it is part of the block universe. So in that sense, the outcome *is* fixed. Although the outcome is physically undetermined, it is block determined.

24 Physical determinism is to be taken as synonymous with nomological determinism. Another, albeit more confusing, term for block determinism is *temporal determinism*, as used by Dainton (2010, 407).

DETERMINED OR DETERMINATE? To avoid unneccesary confusion, I prefer to keep the term 'determined' for physically determined, and to use the term 'determinate' for block determined. The outcome of a quantum event, on this reading, can be undetermined despite being determinate. Conversely, if it were to turn out that we do *not* live in a four-dimensional block universe, but that the universe unfolds over time, with an open and indeterminate future becoming fixed and determinate, then future events might well be determined despite being indeterminate.

To the extent that Rietdijk (1966) believes he has offered proof for physical determinism, he is deeply confused.[25] The RPM argument, after all, establishes determinateness, *not* determinism. Indeed, as Dorato (2008, 65) points out, SR "by itself is clearly *not* sufficient to enforce determinism or indeterminism, despite the fact that [SR] is somewhat friendlier to the requirements of determinism [than, say, classical physics]" (emphasis in original).

In that regard, Maxwell (1985) is more careful than Rietdijk, as he clearly argues for block determinism, and *not* physical determinism. Notice, however, that the block determinism argument (or the determinateness argument if you like) follows directly from the reality argument, referred to above (see §3.1). If future events are real, then they are also fixed and determinate. The converse, however, does not necessarily hold true. We intuitively take past events to be fixed and determinate, even though we no longer consider them real.[26]

FREEDOM IN THE BLOCK. According to Rietdijk, the determinism argument implies a denial of free will. Of course, Rietdijk may well have reached this conclusion by his failure to properly distinguish physical determinism from block determinism. Be that as it may, the tension, to be explored here, is not the traditional tension between free will and physical determinism, but an altogether new, and surprisingly underexplored, tension between free will and block determinism.[27] Dainton (2010, 9) makes the point explicit:

> If the block universe view is true, [...] the future is just as real, solid and immutable as the past. How our lives will unfold from now until the moment of our deaths is (in a manner of speaking) already laid down. How could it be otherwise if the future stages of our lives are just as real as the past stages? This is not to say that we have

25 Unfortunately, this really seems to be the case, as argued for in Dieks (2012a).

26 Notice that on a possibilist view (also known as the growing block theory, becoming theory, or now-and-then-ism), the fixedness and determinateness of past events also renders them real, as illustrated in Figure 2.

27 Both tensions will be studied much more closely in Chapter 4.

> no power over the ways our lives will unfold, for we do. We will all make choices, and the choices that we make will contribute to the ways our lives will turn out. But if the block view is true, the choices that we will make are inscribed in the fabric of reality in precisely the same way as the choices that we have already made.

The same worry was already raised by Sir James Jeans (1937, 145) in his book *The Mysterious Universe* (see also the quote by Jeans in the introduction):

> [O]ur consciousness is like that of a fly caught in a dusting-mop which is being drawn over the surface of the picture; the whole picture is there, but the fly can only experience the one instant of time with which it is in immediate contact, although it may remember a bit of the picture just behind it, and may even delude itself into imagining it is helping to paint parts of the picture which lie in front of it.

The point is the following: if the events in our future are just as real as the events in our past and present, then the entire history of events is fixed and unalterable, with no room for alternative future possibilities. This certainly seems in tension with our freedom to choose and shape our own future. Petkov (2009, 152) thus claims that "in the Minkowski four-dimensional world [...] there is no free will, since the entire history of every object is realised and given once and for all". Bouton (2017, 92) similarly concurs that "since all [...] events are supposed to be fully determinate in space-time, there is no free will."

Notice that it makes no difference whether or not the history of the world is governed by deterministic laws. In the words of Lockwood (2005): "regardless of whether our future choices and actions are fixed relative to earlier events or states of affairs [*i.e.* physical determinism], they are, if they are real, fixed absolutely in virtue of their reality alone [*i.e.* block determinism]" (p. 57).

RELATIVISTIC FATALISM. Levin (2007) calls this *relativistic fatalism*.[28] But in his opinion, the doctrine of relativistic fatalism only threathens certain conceptions of free will. We thus have to distinguish between incompatibilist, libertarian free will and compatibilist free will.

On a libertarian conception of free will, the future has to be open and indeterminate in order for agents to have access to alternative

28 See also Bishop and Atmanspacher (2011). For more on the issue of fatalism in SR, see Miller (2013), Le Poidevin (2013), and Marques (2019).

possibilities. This is known as the principle of alternate possibilities (Frankfurt, 1969).[29] Libertarians, in other words, require our actions to transform a *potential* event into an *actual* one. But if all future events are 'already' actualized, then we "can no longer think of [ourselves] as genuinely adding items to the inventory of the real" (Lockwood, 2005, 55), which rules out libertarian free will.

That is not to say that we have been reduced to mere spectators of our own lives; as Dainton (2010, 9) already pointed out above, our choices and actions do contribute to the ways our lives turn out. Hence, *pace* Jeans, we most certainly *are* shaping the future by helping to paint the picture. But, Dainton would argue, we no longer have the freedom to paint whichever picture we like, since the block contains but one picture.[30]

On a compatibilist conception of free will, relativistic fatalism can easily be outflanked. For the classical compatibilist, after all, free will does not require the ability to do otherwise; it merely requires the ability to do what one wants (McKenna and Coates, 2019). On such a reading, then, free will is perfectly consistent with a causally fixed, unique, and fully determinate future.[31]

I will return to the tension between libertarian free will and block determinism in Chapter 4. As will become clear, the issue is much more subtle than I just oulined above. In fact, it is not clear at all whether block determinism rules out libertarian free will. I will thus propose a new model of libertarian free will that not only answers the traditional challenge from physical determinism, but also the challenge from block determinism, as described above.

3.4 The becoming argument

In his discussion of Putnam's 1967 article, Dorato (2008) points out a "remarkable consequence [that] was not addressed by its author. [. . .] To the extent that the notion of *temporal becoming* presupposes the unreality of future events as its necessary condition, [SR] seems to rule out also temporal becoming" (p. 59, emphasis in original). This necessary condition was first made explicit by Dorato (1996, 586):

> An ontological asymmetry between a "fixed," determinate past, and an "open," indeterminate future, is a necessary condition for objective (mind-independent) becoming.

29 According to the principle of alternate possibilities, the action of an agent is free iff the agent could have acted otherwise under exactly the same conditions. See also Chapter 4.

30 "Assuming that [the four-dimensional Minkowski] picture exists is equivalent to assuming that the universe has a unique history", writes Dieks (2014, 104).

31 The same argument can be found in Miller (2013, 357-358).

Since the RPM argument shows the future to be fixed and determinate, instead of open and indeterminate, it also rules out temporal becoming. Call this the *becoming argument*. In the words of Dickson (1998, 167-168): "the universe does not unfold, one instant at a time; rather, it is given once, as a 'block' of space-time".[32]

GÖDEL AND THE FLOW OF TIME. The becoming argument is not the first argument from SR against temporal becoming. Hermann Weyl (1949), for instance, already pointed out that "[t]he objective world simply *is*; it does not *happen*" (p. 116, emphasis in original). Even Einstein (1961) considered it "more natural to think of physical reality as a four-dimensional existence, instead of, as hitherto, the *evolution* of a three-dimensional existence" (p. 171, emphasis in original). Cassirer (1920, 449) agreed that the world of physics had changed "from a process in a three-dimensional world into a being in this four-dimensional world."

It was Gödel (1949), however, who most famously argued against temporal becoming. Contrary to RPM, Gödel's argument was more directly based on the relativity of simultaneity:

> 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 (p. 558).

As with the issue of libertarian free will in the block universe (§3.3), the issue of temporal becoming is not as straightforward as I just outlined above, and will need more attention in Chapter 2.

For example, even though Minkowski spacetime does not posit a preferred foliation, there are (highly symmetric) general relativistic spacetimes which do admit of a natural foliation (§4.8). A notion of absolute simultaneity might also be added to SR, as in neo-Lorentzian interpretations of SR (§4.9). Finnaly, a global folitation also seems required in quantum physics in order to account for the observed violations of Bell's inequality (§4.10). There may be yet other ways out of Gödel's and RPM's argument against temporal becoming in the block universe, as I show in Chapter 2.

32 The relation between the unreality of the future and temporal becoming can of course be questioned. I return to the alleged tension between the block universe and temporal becoming in Chapter 2.

CHANGE IN A STATIC BLOCK. The becoming argument is sometimes used to argue that the block universe is static or that change is an illusion. But such claims go one bridge too far. First, to say that the block is static suggests that the block *endures* and somehow exists *in* time (Dainton, 2010, 8). But it is the other way round: time exists in the block, as the fourth dimension. This of course does not alter the fact that the content of the block is fixed. The history of the Universe is unique, and cannot be different from what she is. In this atemporal sense, the block is indeed a static, unchanging entity.

Second, even though the block as such cannot change, this does not imply that there can be no change *within* the block. Time is the dimension by virtue of which objects can change by having different properties at different times (*i.e.* at different points along the temporal dimension). As Dieks (2014, 105) correctly observes, the fact that "the block per se is changeless [...] implies nothing about the presence or absence of physical change in the universe."

CONCLUSION. It should be clear from our discussion of the reality argument, the truth argument, the determinism argument and the becoming argument in §§3.1–3.4 that there really is but one master argument: the argument for the reality of all events. The other three arguments are but corollaries to the master argument. The truth of past and future contingents follows from the reality of past and future events. It is because future events are real, that they are block determined (or determinate). And it is because future events are fixed (instead of open), that there is no room for temporal becoming in the block universe.

4 OBJECTIONS

The RPM argument claims to have settled the presentism–eternalism debate on the side of eternalism. Here is Putnam (1967):

> I conclude that the problem of the reality and the determinateness of future events is now solved. Moreover, it is solved by physics and not by philosophy. We have learned that we live in a four-dimensional and not a three-dimensional world [. . .]. Indeed, I do not believe that there are any longer any *philosophical* problems about Time (p. 247, emphasis in original).

Despite Putnam's confidence in the RPM argument, it has repeatedly come under fire. A number of important objections have been raised against it, exposing different flaws and fallacies in the argument. In what follows, I present eleven objections to the RPM argument. The list is by no means exhaustive; there certainly are other objections to be found in the scattered literature on RPM, but the objections to be outlined below are by far the most common and important ones.

Given the contradiction in (C) (see §3), one of the six premisses in the RPM argument must be abandoned. RPM reject premise (vi), and thereby establish the reality and determinateness of past and future events. But there are other ways to avoid the contradiction in (C). According to the conventionality objection (§4.1), premises (i) and (ii) have to yield. The relativity objection (§4.2), the epistemic objection (§4.3) and the presentism objection (§4.4) all argue that premises (iii) and (iv) are flawed, albeit for different reasons. That is, they all take issue with the presentist credo according to which $aSb \implies aRb$. According to the transitivity objection (§4.5), finally, premise (v) is mistaken. Notice that in each of these cases, the conclusion that past and future events are real no longer follows.

The remaining objections are not directed at a particular premise of the RPM argument, but they question the argument in its entirety (again for different reasons). The becoming objection (§4.6) offers an argument *for* temporal becoming, and thereby questions the RPM argument *against* temporal becoming. The modesty objection (§4.7) claims that RPM's conclusion cannot follow from SR *alone*, since it requires extra-theoretical assumptions which fall outside the domain of SR. The robustness objection (§4.8), the neo-Lorentzian objection (§4.9) and the quantum objection (§4.10) do not question the validity of the RPM argument in a special relativistic setting, but argue that it no longer applies in a general relativistic, neo-Lorentzian, or quantum setting, respectively. The triviality objection (§4.11), finally, claims that the presentism–eternalism debate is a pseudo-debate.

With so many objections, it may seem as if the RPM argument is ready for the philosophical dustbin, despite its lasting popularity. However, for each of the objections raised in §§4.1–4.11, I will also advance one or more rebuttals. Some may go some way towards restoring the RPM argument. Most, however, merely show the reality question to be open-ended or ill-defined, and especially underdetermined by the formalism of SR (§5).

4.1 The conventionality objection

Two debates have been central in the philosophical literature on SR:

(1) the debate on the *conventionality of simultaneity*;
(2) the debate on the *dimensionality of the world*.

The former debate was sparked by Einstein in 1905; the latter debate was initiated by Minkowski in 1908, and is at the heart of this chapter. Einstein believed the notion of simultaneity to be conventional, and not factual; Minkowski considered reality to be fundamentally four-dimensional, and not three-dimensional. A major contribution to the second debate, in support of Minkowski's claims, is of course the RPM argument, as outlined in §3.

Yet both debates have lingered on to this day, without definite answers. Most strikingly, the link between both debates has remained largely underexplored. To make matters even worse, whenever the link *is* explored, radically different conclusions are reached about the way the former debate impacts the latter.

According to Weingard (1972) and Petkov (1989, 2007a,b, 2008), the conventionality thesis lends further support to Minkowski's claim (see §4.4.3). Dieks (2012b), Ben-Yami (2015) and Cohen (2016), on the other hand, argue for the opposite thesis and exploit the conventionality of simultaneity to undermine the RPM argument. Sklar (1981), finally, remains largely uncommitted.

In what follows, I attempt to clarify the current situation by carefully exploring what implications the conventionality thesis has for the RPM argument specifically, and the debate on the dimensionality of the world more broadly. I first present the conventionality thesis (§4.1.1), and subsequently raise the conventionality objection (§4.1.2). I then distinguish two possible readings of the conventionality thesis — an ontic and an epistemic one — and highlight the repercussion of this distinction for the conventionality objection and its impact on the RPM argument (§4.1.3). I return to the claim by Weingard and Petkov in §4.4.3.

