Productive Laws in Relativistic Spacetimes

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Abstract

One of the most intuitive views about the metaphysics of laws of nature is Tim Maudlin's idea of a Fundamental Law of Temporal Evolution. So-called *FLOTEs* are primitive elements of the universe that produce later states from earlier states. While FLOTEs are at home in traditional Newtonian and non-relativistic quantum mechanical theories (not to mention our pre-theoretic conception of the world), I consider here whether they can be made to work with relativity. In particular, shifting to relativistic spacetimes poses two threats to FLOTEs. First, the lack of a privileged spacelike hypersurface makes it unclear how to understand what produces what. A survey of several conceptions of the nomic production relation compatible with relativity reveals all of them to be lacking. Second, relativity motivates a four-dimensional block universe conception of time, according to which all events that will ever occur already exist. On such a view, it's unclear what work there is to be done by FLOTEs. I consider how a proponent of FLOTEs might respond, but conclude that these combined threats seriously undermine the prospects of a productive conception of laws. In short, if spacetime is relativistic, laws are not productive.

1 Introduction

In debates about the metaphysics of laws of nature, one of the most plausible and formidable positions is occupied by proponents of *productive* accounts of laws. Foremost among these is Maudlin's (2007), which posits Fundamental Laws of Temporal Evolution (FLOTEs) that guide the development of the universe by producing later states from earlier states. On this view, the productive activity of the laws underwrites their *explanatory* power: laws help to explain events by providing the history of their production.

Maudlin's account is deeply intuitive. If philosophical theories of lawhood were judged solely by their intuitive force, then I think most parties to these debates would admit that this is the clear winner. No doubt this is partly because of the account's natural coherence with the physical theory in which most of us first *acquire* the concept of law, namely Newtonian mechanics. Knowingly or not, that theory probably provides many of us with our paradigm case of lawhood in $F = ma$. With this dynamical law at its center, Newtonian mechanics

does indeed allow us to speak sensibly of the laws evolving earlier states of the world into later states.

What I want to argue here, however, is that the notion of productive laws is seriously problematized by the shift from Newtonian mechanics to relativity. Once we move from the Galilean spacetime of Newtonian mechanics to the sorts of spacetimes required by special and general relativity, productive laws lose most if not all of their intuitive appeal. In particular, by focusing on the simpler Minkowski spacetime of special relativity, I'll argue that there are two significant threats to productive accounts of laws like FLOTEs. First, Minkowski spacetime makes it unclear how we are supposed to understand the *relata* of the nomic production relation. And second, as Putnam (1967) and others have suggested, it motivates a "block universe" view of time that, I will argue, obviates the need for productive laws in the first place.

This agenda raises three dialectical points that ought to be addressed before proceeding. First, Maudlin is sympathetic with Bohmian mechanics, which itself is inconsistent with special relativity because it requires a privileged foliation of spacetime. Thus one might suggest that it is unfair to attack Maudlin on the grounds that his view of laws is inconsistent with special relativity, since he has antecedent commitments that are likewise inconsistent. I agree with this suggestion, and it is not my goal to attack Maudlin in this paper. Rather, my goal is to evaluate the prospects for a particular theory of lawhood that Maudlin has compellingly and persuasively articulated. That view is proposed not as a theory of the laws of Bohmian mechanics, but as a theory of lawhood simpliciter. Some people, including Maudlin himself, have thought that "The idea of a law governing temporal evolution can be extended to special relativistic, and (I think) even general relativistic, contexts" (2007: 48). My aim here is to show that these extensions are untenable. If this is right, then that theory of lawhood is seriously impugned.

This raises the second dialectical point. Given that special relativity is not the final word, how serious, in the end, are my objections? The answer will depend on our final physics, specifically on *why* special relativity is not the final word. Special relativity does not accommodate gravity; to do that we move to a general relativistic framework. If special relativity is merely rejected in favor of general relativity, then as Savitt (2000) points out, every general relativistic spacetime *locally* has the structure of Minkowski spacetime. In that case, the arguments I raise here would, I think, still apply.[1] However, general relativity itself should eventually be supplanted by a theory of quantum gravity. I won't speculate here about the prospects of such a theory maintaining a genuinely relativistic spacetime structure[2]—if it does, then my arguments should still

[1]The significance of the local validity of special relativity has recently been questioned by Fletcher and Weatherall (forthcoming a, b), who argue that every relativistic spacetime locally approximates every other one, so that no special importance attaches to Minkowski spacetime. Nevertheless, the local validity of Minkowski spacetime would still be an instance of that generalization (and one whose implications are easier to evaluate), so I doubt that their discussion undermines my reliance on Minkowski spacetime here. Linnemann, Read, and Teh (ms) provide some further helpful discussion.