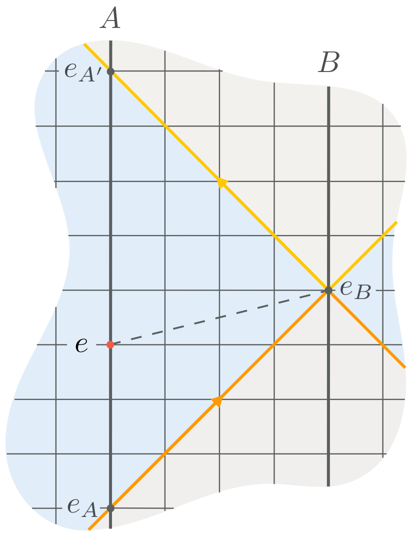

Figure 5: Standard synchrony as defined by Einstein in 1905.

4.1.1 *The conventionality of simultaneity*

The thesis that distant simultaneity is a *conventional* notion (as opposed to a *factual* one) originated in the writings of Poincaré and Einstein and was further developed by Reichenbach in the 1920s and by Grünbaum in the 1950s (see Jammer, 2006 for a historical overview).[33] The conventionality thesis can be summarised as follows. Consider two distant events, one at location A in space, the other at location B. To say that both events are simultaneous is to say that they occur at the same time. That is, if an A- and a B-clock were placed at the locations A and B respectively, both clocks should indicate the same time. This of course presumes that the clocks have been previously *synchronised*.

CLOCK-SYNCHRONISATION. In his 1905 paper, Einstein (1989) proposed the following clock-synchronisation procedure (Figure 5).[34] At time t_A, a light signal is emitted from point A towards point B (event e_A). At time t_B, the signal is reflected back from B to A (event e_B) and returns at A at time $t_{A'}$ (event $e_{A'}$). Notice that the times t_A and $t_{A'}$ are measured by the A-clock, whereas the time t_B is measured by the B-clock. If the speed of light is the same in the AB and BA directions, it follows that the two clocks are synchronous when

$$t_B = t_A + \frac{1}{2}(t_{A'} - t_A). \tag{3}$$

33 The *conventionality* of simultaneity should not be confused with the *relativity* of simultaneity. Whereas the latter refers to the relativity of *intersystemic* simultaneity, the former refers to the relativity of *intrasystemic* simultaneity.

34 See also the Appendix for the Einstein–Poincaré convention for simultaneity.

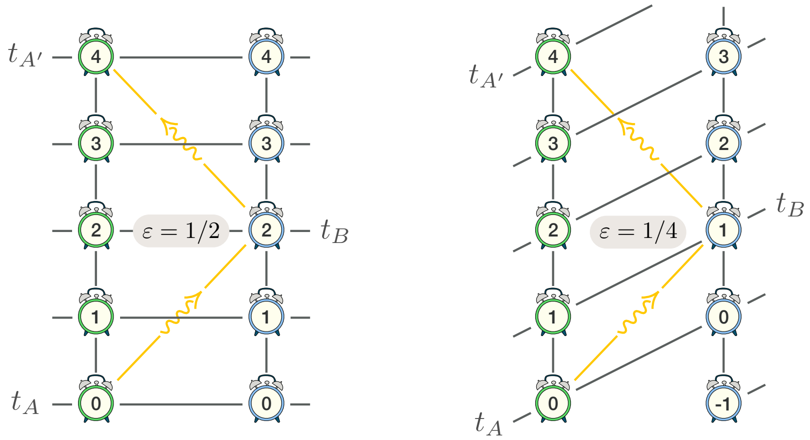

Figure 6: Standard $\varepsilon = \frac{1}{2}$ versus non-standard $\varepsilon = \frac{1}{4}$ synchrony. Figure adapted from Norton (2018a).

THE CONVENTIONALITY THESIS. Einstein's procedure however relies on an important assumption: the isotropy of the speed of light. In order to verify the truth of this assertion, the one-way velocity of light would have to be measured. But this requires the use of spatially separated clocks that are already synchronised. As Einstein (1920, 27) observed: "It would thus appear as though we were moving here in a logical circle." Reichenbach called this the '*velocity-simultaneity circle argument*'. Einstein avoided the circularity by *assuming* the isotropy of the velocity of light without further (experimental) proof.[35] Einstein's definition of distant simultaneity is thus only a convention. Other definitions are possible according to which

$$t_B = t_A + \varepsilon\,(t_{A'} - t_A)\,, \quad 0 < \varepsilon < 1, \tag{4}$$

with ε the *Reichenbach synchronisation parameter*. The choice $\varepsilon = \frac{1}{2}$ is called *standard synchrony* and leads to Einstein's definition of simultaneity. But according to Reichenbach, the choice of ε is completely arbitrary (see Figure 6). This, in short, is the conventionality thesis of simultaneity.

THE CAUSAL THEORY OF TIME. Reichenbach arrived at the conventionality thesis via a different route.[36] According to his causal theory of time (see also Chapter 3), all temporal relations are reducible to causal relations. An event e_1 is earlier than an event e_2 if and only if e_1 can causally affect e_2. Since e_A, e_B, and $e_{A'}$ in Figure 5 are

35 Einstein was probably aware of the conventional character of his synchronisation procedure. He was careful, after all, to use the words "*by definition*" when establishing the isotropy of the speed of light, and titled the first section of his 1905 paper "*§1. Definition of Simultaneity*". See Einstein (1989, 142).

36 See Reichenbach (1922, 1924, 1928) (translated in Reichenbach, 1959, 1969, 1958 respectively).

connected via a light signal, e_A can affect e_B and e_B can affect $e_{A'}$. It follows that $t_A < t_B < t_{A'}$. But for any event e in the open interval between e_A and $e_{A'}$, e can only affect e_B, or *vice versa*, if a causal signal were to travel between them at superluminal speeds, which is forbidden according to SR. It is this causal non-connectibility of e and e_B that leaves their temporal order indeterminate according to Reichenbach. The event e is neither past, present, nor future with respect to e_B.

In summary, the temporal order for any two spacelike separated events is indeterminate. It is only when a definition of distant simultaneity is introduced by hand (via a conventional choice of ε) that a temporal order between spacelike separated events can be established. But this order merely reflects our choice of ε, rather than being an objective matter of fact.

MALAMENT. The thesis that distant simultaneity is a conventional notion is not universally accepted. The most influential objection was probably voiced by Malament (1977). According to Norton (1992, 194), Malament's publication represented "one of the most dramatic reversals in the philosophy of space and time." It is not my aim in this thesis to take a position with regard to the conventionality debate; I merely want to point out what impact the conventionality thesis would have on the debate about the dimensionality of the world (and the RPM argument in particular) *if it were true*.

4.1.2 *The conventionality objection*

According to the conventionality thesis, the temporal order for spacelike separated events is indeterminate. Hence, since c is spacelike separated from a in Figure 4, it cannot be maintained that c is present relative to $\mathcal{O}_1$ at a. Similarly, since b is spacelike separated from c, it cannot be maintained that b is present relative to $\mathcal{O}_2$ at c. Both premises (i) and (ii) are thus false, rendering the RPM argument unsound. Call this the *conventionality objection*.

Weingard (1972) and Sklar (1981) were among the first to apply the conventionality thesis to the RPM argument. More recently, Dieks (2012b), Ben-Yami (2015) and Cohen (2016) endorsed the same viewpoint. Here is Sklar (1981, 135-136) by way of example:

> If we now associate the real (for an observer) with the simultaneous for him, we must, accepting the conventionality of simultaneity, accept as well a conventionalist theory of 'reality for'. It is then merely a matter of arbitrary stipulation that one distant event rather than another is taken as real for an observer. Now there is nothing inconsis-

> tent or otherwise formally objectionable about such a relativized notion of 'reality for', but it does seem to take the metaphysical heart out of the old claim that the present had genuine reality and the past and future lacked it. For what counts as the present is only a matter of arbitrary choice, and so then is what is taken as real.

4.1.3 *Ontic or epistemic?*

In deciding whether the conventionality objection referred to above has any strength, I believe one first has to decide whether the conventionality thesis is an ontic or an epistemic thesis.[37]

ONTIC OR EPISTEMIC? On an *ontic* reading of the conventionality thesis, the relation of distant simultaneity is conventional, as opposed to factual, because this relation does not exist in the objective world. "[I]t is because no relations of absolute simultaneity *exist* to be measured that measurement cannot disclose them", argues Grünbaum (1955, 456). I will call anyone upholding this position an *irrealist* about distant simultaneity.

On an *epistemic* reading of the conventionality thesis, on the other hand, the relation of distant simultaneity is conventional, as opposed to factual, because it is unverifiable. Even if the relation of distant simultaneity exists, we nevertheless fail to have epistemic access to it, and are thus forced to treat this notion in a conventional manner.

AGNOSTIC OR EPISTEMICIST? With respect to the epistemic reading of the conventionality thesis, it is worth distinguishing two further positions. The *agnostic* is non-committal about the possible existence of distant simultaneity. The *ε-epistemicist*, on the other hand, is convinced that there *is* "a fact of the matter as to which distant events are 'really' simultaneous with a given event", even though we cannot measure it empirically. That is, the Reichenbach ε-parameter has a determinate value, but due to the velocity-simultaneity circle argument (referred to above, see §4.1.1), there is no way for us to determine its value.[38] I call this position *ε-epistemicism*, borrowing the term from debates on vagueness.[39]

---

37 I owe a great debt to Dennis Dieks for his time and careful remarks, which greatly improved this section on the ontic–epistemic distinction.

38 This is similar to the hidden variables in certain interpretations of quantum mechanics, such as the particle positions in Bohmian mechanics. Even though each particle always has a definite position, thereby tracing out a classical (or semi-classical) trajectory over time, we do not have epistemic access to these positions.

39 Epistemicism is a philosophical position according to which propositions involving vague predicates (such as 'is thin' or 'is a heap of sand') have definite truth values,

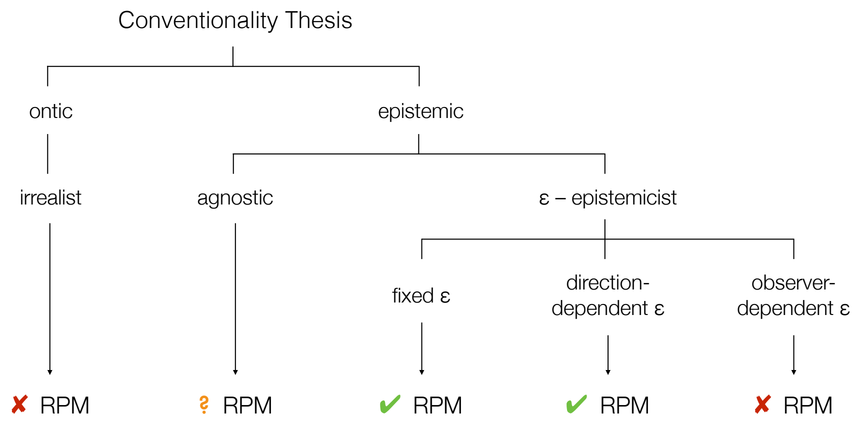

Figure 7: The impact of the conventionality thesis on the RPM argument.

ONTIC IMPACT. On the ontic reading of the conventionality thesis, the conventionality objection certainly applies. After all, if the notion of distant simultaneity does not belong to the ontological furniture of the world, then clearly premises (i) and (ii) are without substance. Not surprisingly, Weingard, Sklar, Dieks, Ben-Yami, and Cohen all subscribe to this ontic interpretation when raising the conventionality objection.

Sklar (1981), for instance, takes the simultaneity of distant events to be "irrealist." We are of course free to introduce such a notion by choosing a particular value for the Reichenbach ε-parameter. But, argues Sklar (1981, 135), if every choice of ε "can explain equally well all the hard data of experience, why should we take the accounts as differing at all in the *real* features they attribute to the world?" (emphasis added). There is, in other words, "no fact of the matter at all about which distant events are 'really' simultaneous with a given event". Ben-Yami (2015, 278) agrees that the definitions of distant simultaneity "do not express any objective temporal order between [spacelike separated] events."

The consequence for the RPM argument is fatal. "If simultaneity is purely conventional and lacks metaphysical significance," Dieks (2012b, 618–19) continues, "there is obviously no reason to suppose that simultaneous events share a special 'reality-property', so that the [RPM] argument seems to become a non-starter." Cohen (2016, 46) concurs that "since simultaneity between spatially separated events is merely conventional and ***not*** an objective constituent of reality", the premises (i) and (ii) above are "devoid of physical import."

POINT PRESENTISM. Granting that the ontic interpretation of the conventionality thesis undermines the RPM argument, where does

even though it is impossible in principle to know what they are. I wish to thank Sylvia Wenmackers for her suggestion to borrow this term here.

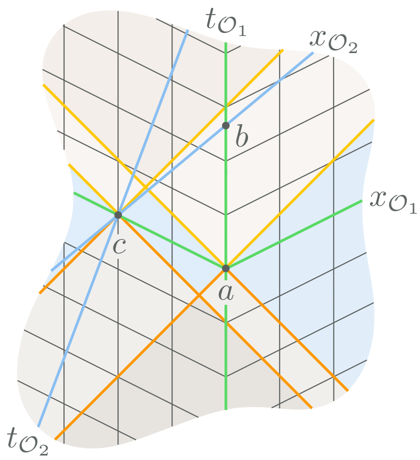

Figure 8: The RPM argument with $\varepsilon = \frac{1}{4}$.

it leave us with regard to the debate on presentism and eternalism? If there is no such thing as distant simultaneity of events, it would seem that the present gets reduced to the here-and-now of each observer. And if we accept the presentist credo that all that exists, exists presently, then reality itself would get reduced to a single point (Figure 1). This was called *point presentism* by Harrington (2008). The problem, according to Stein (1968, 18), is that it leads to "a peculiarly extreme (but pluralistic!) form of solipsism."

Not everyone has reached this conclusion though. Weingard (1972), for instance, while agreeing that the conventionality thesis undermines the RPM argument, offers a new argument, based on the conventionality thesis, in support of eternalism (see §4.4.3).[40]

EPISTEMIC IMPACT. Let us turn to the epistemic interpretation of the conventionality thesis and its impact on the RPM argument. Here the situation becomes more subtle (Figure 7). To start, the agnostic cannot judge the soundness of the RPM argument since he remains undecided as to whether distant simultaneity exists or not.

The ε-epistemicist, on the other hand, argues that the notion of distant simultaneity exists, despite it being epistemically inaccessible, and unlike the irrealist position which we just discussed. As such, the epistemicist can still go both ways. Three situations are worth distinguishing, as summarized in Figure 7:

Situation 1: If she assumes that ε has a *fixed* value, different from $\frac{1}{2}$, then the conventionality objection fails, and the RPM argument nevertheless goes through. To see that, compare Figures 4 and 8. RPM assume standard synchrony with $\varepsilon = \frac{1}{2}$, leading to the familiar *hyperplanes* of simultaneity which are orthogonal to the worldlines of the observers (Figure 4). But suppose now that ε had a different

40 Sklar (1981) also voices a number of ways to deal with the threat of conventionality.

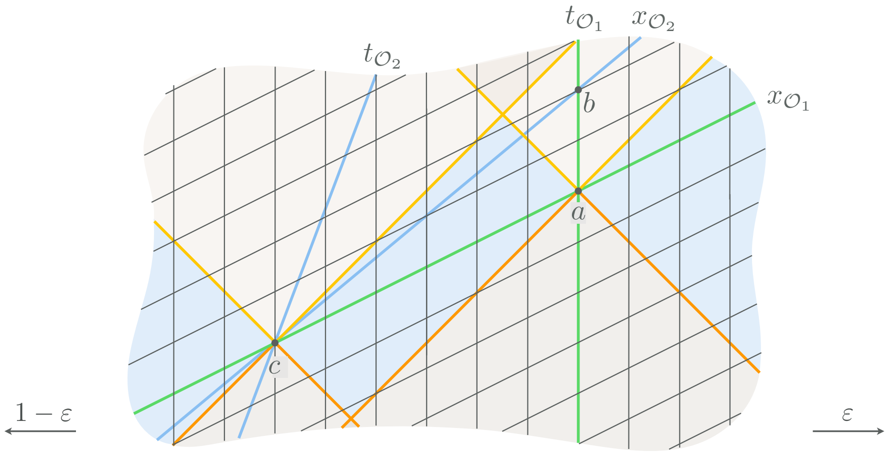

Figure 9: The RPM argument with direction-dependent ε.

value in reality, say $\varepsilon = \frac{1}{4}$. In that case, spacetime would be foliated into one-sheeted *hypercones* of simultaneity (Figure 8).[41] Yet, despite such a different foliation of Minkowski spacetime, the relativity of simultaneity still holds true, and the RPM argument goes through unaffected, as can be judged from Figure 8.

Situation 2: One problem with the hypercones of simultaneity, though, is that the notion of intrasystemic simultaneity is no longer symmetric and transitive, and thus no longer an equivalence relation. For example, although c is simultaneous with a in Figure 8 (cSa), a is not simultaneous with c ($\neg aSc$).

It is customary therefore to make ε direction-dependent (with a choice of $\varepsilon = \frac{1}{4}$ to the right implying $1 - \varepsilon = \frac{3}{4}$ to the left, as explained by Dieks, 2014). This leads to a foliation of Minkowski spacetime into *hyperplanes*, rather than hypercones, and restores the symmetry and transitivity of intrasystemic simultaneity (Figure 9). However, for $\varepsilon \neq \frac{1}{2}$, the hyperplanes are no longer orthogonal to the time axis. Even so, the relativity of simultaneity continues to hold true, and the RPM argument still applies, as can be seen in Figure 9.

Situation 3: Finally, since the choice of the ε-parameter is conventional, nothing prevents the epistemicist from making ε observer-dependent as well. That way, a notion of *absolute* simultaneity can be reintroduced, in which case the RPM argument obviously fails (Figure 10). Neo-Lorentzian interpretations of SR, in particular, subscribe to this position (see for instance Craig, 2001, Craig and Smith (2008), and the discussion in §4.9). The threat of non-locality, finally, has led some Bohmians to similarly introduce a preferred foliation of spacetime (Dürr et al., 2014, see also §4.10).

41 Only for standard synchrony with $\varepsilon = \frac{1}{2}$ do the hypercones degenerate into the familiar horizontal *hyperplanes* of simultaneity. See Torretti (1983), Redhead (1993).

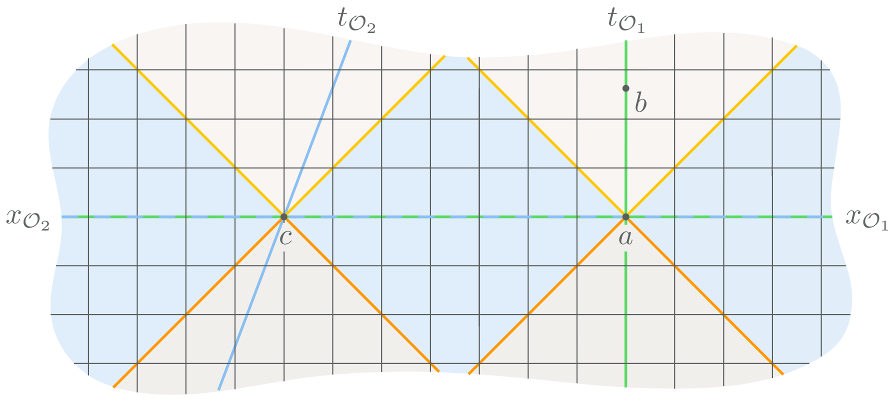

Figure 10: The RPM argument with observer-dependent ε.

SUMMARY. According to Weingard, Sklar, Ben-Yami and others, the conventionality of simultaneity undermines the RPM argument. I have shown the situation to be more subtle than that and have argued that the way in which the conventionality thesis impacts the RPM argument depends on whether it is an ontic or an epistemic thesis. If it is an ontic thesis, the RPM argument cannot be saved. But on certain epistemicist positions regarding distant simultaneity, the RPM argument is unaffected by the conventionality objection (Figure 7).

4.2 The relativity objection

Why take simultaneity as the determiner of what is real? "We must accept that simultaneity and determinateness go hand in hand", begins Norton (2018b) in his evaluation of the RPM argument. But "I see no good reason to accept this", he continues. "The notion of determinateness itself is sufficiently unclear as to leave me uncertain of its connection to simultaneity" (see also §4.7 in that respect).

The connection, however, is easily made. RPM start from the presentist claim that all (and only) present events are real. Whether an event e is real or unreal thus depends on its being present or not. But which events are to be considered present in SR? According to RPM, the present of an event e is the set of all events simultaneous with e. Hence, whichever event stands in the simultaneity relation S to e must be real for e, according to the presentist credo in Eq. (2).

Three objections can be raised against RPM's use of the simultaneity relation S to gauge what is present, and by extension real, in Minkowski spacetime: (1) distant simultaneity only holds *relative* to a frame of reference, (2) distant simultaneity is *epistemically inaccessible*, and (3) it is not clear whether the *present* in SR should be defined in terms of simultaneity relations. I start with the former objection, and discuss the latter two objections in the next two sections (§§4.3–4.4).

RELATIVISTIC INVARIANCE. The RPM argument uses the notion of distant simultaneity S to partition Minkowski spacetime $\mathcal{M}$ into the past, present and future. But distant simultaneity is a *relative* notion in SR. What is simultaneous with an event e depends on the frame of reference that is adopted. Different observers in relative motion will judge the simultaneity of events differently. As a result, they will partition Minkowski spacetime $\mathcal{M}$ differently, and will therefore fail to share the same past, present and future. The past, present and future on this reading are not relativistically invariant.

It might seem odd to gauge the reality of events via such observer-dependent notions. Why base our ontology on frame-dependent concepts such as S? Acceding to Weingard (1972, 119), the relation of distant simultaneity S "cannot have physical significance" since it fails to be relativistically invariant. In his opinion, one should base one's ontological claims on the use of invariant notions, such as the lightcone structure of Minkowski spacetime. "[W]e would expect physically significant concepts of past, present, and future to be relativistically invariant ones so that the past, present and future of an event [...] are the same in every frame of reference" (pp. 119-20). Call this the *relativity objection*.

The same worry was already raised by Capek (1975, 612-613): "Like Rietdijk, Putnam retains the old notion of the universal present spread as a 'world-wide instant' across the whole universe, and uses this notion in order to conclude that, in a sense, *everything* is present." But, objects Capek, Rietdijk and Putnam neglect "the one essential idea of relativity that [...] 'Here-Now' can never be extrapolated to 'Everywhere-Now"' in a relativistically invariant way. Or in the words of Stein (1968, 16):

> [T]he fact that there is a time axis orthogonal to the direction from a to c (or a time-coordinate function having equal values at a and c) adds nothing [...] because *"a time coordinate" is not "time."* Neither a nor b is, in any physically significant sense, "present" [...] for any observer at c — regardless of his velocity. (emphasis in original)

The common fallacy, then, in the arguments by Rietdijk, Putnam and Maxwell is "their employment, in the context of the Einstein-Minkowski theory, of notions about time that are illegitimate in that theory" (Stein, 1968, 15-16).

4.3 The epistemic objection

EPISTEMIC INACCESSIBILITY. One motivation, according to Sklar (1981), for the presentist credo that all (and only) present events are real, is the *epistemic remoteness* of past and future events. However, if we are to consider the past and future as unreal due to their epistemic distance from us, then "surely we are to declare everything outside the lightcone as unreal as well", Sklar continues (p. 139). Events at spacelike separation from us are, after all, causally non-connectible to us, and therefore "totally immune from epistemic contact by us" (at least at the present moment). Put differently, if we are to judge the reality of events by their epistemic accessibilitiy, then there is no reason at all why we should treat the *elsewhere* any different from the *elsewhen*; the elsewhere is just as epistemically distant and inaccessible from us as the elsewhen.[42]

On this reading, since c is spacelike separated from a in Figure 4, it cannot be maintained that c is real for a, despite it being simultaneous (and hence, present) with a relative to observer $\mathcal{O}_1$. Similarly, since b is spacelike separated from c, it cannot be maintained that b is real for c. The reality claims in premises (iii) and (iv) are thus false, and undermine the RPM argument. Call this the *epistemic objection*.

THE VERIFICATIONIST STANCE. The epistemic objection resembles the conventionality objection (§4.1.2). It was the epistemic remoteness of spacelike separated events, after all, that first led Reichenbach to his conventionality thesis of distant simultaneity (§4.1.1). But just as the epistemic inaccessibility of distant simultaneity does not necessarily imply the non-existence of this relation (§4.1.3), so the epistemic remoteness of spacelike separated events should not necessarily imply their unreality.

Why then, do so many jump from the (fairly weak and rather uncontroversial) epistemic reading to the (much stronger) ontic reading? One reason for this attitude, I believe, finds its origin in the ideas of logical positivism and the adoption of a *verificationist stance*. Logical positivism, as developed in the 1920s by the Vienna and Berlin Circle, subscribed to the *verifiability criterion of meaning*, according to which propositions are meaningful only when they are empirically verifiable. The proponents of logical positivism saw a beautiful example of their core ideas in the theory of SR. Einstein, after all, had successfully eliminated the aether from physics since there is no empirical way to verify our motion through it. On such verificationist grounds, the epistemic inaccessibility of spacelike separated events would likewise lead to a rejection of their reality (see Dorato, 2008, 60 for a similar argument, based on the empiricist foundations of SR).

As with the conventionality thesis of distant simultaneity, it is not my intention here to defend the verificationist stance, nor to reject

42 On this view, only the spatiotemporal coincidence of two events is epistemically available to us, reducing reality to a point, as discussed in §4.1.3.

it, as this would fall outside the scope and aims of this chapter. I merely want to explore what implications the verificationist stance would have for the RPM argument, *if it were true*.

4.4 The presentism objection

A MULTITUDE OF PRESENTS. According to Baron (2018), the present in Minkowski spacetime can be defined in an infinite number of ways. That is, since it is not clear what requirements to impose on the present, *any* set of spacetime points could be taken as constituting the present. As a result, there is no best definition for the present in SR. Yet, among the infinite possibilities, some definitions certainly stand out. Let $e \in \mathcal{M}$ be an event in Minkowski spacetime. It is worth distinguishing between the following four presents (Figure 1):

1. *Point present*: the present of e consists only of e itself.
2. *Hyperplane present*: the present of e consists of e itself and a hyperplane through e.
3. *Bow-tie present*: the present of e consists of e itself and all events in the absolute elsewhere of e.
4. *Cone present*: the present of e consists of e itself and all events on the backward lightcone of e.[43]

FLAVOURS OF PRESENTISM. Depending on which of the above four presents is adopted by the presentist, different sets of spacetime points will be considered real. For the point presentist, for instance, the sum total of reality is reduced to a single point: the here-and-now of every observer. As already mentioned, Stein (1968, 18) calls this "a peculiarly extreme (but pluralistic!) form of solipsism."

The hyperplane presentist, in contrast, sticks to the pre-relativistic notion of the present by drawing hypersurfaces of simultaneity. This is also the definition of the present adopted by RPM. For the bow-tie presentist, all events in the absolute elsewhere of e are considered real. And finally, for the backward cone presentist, reality is reduced to what is observable. That is, reality is confined to the set of points on the backward lightcone of e.

Each of these presentist positions has been advanced and argued for in the philosophical literature (see Harrington, 2008 for a defense of the point present,[44] Weingard, 1972 for a defense of the bow-tie present, and Godfrey-Smith, 1979 for a defense of the cone present.)

43 Besides the *backward* cone present, Baron (2018) also defines the *forward* cone present and *double* cone present.

44 This view was first articulated by Robb, 1911, 1914, 1921, 1936. It was later also advanced by Capek, 1966, 1975 and by Stein, 1968. See Arthur, 2006, 143-144 for more details on the punctual (or point) present.

And of course, all of these positions come with their own set of advantages and disadvantages (see Wüthrich, 2013 for a critical survey of all the presentist positions).

VARIATIONS ON THE RPM THEME. Since SR does not dictate which present to adopt, our choice will have to depend on which extra-theoretical assumptions and requirements we impose on the present. Do we want the present to be *global* (like the hyperplane present) or *local* (like the point present)? Does it have to be *relativistically invariant* (like the bow-tie present and cone present)? Or should it be *achronal* (like the hyperplane present)?