[2]For some such speculation, see, e.g., Chapter 4 of Callender (2017).

apply; if not, not. Such is life for the non-omniscient.[3]

The third dialectical point is that you might think that it's just *obvious* that FLOTEs will not work in relativistic spacetimes. After all, the problems I'll be pointing out are based on relatively straightforward issues that arise as soon as one moves to a relativistic context, and they have analogs in discussions about the metaphysics of time. But I hope to show that the issues here are actually fairly subtle: there are moves open to a proponent of FLOTEs that *strictly speaking* would render them compatible with relativity. It's just that by employing these moves, the view loses most or all of its theoretical advantages over other theories of lawhood.

So much for the dialectical points. Here's how this paper will proceed. In §2 I'll review Maudlin's account of FLOTEs and what he says about their relationship with the passage of time. In §§3-4, I'll explicate the dual threats to FLOTEs posed by relativistic spacetimes and consider how a proponent of FLOTEs might respond. In §5, as a way of avoiding these threats, I'll consider the merits of positing a privileged foliation along which the productive activity of the FLOTEs proceeds. I'll conclude in §6.

2 Maudlin's Non-Humean Package

Maudlin's FLOTEs are fundamental entities of the universe that occupy a distinct ontological category from the constituents of spacetime and the spatiotemporal arena itself. Their job, as he puts it, is to "specify how the state of the universe will, or might, evolve from a given initial state" (2007: 172). Of course, a great deal hangs on what Maudlin means by "specify" here. One reading would be that the laws merely *entail* what happens at later times given what happens at an initial time. This is not what Maudlin intends. Rather, "specification" has metaphysical import: "the laws of temporal evolution operate, whether deterministically or stochastically, from the initial state to *generate* or *produce* later states" (*ibid.*: 174, my emphasis). The basic picture is thus that the laws have a sort of input/output form, where the input is an earlier state and the output is a later state, and their role is to produce the later state from the earlier one.

According to Maudlin, this nomic production relation underwrites the laws' ability to explain natural phenomena: "This sort of explanation takes the term *initial* state quite seriously: the initial state temporally precedes the *explananda*, which can be seen to arise from it (by means of the operation of the law)" (*ibid.*: 176). So if you want to know why such-and-such an event occurred at time t_2, we can appeal to the state at t_1 as well as the operation of the laws to show that the state at t_1 evolves, according to the laws, into the state at t_2.

[3]It is tempting to take a more hard-line approach to the question of incompatibility with relativity: even if our universe's spacetime is not relativistic, it *could have been*, and a theory of laws ought to be compatible with this possibility, else it would not apply to such a world. I am genuinely unsure what to make of this sort of metametaphysical position, so I will confine myself to lower-order physical and metaphysical worries about Maudlin's theory of lawhood. I'll return to this metametaphysical question briefly in the conclusion.

Superficially, this looks like the old-fashioned Deductive Nomological model of explanation (Hempel and Oppenheim, 1948). One of the familiar problems with that model was that it allowed explanations in the wrong directions. Not only can one derive the length of the shadow from the angle of the sun above the horizon, the height of the flagpole, and the laws of optics, but one can also derive the height of the flagpole from the length of the shadow, the angle of the sun above the horizon, and the laws of optics. Only one of these derivations should count as an explanation, but both satisfy the DN model's criteria. So there's an explanatory asymmetry that the DN model fails to capture.

Maudlin's view captures this asymmetry of explanation by appeal to the asymmetry of production. The laws produce the later state from the earlier state, but not vice versa. Thus even if the laws allow us to infer the earlier state from the later state, this would not give us an explanation of how the earlier state arose in the first place.