It bears repeating that SR leaves these questions underdetermined (see also §4.7). Each of the above-mentioned presents, therefore, is worth taking seriously. It is thus reasonable to ask how the RPM argument would fare if we were to adopt a different definition of the present. That is, would the RPM argument still go through if we were to change the hyperplane present for one of the other three presents?

4.4.1 *RPM and point presentism*

If one reduces the present to a point, the RPM argument cannot get off the ground since the present for any observer does not extend beyond the here-and-now (see also §4.1.3, where the ontic reading of the conventionality objection led to the same conclusion).

4.4.2 *RPM and cone presentism*

If the present for any observer is reduced to what is observable to that observer, the situation becomes more interesting. To see why, let us first rewrite the presentist credo for the (backward) cone presentist, and then run the RPM argument anew on the basis of this modified credo.

CONE PRESENTISM. Let E^- be the relation among the elements of $\mathcal{M}$ where E^- stands for 'is on the backward lightcone of' (or 'is in the past horismos of', see the Appendix). Then aE^-b is shorthand for 'event a is on the backward lightcone of event b'. Now assuming b to represent the here-and-now, b is real. The cone present for b contains all events on the past lightcone of b. Hence, if aE^-b holds true, then a is present for b. Following the presentist credo that all (and only) present events are real, a must be real for b:

$$aE^-b \implies aRb. \tag{5}$$

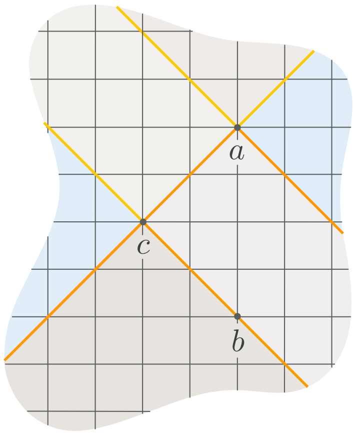

Figure 11: The RPM argument starting from backward cone presentism.

RPM AND CONE PRESENTISM. With that in place, let us re-run the RPM argument, but using Eq. (5) instead of Eq. (2) to gauge what is real (Figure 11):

(i) $cE^{-}a$;
(ii) $bE^{-}c$;
(iii) $cE^{-}a \implies cRa$;
(iv) $bE^{-}c \implies bRc$;
(v) $bRc \wedge cRa \implies bRa$;
(vi) $\neg bE^{-}a \implies \neg bRa$;
(C) $bRa \wedge \neg bRa$.

As with the original RPM argument, a contradiction arises in (C). However, while this refutes backward cone presentism, it fails to fit the eternalist bill, and rather seems to establish a special relativistic version of *possibilism*. It leads to the view that all (and only) events in the causal past of b are real.[45] As we will see in §4.6, the same view of reality also follows from Stein's theorem.

OSCAR'S WORLDLINE. The possibilist view was ridiculed by Putnam (1967) for two reasons. First of all, unless two observers share the same here-and-now, they will not agree on what events are real and determinate, as each observer has their own past lightcone. In lieu of a global, observer-independent, division between the real and unreal, every observer would have their own reality, leading to a fragmentation of reality.

Second, Putnam asks us to imagine a person, called Oscar. While Oscar's worldline lies entirely in the elsewhere of me-now, it does

45 I leave it as an exercise to the reader to run the same argument starting from forward or double cone presentism. In the former case, reality is confined to the causal future of any event; in the latter case, eternalism can be recovered.

intersect the past lightcone of me-later. Then it will be true in my future that Oscar has existed, even though Oscar does not exist in my present. "Things could come to *have been*, without its ever having been true that they *are*!", exclaims Putnam (1967, 246, emphasis in original).

Although startling, Sklar (1981) is not convinced that this refutes the possibilist view. After all, Sklar dryly remarks, "we expect that a move to a relativistic picture will force some violence on our ways of speaking" (p. 138). Stein (1968) furthermore objects that one has no right to apply the present tense to Oscar, as in SR "*an event's present is constituted by itself alone*" (p. 15, emphasis in original).

4.4.3 *RPM and bow-tie presentism*

So far, substituting the hyperplane present with the point or cone present has been detrimental to the RPM argument. This just goes to show that the RPM argument will not hold water on *every* possible definition of the present. Call this the *presentism objection*.

That being said, it turns out that adopting the bow-tie present *is* instrumental in reaching the eternalist conclusion. This version of the RPM argument was first proposed by Weingard (1972) and has since been advocated by Petkov (2007a,b, 2008). Call this the Weingard–Petkov argument, or WP argument, for the four-dimensionality of the world.

Whereas the RPM argument relies on the *relativity* of simultaneity, the WP argument relies on the *conventionality* of simultaneity. That is, Weingard uses the conventionality thesis to first plead for the bow-tie present, and then uses the bow-tie present to argue for eternalism.

TOPOLOGICAL SIMULTANEITY. Consider the set $\mathcal{M}$ of spacetime events $a, b, \ldots$, and let b represent the here-and-now. By carefully choosing the ε-parameter, any event in the absolute elsewhere of b can be considered simultaneous with b, and hence present. The present for b, in other words, coincides with the absolute elsewhere of b — a spatially extended bow-tie-shaped region (Figure 1). The bow-tie present contains all events that are causally non-connectible to b, and are thus *topologically simultaneous* with b (following Reichenbach and Grünbaum's terminology).[46]

Contrary to the (standard, $\varepsilon = \frac{1}{2}$) hyperplane present for b, the bow-tie present for b *is* relativistically invariant. It neatly partitions Minkowski spacetime into an absolute present (b + elsewhere of b),

46 Sklar (1981, 136) refers to the bow-tie present of b as "the region of the 'absolutely simultaneous' and 'absolutely present' ".

absolute future (upper lightcone of b) and absolute past (lower lightcone of b).[47]

BOW-TIE PRESENTISM. Let A be the relation among the elements of $\mathcal{M}$ where A stands for 'is in the absolute elsewhere of'. Then aAb is shorthand for 'event a is in the absolute elsewhere of event b'. Since b represents the here-and-now, b is real. The bow-tie present for b consists of all events topologically simultaneous with b. Hence, if aAb holds true, then a is present for b. Following the presentist credo that all (and only) present events are real, a must be real for b:

$$aAb \implies aRb. \tag{6}$$

This position was dubbed *bow-tie presentism* by Gilmore et al. (2016). Although Sklar (1981) fails to see any way of 'refuting' this position, it remains a peculiar view to say the least:

> Having dismissed as unreal things whose only deficiency is the fact that causal signals from them have taken time to arrive at us now, or that causal signals from us will take some time to arrive at them, it seems very suspicious indeed to promote into the domain of the fully real those things causally inaccessible to us (now) altogether. (p. 137)

Leaving these reservations aside, let us move on to the WP argument.

THE WEINGARD–PETKOV ARGUMENT. The WP argument, in essence, is just the RPM argument, but using Eq. (6) instead of Eq. (2) to gauge what is real (Figure 12):

(i) cAa;
(ii) bAc;
(iii) $cAa \implies cRa$;
(iv) $bAc \implies bRc$;
(v) $bRc \wedge cRa \implies bRa$;
(vi) $\neg bAa \implies \neg bRa$;
(C) $bRa \wedge \neg bRa$.

Once again, a contradiction arises in (C), thereby refuting bow-tie presentism and establishing eternalism.

47 Savitt (2000) rejects the bowtie present because it fails to be *achronal*. According to him, no events in the present of b should be in each other's absolute future or absolute past. To see why, imagine that your entire worldline from birth to death was contained in the absolute elsewhere of b. Then according to b, your entire life is present, which sounds absurd.

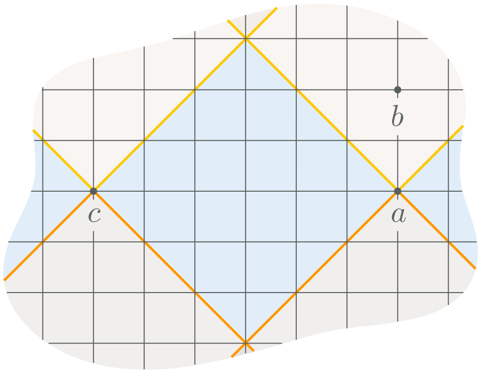

Figure 12: The Weingard–Petkov argument.

4.5 The transitivity objection

The most common objection to the RPM argument focusses on the transitivity of the relation 'is real for'.[48] For — the objection runs — the hyperplane present in SR is a relative (frame-dependent) notion. What is present for $\mathcal{O}_1$ need not be present for $\mathcal{O}_2$. And since the reality of events is tied up with their being present, reality itself is bound to be relativized. What is real for $\mathcal{O}_1$ need not be real for $\mathcal{O}_2$.

There is thus "no compelling reason" according to Hinchliff (1996, 131) to subscribe to the transitivity of reality across different inertial frames, as is done in premise (v) of the RPM argument. Quite the contrary, we must accept the *non-transitivity* of R, lest we fail to "fully [...] enter the relativistic spirit", dixit Dainton (2010, 331). Just as bSc and cSa in Figure 4 do not imply that bSa, so bRc and cRa do not imply that bRa. Call this the *transitivity objection*.

TERNARY RELATIONS. To see all this more clearly, recall that the relation of simultaneity in SR is a ternary (three-place) relation among two events *and* a given reference frame. Two events can only be said to be simultaneous with one another *relative* to some observer. When this is taken into account, the non-transitivity of S across observers follows automatically:

$$bS_{\mathcal{O}_2}c \wedge cS_{\mathcal{O}_1}a \not\Rightarrow bS_{\mathcal{O}_1}a. \tag{7}$$

If we now associate the real with the simultaneous, then R becomes a ternary (three-place) relation as well, in which case:

$$bR_{\mathcal{O}_2}c \wedge cR_{\mathcal{O}_1}a \not\Rightarrow bR_{\mathcal{O}_1}a, \tag{8}$$

contrary to premise (v) of the RPM argument. The flaw in the RPM argument, in other words, is that R is taken to be a binary (two-place) relation among events, rather than a ternary one like S.

48 See, for instance, Sklar (1974), Godfrey-Smith (1979), Sklar (1981) (republished in Sklar, 1985), Hinchliff (1996, 2000), Dieks (2014), Norton (2015) and Norton (2018b).

WEINGARD–PETKOV. Observe that the transitivity objection also applies to the WP argument. For even the bow-tie present is a relative notion. And so here as well, the non-transitivity of R follows directly from the non-transitivity of A. That is, starting from:

$$bAc \wedge cAa \not\Rightarrow bAa, \tag{9}$$

and applying the presentist credo in Eq. (6), one obtains:

$$bRc \wedge cRa \not\Rightarrow bRa, \tag{10}$$

in contradiction with premise (v) of the WP argument.

ONTIC PROTAGOREANISM. Giving up the transitivity of R, however, comes at a price. If R is not transitive, then there exists not one reality, but a plurality of (observer-dependent) realities (Bouton, 2017). The non-transitivity of R would lead to a relativisation of existence, which could serve as a basis for a form of ontological pluralism. Hinchliff (1996) calls this position *relativized presentism*; Dorato (2008) refers to it as *ontic protagoreanism*.

Whichever name one attaches to this position, the question is whether such a position is even defendible. On this view, when two observers in relative motion meet, they only share their here-and-now without sharing any other point at spacelike separation (Figure 1). What is more, one could change what is real for us by changing our state of motion (*e.g.* by jumping on a train, or travelling by plane).

If all of this sounds absurd to you, you are not alone. Callender (2017, 54), for example, finds the relativisation of reality "more or less nonsense — or at the very least, desparate". Dorato (2008) similarly maintains that the reality relation R "calls for transitivity *as a matter of meaning*" (p. 60, emphasis in original).

PUTNAM'S PRINCIPLE. Putnam (1967) must have been aware of the looming threat of relativisation too, as he considered the transitivity of R to be his "most important assumption" (p. 240). He thus elevated it to the principle that There Are No Privileged Observers.

Now, Putnam's choice of words here is unfortunate at best, and misleading at worst, as Sklar (1981) correctly remarks. The absence of privileged observers in SR follows from the relativity postulate. Einstein advanced this principle in order to prevent the introduction of a privileged aether frame. However, it is not because all observers have "equal rights to a legitimate world-description" (p. 130), that all observers must also share the same reality. This is precisely the point of the transitivity objection. If observers in relative motion can disagree about what is simultaneous, why could they then not disagree about what is real as well?

Craig (2000, 4) therefore suggests it would have been better to call Putnam's principle the One Common Reality principle, to highlight the fact that reality is assumed to be absolute, objective, monistic and observer-independent — not relative, subjective, pluralistic and observer-dependent.

THE UNIQUENESS CRITERION. The One Common Reality principle is also at work in Peterson and Silberstein (2010), although they refer to it as the *uniqueness criterion* (see §2). Peterson and Silberstein thus require every spacetime event to have a unique, observer-independent $\mathcal{R}$-value. An event is either real for all observers (with $\mathcal{R} = 1$) or unreal ($\mathcal{R} = 0$). The uniqueness criterion "seems intuitive" enough, write Peterson and Silberstein (2010, 212), "since an event with an $\mathcal{R}$-value of both 1 and 0 [...] would be both real and unreal, which would be a contradiction." The uniqueness criterion, therefore, is an "absolute minimal criterion" for the notion of reality to make any sense at all (p. 212).

It is also the uniqueness criterion that endows the reality relation R with its transitive property. After all, if bRc implies that b and c share the same $\mathcal{R}$-value, and cRa means that c and a have the same $\mathcal{R}$-value, and b, c and a all have a unique $\mathcal{R}$-value, then b and a must have the same $\mathcal{R}$-value as well.

SUMMARY. The fact though remains that both the One Common Reality principle and the uniqueness criterion are being introduced for *intuitive reasons* alone. And intuitions, everyone knows, are not necessarily the most reliable guide to ontology. The ever-nuanced Sklar (1974, 275) thus reminds us that it is "by no means inconsistent or patently absurd" to assume that an event *can* have an $\mathcal{R}$-value of both 1 and 0, dependening on the point of view one considers. Even if this leads to a relativisation of existence, "there doesn't seem to be anything very objectionable a priori about this" (Sklar, 1985, 296). In short, the question whether the reality relation R is transitive or not remains very much open.

4.6 The becoming objection

So far we have focussed on *negative* responses to RPM which seek to expose different fallacies in their argument. Stein (1968, 1991), in contrast, offers a *positive response* by showing that time-oriented Minkowski spacetime is compatible with a relation of objective becoming.[49] Stein thereby indirectly rebuts the RPM argument against temporal becoming (§3.4). Call this *the becoming objection*.

49 Stein (1968) is a direct response to Rietdijk (1966) and Putnam (1967), whereas Stein (1991) was provoked by Maxwell (1985). Stein's theorem was further generalized by

OBJECTIVE BECOMING. 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.* $aJ^-b \implies aBb$.[50]

Stein then proceeds to prove the following theorem:

Theorem 1. *Consider the binary relation B among the elements of time-oriented Minkowski spacetime $\langle \mathbb{R}^4, \eta_{ab}, \uparrow \rangle$, 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:*

$$aBb \iff aJ^-b.$$

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

Stein's theorem shows that there is only one relation satisfying the five constraints above, namely the relation of being in the causal past. In other words, all events in and on the past lightcone of b have become for b and are thereby fixed, determinate and real; all events outside the past lightcone of b have not yet become for b and are therefore open, indeterminate and unreal (Figure 13).[51,52]

Clifton and Hogarth (1995), and was later extended to arbitrary spacetime regions by Myrvold (2003). See also footnotes 51 and 52.

50 $J^+(p)$ and $J^-(p)$ denote the causal future and past of an event $p \in \mathcal{M}$; $I^+(p)$ and $I^-(p)$, in contrast, denote the chronological future and past of p. For more on the causal structure of Minkowski spacetime, see the Appendix.

51 The fifth requirement that aBb holds whenever a is in the *causal past* of b can be relaxed by the weaker condition that aBb only holds when a is in the *chronological past* of b (*i.e.* when a is inside the past lightcone of b): $aI^-b \implies aBb$. In that case, Stein's becoming relation B would reduce to past *chronological* connectibility, rather than past *causal* connectibility, as shown by Clifton and Hogarth (1995). As a result, only the events *inside* the past lightcone of b would have become for b.

52 Stein's becoming relation can also be extended to arbitrary spacetime regions, as shown by Myrvold (2003). For any two arbitrary spacetime regions α and β, α has become for β iff for every spacetime point $a \in \alpha$ there is a $b \in \beta$ such that aBb.

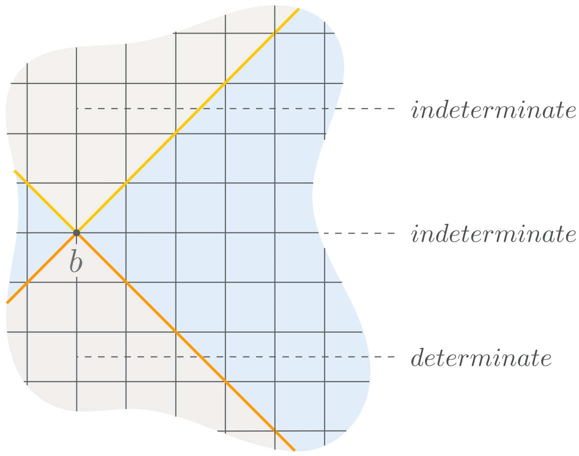

Figure 13: The past, present and future for b according to Stein's notion of objective becoming.

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. Callender (2000, S592) agrees that "the idea that Stein conclusively refuted Putnam et al [...] seems to have achieved the status of conventional wisdom." Despite these claims, a number of important criticisms have been voiced in the past.

To start, one might object that Stein's becoming relation is importantly different from the one employed by RPM (Faye et al., 1997). Stein considers what has become with respect to an event. Call this *worldline-independent becoming*. RPM consider what has become with respect to an event *on a particular intertial worldline*. Call this *worldline-dependent becoming*. As a result, Stein's becoming relation is relativized to a local spacetime point (*viz.* the here-and-now), whereas RPM's becoming relation is relativized to a global temporal moment (*viz.* the spatially extended present).

CALLENDER'S NO-GO THEOREM. According to Stein's becoming relation, the present of an event is reduced to its here-and-now. This point present is so far removed from our traditional conceptions of a spatially extended present that Callender (2000, S592) wonders "whether [B] is a relation of serious philosophical interest." He thus imposes one further condition upon B:

6. $\exists a\, \exists b\, \exists B : aBb \wedge bBa \wedge a \neq b.$

This non-uniqueness condition requires that every event a shares its present with at least one other event b in Minkowski spacetime. That is, Callender requires the present to have at least *some* spatial extent (see also Callender, 2017). As weak as it is, Callender's non-uniqueness condition turns Stein's theorem *for* becoming into a no-go theorem *against* becoming. Indeed, it can be shown that the only relation B satisfying conditions 1. to 6. is the universal relation U, where each element of the set $\mathcal{M}$ is related to every element of $\mathcal{M}$.

BIGAJ'S RESPONSE. According to Bigaj (2008), Stein's analysis is incomplete as it leaves the complement of the becoming relation B undefined. That is, whereas B relates all events a to b that *have become* for b, we also need the complementary relation O, relating all events a to b that *have not yet become* for b. Call this relation the openness relation, and let O stand for 'is open for'. Then aOb is shorthand for 'event a is open for event b' (*i.e.* 'event a has not yet become for b' or 'event a is indeterminate for event b'). In analogy with Stein's procedure, Bigaj requires O to satisfy the following five constraints:

1. O is definable from time-oriented metrical relations;
2. O is irreflexive, *i.e.* a is not open for a ($\neg aOa$);
3. O is transitive, *i.e.* $aOb \wedge bOc \implies aOc$;
4. O is non-universal, *i.e.* for any point b, there is a point a such that $\neg aOb$;
5. aOb holds whenever b is in the causal past of a, *i.e.* $bJ^{-}a \implies aOb$.

Bigaj finally introduces one further constraint:

6. For every a and b in $\mathcal{M}$, either aBb or aOb.

With that in place, it is easy to show that no relations B and O can possibly satisfy all of the above constraints. To that aim, let a and b be two events such that a chronologically precedes b. Next, consider an event c that is spacelike separated from both a and b (Figure 14). According to Stein's theorem, $\neg aBc$ and $\neg cBb$. It follows that aOc and cOb. Using the transitivity of O, $aOc \wedge cOb \implies aOb$. However, since a is in the chronological past of b, it follows from Stein's theorem that aBb. We thus obtain the result that $aOb \wedge aBb$, contrary to the sixth requirement above.

FURTHER OBJECTIONS. Yet other objections can be raised against Stein's theorem. In the next chapter on temporal becoming, I will develop two more objections. The first one refers to the fact that Stein's theorem requires Minkowski spacetime to be temporally oriented. That is, for Stein's becoming objection to pass muster, Stein cannot work with Minkowski spacetime $\langle \mathbb{R}^4, \eta_{ab} \rangle$ as such, but needs to consider the beefed-up structure $\langle \mathbb{R}^4, \eta_{ab}, \uparrow \rangle$ instead, where the time orientation $\uparrow$ is added by hand as *extra structure*.

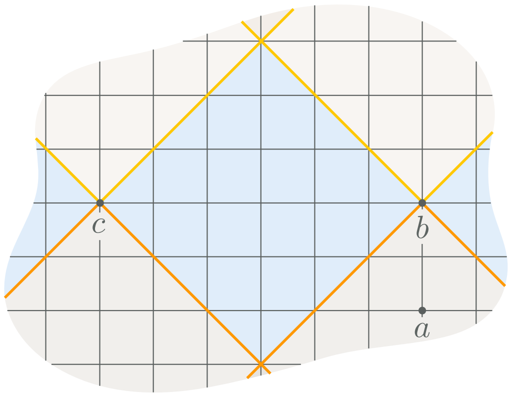

Figure 14: Bigaj's objection to Stein's theorem.

The second objection to Stein's theorem argues that there is nothing dynamic or flow-like to Stein's becoming relation, and that it cannot pick out a distinguished present. As such, Stein's becoming relation B fails to meet two defining requirements for a strong, dynamic form of becoming, and can only aspire to a much weaker, deflated notion of becoming.

4.7 The modesty objection

MORALS ABOUT SPACE AND TIME. In a recent paper, Norton (2015) wonders what one can learn about the ontology of space and time from the theory of relativity. He deplores the fact that Einstein's theories are all too often misinterpreted. In order to sift among the plethora of answers on record, Norton (2015, 186-187) introduces four requirements which any ontological claim should meet:

1. "*Novelty*. The morals we draw should be novel consequences of relativity theory. They should not be results that could have been drawn equally from earlier theories.
2. *Modesty*. The morals we draw should be consequences of relativity theory. They should not be results we wish could be drawn from relativity theory but are only suggested to us by the theory.
3. *Realism*. Relativity theory is to be construed as literally as possible.[53]
4. *Robustness*. We should not draw morals in one part of the theory that are contradicted in others. In particular the morals we draw from examination of special relativity should survive the transition to general relativity."

53 Norton (2015, 187) here implies that "we must take the theory to mean literally what it says", in contrast to a "fictionalist" reading of the theory according to which its ontological pronouncements are nothing more than "useful mythmaking".

Failure to meet any of these requirements implies one is not dealing with a moral worthy of inclusion in our catalog.

The RPM argument aspires at drawing an important ontological moral from SR. It exploits the relativity of simultaneity to force upon us an eternalist worldview. But does it meet Norton's four requirements? Since the relativity of simultaneity is distinctive of SR, and not to be found in classical mechanics, the RPM argument satisfies the *novelty* requirement. RPM also take SR to provide an account of the physical world that is literally true, thereby satisfying the *realism* requirement. But according to Norton (2015, 196), the RPM argument violates the requirement of *modesty* and *robustness*. I start with the former violation, and discuss the latter in the next section (§4.8).

RPM AND MODESTY. Notice the crucial role that is played by the reality relation R in the RPM argument above (§3). And yet, R "*has nothing to do with physics!*", exclaims Dorato (2008, 58, emphasis in original). "Unlike the [...] relation of simultaneity, denoted above by S", the reality relation R "plays no role whatsoever in any physical theory" (p. 58). SR, as a theory of space and time, does not speak of the reality or determinateness of events. No textbook on SR offers a definition of these terms. Norton (2018b) thus finds it "awkward" that the reality relation R plays such a prominent role in the RPM argument, since the notions of determinanetess and indeterminateness "are not supplied as a theoretical term in special relativity."

By invoking the reality relation R in the RPM argument, RPM *supplement* the theory of SR with extra-theoretical metaphysical assumptions, which are supplied externally. According to Norton (2015, 196), the use of R thus "amounts to introducing new physical assumptions [...] into relativity theory", thereby violating the requirement of modesty. In the words of Sklar (1981, 131): "it is a great mistake to read off a metaphysics superficially from the theory's overt appearance, and an even graver mistake to neglect the fact that metaphysical presuppositions have gone into the formulation of the theory."

The RPM argument, therefore, is not an argument for eternalism from SR *alone*, but an argument for eternalism from SR *plus* numerous assumptions about the reality of events (such as the intimate link between the reality and simultaneity of events, as discussed in §4.2, or the transitive character of reality, as discussed in §4.5).

4.8 The robustness objection

"Many of the philosophical responses to relativity theory look at the special theory alone", writes Norton (2015, 187). They thereby "trumpet results that are almost immediately contradicted by the emergence of general relativity." That is, many of the ontological morals that are drawn from relativity theory violate *robustness*. They might hold in a special relativistic framework, but they do not survive the transition to a general relativistic one. The RPM moral that past and future events are determinate is but one example of this problem according to Norton (2015, 196).

TWO REMARKS. Two remarks are in order before we proceed. First, whereas all of the previous objections, as outlined in §§4.1–4.7, accept SR but reject RPM, the robustness objection accepts RPM but rejects SR. That is, whereas the former objections questioned the validity of the RPM argument in a special relativistic setting, the robustness objection questions the setting itself. The end result, however, remains the same. In rejecting SR, the robustness objection nonetheless ends up overturning the RPM argument as well.

Second, the rejection of SR, to be considered here, does not occur on antinaturalist grounds by a wholesome rejection of science. This, after all, would go against the naturalist attitude which requires philosophical and metaphyical inquiry to be continuous with scientific inquiry (Wüthrich, 2013). Instead, SR is rejected because is was superseded by general relativity, just like Newtonian relativity was superseded by SR. The reason is that SR only applies to 'flat' spacetimes in the absence of gravity, which is hardly realistic and which does not accord with the actual spacetime structure of our Universe. It furthermore fails to take any quantum effects into account. As a result, it is only natural to also consider the more fundamental, more broadly encompassing theories, such as the theory of general relativity (GR), quantum mechanics (QM), quantum field theory (QFT) and quantum gravity (QG).

Indeed, Norton's robustness objection is not merely applicable in a general relativistic framework. It can also be extended to a neo-Lorentzian or quantum framework. To keep matters clear, I limit the discussion here to the validity of the RPM argument in GR, and discuss its validity in a neo-Lorentzian and quantum setting in the next two sections (§§4.9–4.10).

All of the objections to be raised in this and the next two sections have in common that they reject the relativity of simultaneity by the introduction of a preferred frame of reference. In doing so, they not only contradict SR, but they also undermine the RPM argument which so crucially exploits the relativity of simultaneity in order to drive a stake through the presentist heart.

COSMOLOGICAL MODELS. The problem with the presentist enterprise, according to RPM, is that it is not clear which hypersurface of simultaneity is to be taken as the *Now*. Worse still, according to the relativity postulate, no observer (or frame of reference) is privileged. The A-theoretic assumption, then, that there nevertheless *is* a preferred foliation of Minkowski spacetime seems to go against the spirit of SR.