As all of this suggests, Maudlin also has a robust conception of the passage of time. Part of what allows us to speak sensibly about the laws producing later states from earlier states, he thinks, is that there is an inherent anisotropy in the temporal dimension. That is, given an event, there is an objective fact about which direction is forward in time from that event. And unlike others who have sought to reduce the temporal asymmetry to other asymmetries in the total distribution of events (e.g. Albert (2000), Loewer (2007, 2012)), Maudlin regards the temporal asymmetry as fundamental, maintaining that it both supports talk of the *passage* of time, and is required for the very notion of nomic production to be coherent in the first place; without it there would be no sense to talk of "production."[4]

The passage of time, however, is meant to be more than just a temporal asymmetry:

> The passage of time connotes more than just an intrinsic asymmetry. . . [it] underwrites claims about one state "coming out of" or "being produced from" another, while a generic spatial (or temporal) asymmetry would not underwrite such locutions. (2007: 109-110)

So talk of the passage of time is supported by an intrinsic asymmetry in the temporal dimension, but it also requires some extra ingredient, because not just any asymmetry would support talk of production. What is this extra ingredient? According to Loewer's (2012: 119) interpretation of Maudlin, the passage of time "consists in the fundamental arrows of time [i.e. the fundamental temporal asymmetry] determining the direction in which the laws operate." So it is the *conjunction* of the temporal direction and the operation of the FLOTEs along that direction that makes it sensible to talk about genuine temporal passage, and the genuine production of later states from earlier states, in the way that a generic asymmetry by itself would not.

Maudlin's view is clearly at home in a theory like Newtonian mechanics. Not only did Newton espouse something very much like Maudlin's notion of temporal

[4]See Maudlin (2007: 110, 116, 175).

passage[5], but the Newtonian picture also allows us to make good sense of the operation of the FLOTEs. As we saw, the form of the FLOTEs requires us to identify both an input state and an output state to serve as the *relata* of the production relation. In the Newtonian picture, there are clear and unambiguous choices for these *relata*: the *present state of the world* that pervades all of space provides the input on which the Newtonian laws act to produce subsequent states of the world as output. These global states at moments of time are natural *relata* for the production relation.

Moreover, there really are no other candidate *relata* to be found in Newtonian mechanics. One might *try* to specify *relata* that are less spatially expansive, but no matter where one draws the boundary of such regions, the Newtonian laws will allow that events outside of that region may influence the events within that region at subsequent moments. As Maudlin notes (*ibid.*: 178), this forces us to make the input *relatum* a global state.

Once we have expanded the input *relatum* to encompass all of space, there is no reason not to do the same with respect to the output *relatum*. I suppose that *in principle* one might take the output *relatum* to be a local state or even a single event, and allow that the laws produce each of the events at t_n from the preceding global state at t_{n-1} on a piecemeal, albeit simultaneous, basis.[6] But it is hard to see what motivation there could be for fragmenting the productive activity of the laws like this, and this does not seem to be Maudlin's view.

Note that *locality*, on this view, is a rather superficial phenomenon. If the *relata* of FLOTEs are global states of the world, then while it may indeed turn out that there are stronger correlations between spatially local variables than there are between spatially distant ones, fundamentally speaking the *entire* earlier state is nomically tied to the *entire* later state. Nor would genuine locality be saved if we followed the suggestion in the previous paragraph and made the output *relatum* a single event, since the earlier *relatum* from which the event is produced is still a global state, and is not confined to the region in the spatial vicinity of the event being produced.

Despite this result, on the whole the view is incredibly intuitive. This fact is not lost on Maudlin; indeed he takes it to be one of the primary attractions of the view, especially over Humean alternatives that regard facts about the temporal asymmetry and laws as reducible to facts about the entire manifold of events. Dubbing his theories of FLOTEs and temporal passage as "Maudlin's Non-Humean Package," he says that his motivation for accepting it over the Humean alternative is that it is "much closer to the intuitive picture of the world that we begin our investigations with" (*ibid.*: 182).

[5] "Absolute, true and mathematical time, of itself, and from its own nature flows equably without regard to anything external..." (1689: 6). (Maudlin prefers to speak of time's 'passage' rather than its 'flow,' though I am not entirely sure how to understand this distinction—cf. Healey (2008).) I should note, however, that the similarity between Newton and Maudlin's views of time may be only superficial. If, as Maudlin argues, the passage of time is a fundamental asymmetry in the temporal dimension, then this is consistent with a spatiotemporal block universe that Newton would find foreign.