But when we move from SR to GR, the addition of a privileged set of simultaneity hypersurfaces might be justified. First of all, in GR the relativity of simultaneity no longer holds globally, as in SR, but only locally for events infinitesimally close to any particular event (Norton, 2015). Second, there are solutions to the Einstein field equations which describe universes that admit a preferred foliation (Dieks, 2014, 106).

Friedmann-Lemaître-Robertson-Walker (FLRW) universes have a symmetric and homogeneous distribution of matter and energy, and exhibit exact spherical symmetry about every spacetime point. As a result, FLRW spacetimes posess a natural foliation into spacelike hypersurfaces of constant spatial curvature that is unique and physically privileged (Wüthrich, 2013). The different folia can moreover be labeled by a global cosmological time parameter t. As such, FLRW spacetimes admit the reintroduction of a privileged time and an absolute notion of simultaneity. Following Wüthrich (2013), "two events are *FLRW-absolutely simultaneous* just in case they are within the same spatial hypersurface of the privileged foliation, or, equivalently, occur at the same cosmological time t." In summary, FLRW spacetimes seem much more hospitable to the presentist enterprise.

A number of problems remain however. First, the question arises whether and why we should imbue cosmological time with any ontological significance in order to objectively distinguish space from time, and past from present and future. Second, the perfectly homogeneous FLRW spacetimes are but idealizations; they offer an approximate description of our actual Universe which, at least locally, is far from spatially homogeneous.[54] Finally, it is not clear how the spacelike hypersurfaces of constant spatial curvature connect to our presentist intuitions with regard to the present and temporal becoming. "[I]t is not enough to simply identify a folium [...] as the present and believe that one has explained our presentist intuitions", writes Wüthrich (2013, 19).

4.9 The neo-Lorentzian objection

There are other ways to introduce a preferred frame of reference. Hendrik Lorentz famously postulated an immobile and empirically unde-

54 This problem was already noted by Gödel (1949), and has been amply repeated in the contemporary literature (see, for instance, Wüthrich, 2013).

tectable aether while developing his aether theory between 1892 and 1895. He thereby introduced a unique rest frame and an absolute notion of simultaneity.

In the neo-Lorentzian interpretations of SR today, the existence of an aether is no longer postulated, but a preferred frame is still introduced (Craig, 2000, 2001, Craig and Smith, 2008, Bourne, 2006). The background spacetime, therefore, is no longer Minkowskian, but Newtonian or neo-Newtonian. However, due to Lorentz symmetry, the preferred frame is in principle undetectable, just as with the aether frame in Lorentz's theory. It is, in other words, impossible to empirically distinguish SR from its neo-Lorentzian cousins. Neo-Lorentzian SR is just SR with an extra non-empirical preferred frame.

OCKHAM'S RAZOR. "The reason why some [presentists] have sought all manner of strange replacements for special relativity when this comparatively elegant theory exists is baffling", writes Callender (2008). Yet Callender reminds us that the addition of an absolute notion of simultaneity does violate the demands of Ockham's razor (see also Wüthrich, 2013). Ockham's law of parsimony, after all, states that entities should not be multiplied without necessity. And since the preferred frame cannot even be detected, it seems to be an unnecessary *ad hoc* addition to the relativistic framework. That is, when presented with the Einsteinian and neo-Lorentzian interpretations of SR that make the same predictions, and whose mathematical formalisms are identical, one should opt for the simpler, and more parsimonious Einsteinian interpretation.

4.10 The quantum objection

Norton (2015) does not apply his robustness requirement outside the realm of relativity theory, but it certainly could be extended to the quantum realm as well. Quantum mechanics, after all, may offer a more promising way of introducing a preferred frame of reference, which could then be put into effect by the presentist to reintroduce a notion of absolute simultaneity and to argue against RPM. Call this the *quantum objection*. Two approaches can be distinguished: the first approach is based on the collapse of the wavefunction; the other relies on the violations of the Bell inequalities and quantum non-locality. I briefly discuss both in the next two sections (§§4.10.1–4.10.2).

4.10.1 *Quantum becoming*

Some advocates of collapse interpretations have invoked the objective quantum collapse of the wavefunction as a potential mechanism to distinguish the present (Stapp, 1977, Popper, 1982, Shimony, 1993, 1998, Lucas, 1998, 1999, 2008, Tooley, 2008). Here is Lucas (1999, 10), arguing to that end:

> There is a worldwide tide of actualization — collapse into eigenstate — constituting a preferred foliation by hyperplanes (not necessarily flat) of co-presentness sweeping through the universe — a tide which determines an absolute present [...]. Quantum mechanics [...] not only insists on the arrow being kept in time, but distinguishes a present as the boundary between an alterable future and an unalterable past.

The fixed and determinate past, on this reading, corresponds to wavefunctions which have collapsed to eigenstates, whereas the open and indeterminate future corresponds to wavefunctions which are still in a superposition of eigenstates.

Lucas's presentist hopes have to be tempered in at least three ways. First, the quantum collapses invoked by Lucas would have to occur in a preferred basis, as superpositions in one basis can always be written as eigenstates in another. An electron that is determinately x-spin up, for example, can be written as a superposition of z-spin up and z-spin down:

$$|\uparrow\rangle_x = \frac{1}{\sqrt{2}}\left(|\uparrow\rangle_z + |\downarrow\rangle_z\right). \tag{11}$$

Hence, "a collapse to fixity in x-spin buys openess in z-spin", writes Callender (2017, 95). What is more, not all measurements need to involve collapse. Consider measuring the x-spin of the electron above, which is already in an x-spin eigenstate. Callender (2017, 95) thus wonders whether the measurement outcome is "open because future or [...] fixed because eigenstate". In summary, it is far from clear how one should map the determinate/indeterminate distinction into the eigenstate/superposition distinction.

Second, even if a distinguished basis is postulated, such as the position basis in GRW dynamical collapse theories, most collapse theories fail to be Lorentz invariant. This is "usually regarded by physicists not as a metaphysical virtue," observes Wüthrich (2013, 19), "but as a physical vice".[55]

Third, which interpretation of QM to adopt is heavily disputed. There are many viable alternatives to GRW or other collapse interpretations. Importantly, neither hidden-variable interpretations (such as Bohmian mechanics) nor many-worlds interpretations (such as Everettian QM) require collapse to solve the measurement problem.

55 It is worth observing, in that respect, that the only relativistic version of GRW (namely rGRWf, as developed by Tumulka, 2006) does *not* violate Lorentz symmetry.

4.10.2 *Quantum non-locality*

The influential philosopher of science, Sir Karl Popper, was among the first to invoke the spooky correlations between spacelike separated events (as theoretically predicted by Bell, 1964/2004a and experimentally confirmed by Aspect et al., 1981) to reintroduce a preferred frame in SR. Popper (1982, 30) thus wrote:

> It is only now, in the light of the new experiments stemming from Bell's work, that the suggestion of replacing Einstein's interpretation by Lorentz's can be made. If there is action at a distance, then there is something like absolute space. If we now have theoretical reasons from quantum theory for introducting absolute simultaneity, then we would have to go back to Lorentz's interpretation.

Before continuing, it bears repeating that the no-signalling theorem (Redhead, 1989) ensures that non-local correlations cannot be used to send superluminal signals or any other information across spacelike hypersurfaces. As such, non-local correlations cannot be used to empirically detect the preferred frame. The preferred frame, while metaphysically distinguished, is bound to remain hidden. While this *empirically* ensures a 'peaceful co-existence' between QM and SR (Shimony, 1984), *theoretically* and *metaphysically* the tensions between QM and SR are not so easy to ignore, as Bell himself knew all too well.[56]

RELATIVISTIC EPR. To see how quantum non-locality may force a preferred foliation upon spacetime by entailing a notion of absolute simultaneity, I here follow the discussion in Callender (2008) (see also Callender, 2017, 84-94 and Aharonov and Albert, 1981 for more details). Consider Bohm's reformulation of the famous EPR paradox (Einstein et al., 1935, Bohm, 1951). A pair of spin 1/2 particles (say two electrons), labeled 1 and 2, is generated by a common source $\mathcal{S}$ in the singlet state:

$$|\psi\rangle = \frac{1}{\sqrt{2}} \left(|\uparrow_x\rangle_1 \, |\downarrow_x\rangle_2 - |\downarrow_x\rangle_1 \, |\uparrow_x\rangle_2 \right) . \tag{12}$$

Both electrons are sent in opposite directions, with electron 1 moving to the left and electron 2 moving to the right. In the Minkowski diagram in Figure 15, L and R are two spacelike separated events. At L, the x-spin of electron 1 is measured; at R, the z-spin of electron 2 is measured. Finally, let us introduce two inertial observers, Alice and Bob, who are in relative motion with respect to each other, and thus foliate Minkowski spacetime differently, as indicated in Figure 15 by the foliations t_A and t_B respectively.

56 According to Bell (2004b, 172), there exists "an apparent incompatibility, at the deepest level, between the two fundamental pillars of contemporary theory".

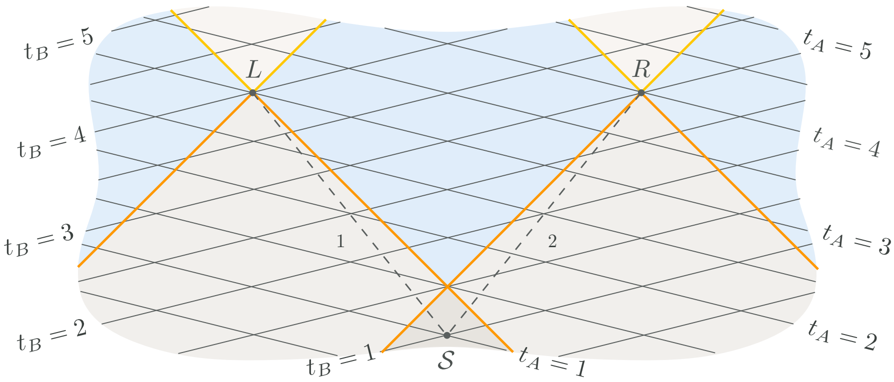

Figure 15: A relativistic EPR experiment as seen from the perspectives of Alice and Bob. Figure adapted from Callender (2008).

For Alice, the situation looks as follows. At time $t_A = 1$, the electrons are in the singlet state:

$$|\psi\rangle_{A;1} = \frac{1}{\sqrt{2}} \left(|\uparrow_x\rangle_1 |\downarrow_x\rangle_2 - |\downarrow_x\rangle_1 |\uparrow_x\rangle_2 \right). \tag{13}$$

But at $t_A = 3$, the x-spin of electron 1 is measured at L. Both outcomes are equiprobable, but suppose that the electron is measured to be x-spin up. This implies that the superposed singlet state (13) must have collapsed to the first term:

$$|\psi\rangle_{A;3} = |\uparrow_x\rangle_1 |\downarrow_x\rangle_2 . \tag{14}$$

At $t_A = 4$, the z-spin of electron 2 is measured at R. Since the singlet state collapsed at $t_A = 3$, electron 2 is determinately x-spin down, as indicated in (14). There thus is an equal chance of obtaining z-spin up or z-spin down. Assuming the former, the wavefunction becomes:

$$|\psi\rangle_{A;4} = |\uparrow_x\rangle_1 |\uparrow_z\rangle_2 . \tag{15}$$

Now let us move to Bob's perspective. At time $t_B = 1$, the system is in the singlet state (12), which can be rewritten in the z-spin basis as:

$$|\psi\rangle_{B;1} = \frac{1}{\sqrt{2}} \left(|\uparrow_z\rangle_1 |\downarrow_z\rangle_2 - |\downarrow_z\rangle_1 |\uparrow_z\rangle_2 \right). \tag{16}$$

At $t_B = 3$, the z-spin of electron 2 is measured to be z-spin up at R, implying a collapse to the second term:

$$|\psi\rangle_{B;3} = |\downarrow_z\rangle_1 |\uparrow_z\rangle_2 . \tag{17}$$

Finally, at $t_B = 4$, the x-spin of electron 1 is measured to be x-spin up at L, reducing the wavefunction to:

$$|\psi\rangle_{B;4} = |\uparrow_x\rangle_1 |\uparrow_z\rangle_2 . \tag{18}$$

Here is the problem. First, Alice and Bob disagree on which measurement, L or R, caused the collapse of the singlet state. Alice says L; Bob claims R. Second, the histories as told by Alice and Bob are completely different. Although the initial and final states at $t_{A/B} = 1$ and $t_{A/B} = 4$ agree on both accounts, the intermediate states at $t_{A/B} = 3$ are clearly incompatible. As Callender (2017, 88) points out, "if we take the wavefunction at all seriously disagreements like this will not do." Either Alice is right and Bob is wrong, or *vice versa*. In any case, by insisting on one (and only one) correct story, we must assume a preferred foliation of Minkowski spacetime.

THE COORDINATION PROBLEM. Although this is congenial to the presentist dream of reintroducing absolute time and temporal becoming, it threatens the eternalist outlook and the validity of the RPM argument. However, the argument just given relies on a collapse interpretation of QM (such as the Copenhagen interpretation or GRW theory). Most hidden-variable interpretations (such as Bohmian mechanics) also demand a preferred frame. But epistemic interpretations (such as Qbism) or retrocausal interpretations (such as the two-state vector formalism) do not run into this problem. It also remains a matter of debate as to how a relative-state formulation of QM fares in view of the above (see Bacciagaluppi, 2002, Brown and Timpson, 2016, Norsen, 2016, Vaidman, 2016), and the same can be said for most modal interpretations. It suffices, therefore, for the eternalist to point at any of these interpretations as a possible way out.

Finally, even if we were to adopt a collapse or hidden-variable interpretation with a preferred foliation of spacetime, we would still face what Callender (2008, 2017) calls the *coordination problem*: why should the metaphysically preferred foliation according to which the world unfolds coincide with the physically preferred foliation which quantum mechanics postulates?

4.11 The triviality objection

According to the final objection, the presentism–eternalism debate is a "pseudo-debate" (Dorato, 2008, 66). That is, the ontological dispute between presentists and eternalists lacks substance and is therefore without meaning. To see this, consider the two different senses of the copula 'IS':[57]

57 Savitt (2006) distinguishes no less than five temporal senses of the copula IS. Besides the tensed and tenseless sense, as defined below, Savitt also differentiates between the *omnitemporal* and *transtemporal* sense of the copula IS, where e IS real $\iff$ e is always real in the former sense, and e IS real $\iff$ e is real during a certain amount of time in the latter. Finally, Savitt introduces the *atemporal* sense of the copula IS where e IS real $\iff$ e is timelessly real, in order to cash out the difference between

1. *Tensed sense*: an event e IS real $\iff$ e is real now.
2. *Tenseless sense*: an event e IS real $\iff$ e was real in the past, is real now, or will be real in the future.

Now recall the presentist credo:

i. Any future event f IS not real, as of now.
ii. Any past event p IS not real, as of now.

But which sense of the copula 'IS' is being used here?

1. *Tensed sense*: the future event f is not real now; the past event p is not real now.
2. *Tenseless sense*: the future event f was not real in the past, is not real now, and will not be real in the future; similarly for the past event p.

On a tensed reading, the presentist credo is trivially true, and no different from the eternalist credo. After all, both presentists and eternalists agree that future and past events are not real *now*. On a tenseless reading, however, the presentist credo leads to an outright contradiction. Hence, Dorato (2008) concludes that presentism is "caught between the Scylla of a triviality [and] the Charybdis of a contradiction" (p. 66). Or even shorter, "presentism is either trivial or untenable" (Meyer, 2005, 213). Call this the *triviality objection*.

LIGHTBULBS AND REFRIGERATORS. The triviality objection was first voiced by Callender (2000, S588) who admits that "it's not obvious that the two views [presentism vs. eternalism] differ over much." In order to illustrate his point, Callender introduces the lightbulbs from §2. Recall that a particular lightbulb is ON when the corresponding event is real, and OFF when that event is not real. The presentism–eternalism debate then revolves around the following question: are non-present (past or future) lights ON or OFF?[58]

The problem is that no-one can go out and check, as we are all stuck in the present. That is, unless we *are* in the past or future, we cannot possibly see past or future lightbulbs. Callender likens it to the question: is the refrigerator light ON or OFF when you close the door? Here as well, we can only check by opening the door.

The refrigerator analogy, however, only goes that far. Whereas the refrigerator presentist and eternalist at least agree on the presence of a lightbulb inside the fridge, the temporal presentist maintains that whenever a lightbulb is OFF, it does not exist. Only bulbs that are ON

concrete and abstract existence. Numbers, classes and other mathematical objects, for instance, can only be real in this atemporal sense.

58 'OFF' exclaims the presentist; 'ON' blurts the eternalist.

exist. The sum total of physical existence, then, consists of lightbulbs that are ON. But this is exactly what the eternalist maintains as well. Callender thus wonders where the conflict really lies.

Since then, the same objection has been raised independently by Dorato (2006), Dolev (2006) and Savitt (2006) (see also Meyer, 2005). Dolev (2006, 182) thus deplores the tendency to "parade arguments, and invoke scientific theories, in support of views that cannot even be intelligibly stated, or for settling a matter that has not been given a meaningful formulation".[59]

PUTNAM DEFEATED. Putnam was known to change his philosophical views rather frequently, and should be applauded for it. Interestingly, in 2008 Putnam also had a major change of heart with respect to the RPM argument. Once a staunch eternalist, Putnam now announced defeat. Not because of any of the previously mentioned objections,[60] but because of the triviality objection just developped.

One reason for this sudden turnaround has to do with the fact that Yuval Dolev, an active proponent of the triviality view, worked as a PhD student under Putnam's supervision.[61] Putnam (2008, 71) thus admitted that "Yuval Dolev, Mauro Dorato, and Steven Savitt are absolutely right, and that the question whether the past and the future are 'real' is a pseudo-question." According to Putnam, not much survives of the original RPM argument, in view of these criticisms. Only the truth argument, as developped in §3.2, still holds true.

PROPER SUBSET RELATIONS. The triviality objection, however, is not without counterobjections. I think Callender is mistaken, and that the triviality argument is without force. It suffices to compare which lightbulbs are ON for the presentist and for the eternalist in Figure 2 to see that the former set is a proper subset of the latter set. Clearly then, presentism and eternalism are metaphysically distinct. Even if both agree that all and only lighted bulbs are real, they nonetheless have different ontologies. Reality for the presentist is but a subset of reality for the eternalist.

Wüthrich (2010) debunks the triviality objection in essentially the same manner. "The sum total of physical existence, according to the presentist, can be organized in a three-dimensional manifold", writes Wuthrich. "In contrast, eternalists consider the full four-dimensional 'block universe' as the sum total of existence" (p. 441). That is, the eternalist and (hyperplane) presentist give fundamentally different

59 The argument here could be the RPM argument, the scientific theory SR, and the view it supports eternalism.

60 Putnam (2008, 71), for instance, explicitly said that he was "*not* convinced by a well known criticism due to Howard Stein."

61 Personal communication between Putnam and Dorato. See Dorato (2008).

answers to the dimensionality question. Whereas the eternalist quantifies over all events in $\mathcal{M}$ when quantifying over all real events, the presentist first partitions $\mathcal{M}$ into past, present and future events, and merely quantifies over the equivalence class of present events (Wüthrich, 2013).

5 CONCLUSION

I began this chapter with the reality question and the dimensionality question, and briefly considered the presentist and eternalist answers to it. The RPM argument purports to establish eternalism and four-dimensionalism on the basis of SR. However, in view of the objections raised in §§4.1–4.11, it is clear that the RPM argument is not without problems. Each of its premises can be questioned, and it is doubtful whether the RPM argument can survive the transition to a general relativistic or quantum setting.

But rejecting the RPM argument does not establish presentism and three-dimensionalism either. The presentism–eternalism debate may give the wrong impression that the philosopher of time is dealing with an either-or situation, whereas in actuality other metaphysical positions are on offer too, such as possibilism (or historicism) or the so-called moving spotlight theory (see Chapter 2). Not only that, even presentism comes in mutually contradictory flavours. Whereas the point presentist reduces reality to a point and takes the world to be zero-dimensional, for example, the bow-tie presentist considers the entire elsewhere to be real, and agrees with the eternalist that the world has both spatial *and* temporal extension. Each variety of presentism has its advantages and disadvantages, and it is not clear which one we should adopt. Finally, presentism has to deal with its own set of problems — metatime being just one major, unresolved, problem.[62]

Returning to the RPM argument, the soundness of the argument hinges, above all, on our interpretation of reality, and in particular on the alleged transitivity of the reality relation R and its intimate link with the simultaneity of events. Since the reality relation does not belong to the formalism of SR, SR alone cannot answer the reality and dimensionality question. Indeed, despite claims to the contrary, SR leaves the debate on the reality and dimensionality of our world *underdetermined*. What is needed in order to answer these questions are additional metaphysical assumptions and presuppositions, which fall outside the scope of SR.

62 Metatime seems a prerequisite for the present to undergo a dynamical updating. See Wüthrich (2013) and Chapter 2.

This resonates with the verdict drawn by Sklar (1974, 272): SR "throws novel light on the philosophical questions, but it is unable by itself to resolve fully the long-standing philosophical issues." That is, "acceptance of relativity cannot force one into the acceptance or rejection of any of the traditional metaphysical views about the reality of past and future" events, dixit Sklar (1981, 140). Dieks (1991, 259) concurs that "the theory of relativity does not enforce a particular philosophical position concerning the absolute differences between past, present and future." Wüthrich (2013, 20), finally, concludes that "fundamental physics does not uniquely determine the metaphysics of time [but] it does impose constraints which any naturalist worth her salt must respect." Indeed, the metaphysics of time will always be constrained by the straightjacket of physics, but physics alone is powerless at settling the presentism–eternalism debate. The underdetermination of metaphysics by physics is here to stay.

REFERENCES

Aharonov, Y. and D. Z. Albert 1981. Can we make Sense out of the Measurement Problem in Relativistic Quantum Mechanics? *Physical Review D 24*, 359–370.

Arthur, R. T. W. 2006. Minkowski Spacetime and the Dimensions of the Present. In D. Dieks (Ed.), *The Ontology of Spacetime*, Volume 1, Book section 7, pp. 129–155. Amsterdam: Elsevier.

Aspect, A., P. Grangier, and G. Roger 1981. Experimental Tests of Realistic Local Theories via Bell's Theorem. *Physical Review Letters 47*(7), 460–463.

Bacciagaluppi, G. 2002. Remarks on Space-Time and Locality in Everett's Interpretation. In T. Placek and J. Butterfield (Eds.), *Non-Locality and Modality*, pp. 105–122. Dordrecht: Springer Netherlands.

Baron, S. 2018. Time, Physics, and Philosophy: It's All Relative. *Philosophy Compass 13*(1), e12466.

Bell, J. S. 1964. On the Einstein Podolsky Rosen Paradox. *Physics 1*(3), 195–200.

Bell, J. S. 2004a. On the Einstein-Podolsky-Rosen Paradox. In A. Aspect (Ed.), *Speakable and Unspeakable in Quantum Mechanics: Collected Papers on Quantum Philosophy*, Book section 2, pp. 14–21. Cambridge: Cambridge University Press.

Bell, J. S. 2004b. Speakable and Unspeakable in Quantum Mechanics. In A. Aspect (Ed.), *Speakable and Unspeakable in Quantum Mechanics: Collected Papers on Quantum Philosophy*, Book section 18, pp. 169–172. Cambridge: Cambridge University Press.

Ben-Yami, H. 2015. Causal Order, Temporal Order, and Becoming in Special Relativity. *Topoi 34*, 277–281.

Bigaj, T. 2008. On Temporal Becoming, Relativity, and Quantum Mechanics. In D. Dieks (Ed.), *The Ontology of Spacetime*, Volume 2, Book section 12, pp. 229–244. Amsterdam: Elsevier.

Bishop, R. C. and H. Atmanspacher 2011. The Causal Closure of Physics and Free Will. In R. Kane (Ed.), *The Oxford Handbook of Free Will* (2nd ed.)., Book section 5, pp. 101–111. Oxford: Oxford University Press.

Black, M. 1962. Review of G. J. Whitrow's The Natural Philosophy of Time. *Scientific American CCVI*(April), 181–182.

Bohm, D. 1951. *Quantum Theory*. New York: Prentice Hall.

Bourne, C. 2006. *A Future for Presentism*. Oxford: Clarendon Press.

Bouton, C. 2017. Is the Future already Present? The Special Theory of Relativity and the Block Universe View. In C. Bouton and P. Huneman (Eds.), *Time of Nature and the Nature of Time: Philosophical Perspectives of Time in Natural Sciences*, Boston Studies in the Philosophy and History of Science, Book section 6, pp. 89–122. Switzerland: Springer.

Brown, H. R. and C. G. Timpson 2016. Bell on Bell's Theorem: The Changing Face of Nonlocality. In M. Bell and S. Gao (Eds.), *Quantum Nonlocality and Reality: 50 Years of Bell's Theorem*, Book section 6, pp. 91–123. Cambridge: Cambridge University Press.

Callender, C. 2000. Shedding Light on Time. *Philosophy of Science 67*, S587–S599.

Callender, C. 2008. Finding "Real" Time in Quantum Mechanics. In W. L. Craig and Q. Smith (Eds.), *Einstein, Relativity and Absolute Simultaneity*, Book section 2, pp. 50–72. London: Routledge.

Callender, C. 2017. *What Makes Time Special?* Oxford: Oxford University Press.

Calosi, C. 2014. Metaphysics of Time in Spacetime. *Thought: A Journal of Philosophy 3*(1), 1–8.

Capek, M. 1966. Time in Relativity Theory: Arguments for a Philosophy of Becoming. In J. T. Fraser (Ed.), *Voiced of Times*, pp. 434–454. New York: Brazilier.

Capek, M. 1975. Relativity and the Status of Becoming. *Foundations of Physics 5*(4), 607–617.

Cassirer, E. 1920. *Einstein's Theory of Relativity*. Chicago: Open Court.

Clifton, R. and M. Hogarth 1995. The Definability of Objective Becoming in Minkowski Spacetime. *Synthese 103*(3), 355–387.

Cohen, Y. 2016. Why Presentism Cannot Be Refuted by Special Relativity. In Y. Dolev and M. Roubach (Eds.), *Cosmological and Psychological Time*, pp. 41–51. Cham: Springer International Publishing.

Craig, W. L. 2000. *The Tenseless Theory of Time: A Critical Examination*, Volume 294 of *Studies in Epistemology, Logic, Methodology, and Philosophy of Science*. Dordrecht: Springer.

Craig, W. L. 2001. *Time and the Metaphysics of Relativity*, Volume 84 of *Philosophical Studies Series*. Dordrecht: Springer.

Craig, W. L. and Q. Smith 2008. *Einstein, Relativity and Absolute Simultaneity*. New York: Routledge.

Dainton, B. 2010. *Time and Space*. London: Routledge.

Dickson, W. M. 1998. *Quantum Chance and Non-Locality*. Cambridge: Cambridge University Press.

Dieks, D. 1991. Time in Special Relativity and its Philosophical Significance. *European Journal of Physics 12*(6), 253.

Dieks, D. 2012a. De Natuurfilosofie van C. W. Rietdijk. *Civis Mundi 12*.

Dieks, D. 2012b. Time, Space, Spacetime. *Metascience 21*(3), 617–619.

Dieks, D. 2014. Time in Special Relativity. In A. Ashtekar and V. Petkov (Eds.), *Springer Handbook of Spacetime*, Book section 6, pp. 91–113. Berlin: Springer.

Dolev, Y. 2006. How to Square A Non-Localized Present with Special Relativity. In D. Dieks (Ed.), *The Ontology of Spacetime*, Volume 1, Book section 9, pp. 177–190. Amsterdam: Elsevier.

Dorato, M. 1996. On Becoming, Relativity, and Nonseparability. *Philosophy of Science 63*, 585–604.

Dorato, M. 2006. Absolute Becoming, Relational Becoming and the Arrow of Time: Some Non-Conventional Remarks on the Relationship between Physics and Metaphysics. *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics 37*(3), 559–576.

Dorato, M. 2008. Putnam on Time and Special Relativity: A Long Journey from Ontology to Ethics. *European Journal for Analytic Philosophy 4*(2), 51–70.

Dürr, D., S. Goldstein, T. Norsen, W. Struyve, and N. Zanghì 2014. Can Bohmian Mechanics be made Relativistic? *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Science 470*(2162).

Einstein, A. 1920. *Relativity: The Special and the General Theory: A Popular Exposition by Albert Einstein*. London: Methuen & Co. Ltd.

Einstein, A. 1961. *Relativity: The Special and the General Theory: A Popular Exposition by Albert Einstein*. New York: Wings Books.

Einstein, A. 1989. On the Electrodynamics of Moving Bodies. In *The Collected Papers of Albert Einstein — English Translations*, Volume 2, pp. 140–171. Princeton, New Jersey: Princeton University Press.

Einstein, A., B. Podolsky, and N. Rosen 1935. Can Quantum-Mechanical Description of Physical Reality be Considered Complete? *Physical Review 47*(10), 777–780.

Faye, J., U. Scheffler, and M. Urchs 1997. Introduction. In *Perspectives on Time*, pp. 1–58. Dordrecht: Kluwer.

Frankfurt, H. G. 1969. Alternate Possibilities and Moral Responsibility. *The Journal of Philosophy 66*(23), 829–839.

Gilmore, C., D. Costa, and C. Calosi 2016. Relativity and Three Four–Dimensionalisms. *Philosophy Compass 11*(2).

Gödel, K. 1949. A Remark on the Relationship between Relativity Theory and Idealistic Philosophy. In P. A. Schilpp (Ed.), *Albert Einstein: Philosopher-Scientist*, pp. 555–562. La Salle, IL: Open Court.

Godfrey-Smith, W. 1979. Special Relativity and the Present. *Philosophical Studies: An International Journal for Philosophy in the Analytic Tradition 36*(3), 233–244.

Grünbaum, A. 1955. Logical and Philosophical Foundations of the Special Theory of Relativity. *American Journal of Physics 23*, 450–464.

Harrington, J. 2008. Special Relativity and the Future: A Defense of the Point Present. *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics 39*(1), 82–101.

Hinchliff, M. 1996. The Puzzle of Change. *Philosophical Perspectives 10*, 119–136.

Hinchliff, M. 2000. A Defense of Presentism in a Relativistic Setting. *Philosophy of Science 67*, S575–S586.

Jammer, M. 2006. *Concepts of Simultaneity: From Antiquity to Einstein and Beyond*. Baltimore: Johns Hopkins University Press.

Jeans, J. 1937. *The Mysterious Universe*. Harmondsworth: Penguin.

Le Poidevin, R. 2013. Time and Freedom. In H. Dyke and A. Bardon (Eds.), *A Companion to the Philosophy of Time*, Book section 31, pp. 535–548. West Sussex: John Wiley & Sons, Inc.

Levin, M. 2007. Compatibilism and Special Relativity. *The Journal of Philosophy 104*(9), 433–463.

Lockwood, M. 2005. Taking Space-Time Seriously. In *The Labyrinth of Time: Introducing the Universe*, Book section 3. Oxford: Oxford University Press.

Lucas, J. R. 1998. Transcendental Tense II. *Aristotelian Society Supplementary Volume 72*, 29–43.

Lucas, J. R. 1999. A Century of Time. In J. Butterfield (Ed.), *The Arguments of Time*, pp. 1–20. New York: Oxford University Press.

Lucas, J. R. 2008. The Special Theory and Absolute Simultaneity. In W. L. Craig and Q. Smith (Eds.), *Einstein, Relativity and Absolute Simultaneity*, Book section 11, pp. 279–290. New York: Routledge.

Malament, D. 1977. Causal Theories of Time and the Conventionality of Simultaneity. *Nous 11*, 293–300.

Markosian, N. 2004. A Defense of Presentism. In D. Zimmerman (Ed.), *Oxford Studies in Metaphysics*, pp. 47–82. Oxford: Oxford University Press.

Marques, E. M. 2019. Relativistic Fatalism. *Principia: An International Journal of Epistemology 23*(2), 231–247.

Maxwell, N. 1985. Are Probabilism and Special Relativity Incompatible? *Philosophy of Science 52*(1), 23–43.

Maxwell, N. 1988. Are Probabilism and Special Relativity Compatible? *Philosophy of Science 55*(4), 640–645.

Maxwell, N. 1993. On Relativity Theory and Openness of the Future. *Philosophy of Science 60*(2), 341–348.

McKenna, M. and D. J. Coates 2019. Compatibilism. In E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy*, Volume Winter Edition.

Meyer, U. 2005. The Presentist's Dilemma. *Philosophical Studies 122*, 213–225.

Miller, K. 2013. Presentism, Eternalism, and the Growing Block. In H. Dyke and A. Bardon (Eds.), *A Companion to the Philosophy of Time*, Book section 21, pp. 345–364. West Sussex: John Wiley & Sons, Inc.

Monton, B. 2006. Presentism and Quantum Gravity. In D. Dieks (Ed.), *The Ontology of Spacetime*, Book section 14, pp. 263–280. Amsterdam: Elsevier.

Myrvold, W. C. 2003. Relativistic Quantum Becoming. *The British Journal for the Philosophy of Science 54*(3), 475–500.

Norsen, T. 2016. Quantum Solipsism and Nonlocality. In M. Bell and S. Gao (Eds.), *Quantum Nonlocality and Reality: 50 Years of Bell's Theorem*, Book section 13, pp. 204–237. Cambridge: Cambridge University Press.

Norton, J. D. 1992. Philosophy of Space and Time. In M. H. Salmon, J. Earman, C. Glymour, J. G. Lennox, P. Machamer, J. E. McGuire, J. D. Norton, W. C. Salmon, and K. F. Schaffner (Eds.), *Introduction to the Philosophy of Science*, Book section 5. Indianapolis: Hackett Publishing Company.

Norton, J. D. 2015. What Can We Learn about the Ontology of Space and Time from the Theory of Relativity? In L. Sklar (Ed.), *Physical Theory: Method and Interpretation*, Book section 7, pp. 185–228. Oxford: Oxford University Press.

Norton, J. D. 2018a. *Einstein for Everyone*. Pittsburgh: Nullarbor Press.

Norton, J. D. 2018b. Philosophical Significance of the Special Theory of Relativity: Morals about Time. In *Einstein for Everyone*. Pittsburgh: Nullarbor Press.

Penrose, R. 1989. *The Emperor's New Mind*. Oxford: Oxford University Press.

Peterson, D. and M. Silberstein 2010. Relativity of Simultaneity and Eternalism: In Defense of the Block Universe. In V. Petkov (Ed.), *Space, Time, and Spacetime*, Volume 167, pp. 209–237. Berlin: Springer-Verlag.

Petkov, V. 1989. Simultaneity, Conventionality and Existence. *The British Journal for the Philosophy of Science 40*(1), 69–76.

Petkov, V. 2007a. On the Reality of Minkowski Space. *Foundations of Physics 37*(10), 1499–1502.

Petkov, V. 2007b. Relativity, Dimensionality, and Existence. In V. Petkov (Ed.), *Relativity and the Dimensionality of the World*, Volume 153, Book section 7, pp. 115–135. Dordrecht: Springer.

Petkov, V. 2008. Conventionality of Simultaneity and Reality. In D. Dieks (Ed.), *The Ontology of Spacetime II*, Book section 9, pp. 175–185. Amsterdam: Elsevier.

Petkov, V. 2009. *Relativity and the Nature of Spacetime*. The Frontiers Collection. Berlin: Springer-Verlag.

Popper, K. R. 1982. *Quantum Theory and the Schism in Physics: From the Postscript to the Logic of Scientific Discovery*. London: Hutchinson.

Price, H. 1996. *Time's Arrow and Archimedes' Point*. Oxford: Oxford University Press.

Putnam, H. 1967. Time and Physical Geometry. *Journal of Philosophy 64*(8), 240–247.

Putnam, H. 2008. Reply to Mauro Dorato. *European Journal for Analytic Philosophy 4*(2), 71–73.

Redhead, M. 1989. *Incompleteness, Nonlocality, and Realism: A Prolegomenon to the Philosophy of Quantum Mechanics*. Oxford: Oxford University Press.

Redhead, M. 1993. The Conventionality of Simultaneity. In J. Earman, A. I. Janis, G. J. Massey, and N. Rescher (Eds.), *Philosophical Problems in the Internal and External World: Essays in the Philosophy of Adolf Grünbaum*, pp. 103–128. Pittsburgh: University of Pittsburgh Press.

Reichenbach, H. 1922. Der gegenwärtige Stand der Relativitätsdiskussion. *Logos 10*, 316–378.

Reichenbach, H. 1924. *Axiomatik der relativistischen Raum-Zeit-Lehre*. Braunschweig: Vieweg.

Reichenbach, H. 1928. *Philosophie der Raum-Zeit-Lehre*. Berlin: W. de Gruyter.

Reichenbach, H. 1958. *The Philosophy of Space and Time*. New York: Dover Publications.

Reichenbach, H. 1959. On the Present State of the Discussion on Relativity. In *Modern Philosophy of Science — Selected Essays*, Volume 2, pp. 3–47. London: Routledge and Kegan Paul.

Reichenbach, H. 1969. *Axiomatization of the Theory of Relativity*. Berkeley, California: Univeristy of California Press.

Rietdijk, C. W. 1966. A Rigorous Proof of Determinism Derived from the Special Theory of Relativity. *Philosophy of Science 33*(4), 341–344.

Rietdijk, C. W. 1976. Special Relativity and Determinism. *Philosophy of Science 43*(4), 598–609.

Rietdijk, C. W. 2007. Four-dimensional Reality and Determinism; an Answer to Stein. In V. Petkov (Ed.), *Relativity and the Dimensionality of the World*, Volume 153, Book section 6, pp. 101–113. Dordrecht: Springer.

Robb, A. A. 1911. *Optical Geometry of Motion*. Cambridge, MA: Cambridge University Press.

Robb, A. A. 1914. *A Theory of Time and Space*. Cambridge, MA: Cambridge University Press.

Robb, A. A. 1921. *Absolute Relations of Time and Space*. Cambridge, MA: Cambridge University Press.

Robb, A. A. 1936. *Geometry of Time and Space*. Cambridge, MA: Cambridge University Press.

Saunders, S. 2002. How Relativity Contradicts Presentism. *Royal Institute of Philosophy Supplement 50*, 277–.

Savitt, S. 2000. There's No Time like the Present (In Minkowski Spacetime). *Philosophy of Science 67*, S563–S574.

Savitt, S. 2006. Presentism and Eternalism in Perspective. In D. Dieks (Ed.), *The Ontology of Spacetime*, Volume 1, Book section 6, pp. 111–127. Amsterdam: Elsevier.

Savitt, S. 2014. *Being and Becoming in Modern Physics*. The Stanford Encyclopedia of Philosophy.

Shimony, A. 1984. Controllable and Uncontrollable Non-Locality. In S. Kamefuchi (Ed.), *Proceedings of the International Symposium: Foundations of Quantum Mechanics in the Light of New Technology*, pp. 225–230. Physical Society of Japan.

Shimony, A. 1993. The Transient Now. In *Search for a Naturalistic World View*, Volume II, Book section 18, pp. 271–287. Cambridge: Cambridge University Press.

Shimony, A. 1998. Implications of Transience for Spacetime Structure. In S. A. Huggett, L. J. Mason, K. P. Tod, S. T. Tsou, and N. M. J. Woodhouse (Eds.), *The Geometric Universe: Science, Geometry and the Work of Roger Penrose*, Book section 10, pp. 161–172. Oxford: Oxford University Press.

Sklar, L. 1974. *Space, Time, and Spacetime*. Berkeley: University of California Press.

Sklar, L. 1981. Time, Reality and Relativity. In R. Healy (Ed.), *Reduction, Time and Reality*, pp. 129–142. New York: Cambridge University Press.

Sklar, L. 1985. *Philosophy and Spacetime Physics*. Berkeley: University of California Press.

Stapp, H. P. 1977. Quantum Mechanics, Local Causality, and Process Philosophy. *Process Studies* 7(3), 173–82.

Stein, H. 1968. On Einstein-Minkowski Space-Time. *The Journal of Philosophy 67*, 5–23.

Stein, H. 1991. On Relativity Theory and Openness of the Future. *Philosophy of Science 58*(2), 147–167.

Tooley, M. 1999. Time and Causation. New York: Garland Publishing, Inc.

Tooley, M. 2008. A Defense of Absolute Simultaneity. In W. L. Craig and Q. Smith (Eds.), *Einstein, Relativity and Absolute Simultaneity*, Book section 8, pp. 229–243. New York: Routledge.

Torretti, R. 1983. *Relativity and Geometry*. Foundations and Philosophy of Science and Technology Series. Oxford: Pergamon Press.

Tumulka, R. 2006. A Relativistic Version of the Ghirardi-Rimini-Weber Model. *Journal of Statistical Physics 125*, 825–844.

Vaidman, L. 2016. The Bell Inequality and the Many-Worlds Interpretation. In M. Bell and S. Gao (Eds.), *Quantum Nonlocality and Reality: 50 Years of Bell's Theorem*, Book section 12, pp. 195–203. Cambridge: Cambridge University Press.

Weingard, R. 1972. Relativity and the Reality of Past and Future Events. *The British Journal for the Philosophy of Science 23*(2), 119–121.

Weyl, H. 1949. *Philosophy of Mathematics and Natural Science*. Princeton: Princeton University Press.

Wüthrich, C. 2010. Demarcating Presentism. In H. de Regt, S. Okasha, and S. Hartmann (Eds.), *EPSA Philosophy of Science: Amsterdam 2009*, pp. 441–450. Dordrecht: Springer.

Wüthrich, C. 2013. The Fate of Presentism in Modern Physics. In R. Ciuni, K. Miller, and G. Torrengo (Eds.), *New Papers on the Present — Focus on Presentism*. Philosophia Verlag.