[6] For the sake of simplicity, I am speaking as if at any given moment there is a "next" moment of time, though if the temporal order is dense this won't be strictly true.

I agree. In many ways, Maudlin's Non-Humean Package could be thought of as a sort of default position, a natural starting point that we should abandon only if we find good reasons to do so. Of course, many philosophers claim to have found such reasons. Given that FLOTEs fail to supervene on the particular matters of fact, Humeans have sometimes raised worries about our epistemic access to them (Loewer 2012). Others have objected that taking the laws as primitive makes it unclear how they are supposed to play their explanatory role (Roberts 2016). And still others have objected that positing a primitive anisotropy in the temporal dimension wouldn't help to explain our experience of time's passage (Callender 2017, Price 2011).

Without taking a stand on any of these claims, in the following I want to suggest a different reason that should motivate us to consider abandoning the default position of Maudlin's Non-Humean Package: it is problematized by relativity. The issue, in short, is that while the Package itself is highly intuitive, relativity is not. Insofar as we have good reason to think that our world is relativistic, we also have good reason not to trust the very intuitions about laws and temporal passage that motivate acceptance of the Package in the first place.

In the following, I'll focus for simplicity on special relativity. The two threats I want to consider still have force in general relativity (though see footnote 1), but they are easier to discuss in the flat Minkowski spacetime of SR than in the variably curved spacetimes of GR.

3 What Produces What?

If we want to make sense of the productive activity of the FLOTEs in SR, we need to characterize the kinds of states that serve as the input and output *relata*. Unlike in Newtonian mechanics, this is far from straightforward in SR.

Maudlin gives us the following advice about how to conceptualize FLOTEs in a special relativistic setting:

> [T]ake a deterministic FLOTE and adjunct principles that operate in a special relativistic spacetime. Take a surface that cuts every maximal timelike trajectory in the spacetime exactly once (a Cauchy surface). Specifying a Cauchy surface is the analog to choosing a moment of time in a Newtonian regime; roughly one can think of it as a surface that cuts the spacetime in two horizontally... Boundary values can be specified on this surface, such as the distribution of particles, intensities of fields, etc... The FLOTE now specifies how those values will evolve through time. (*ibid.*: 18)

Maudlin thus appears to be suggesting that we regard the *relata* of the production relation the same way we did in Newtonian mechanics, namely as global states of the entire world.

The problem is that specifying a Cauchy surface is *not* an exact analog to choosing a moment of time in Newtonian mechanics. Given an event in the Galilean spacetime of Newtonian mechanics, there is exactly one moment of

time that it lies on. But given an event in the Minkowski spacetime of special relativity, there are an infinite number of Cauchy surfaces that intersect it. So instead of having a single natural candidate for the input *relatum*, we have a plurality.

Part of what conceals this problem in Maudlin's discussion is that much of it is framed in terms of the evaluation of counterfactuals. His aim is to show that one can use FLOTEs as part of a recipe that delivers intuitively correct results about the truth values of a wide variety of counterfactual conditionals. Given a counterfactual, the core steps of the recipe are: (1) select a Cauchy surface as directed by the antecedent, (2) modify boundary values on that surface as minimally as possible so as to make the antecedent true, and (3) evolve that modified state forward (or backward) according to the laws to see whether the consequent comes out true.[7]

In this context, the productive role of the FLOTEs takes a backseat to their inferential role. To see this, it suffices to note that the recipe directs us to evolve the modified state forward *or backward* according to the laws to *infer* what would have happened if the scenario specified by the antecedent had been true. So it is not the productive activity of the FLOTEs that allows them to play their role in counterfactual reasoning, but rather the inferences they enable us to make about some parts of the manifold given information about other parts. They can play this inferential role without our having to worry about which Cauchy surface we apply them to, as long as we are able to make the changes specified by the antecedent of the counterfactual. All such surfaces will give us consistent results about which events occur, so there is no worry about whether the laws *really* act on all of them or one of them. The laws don't *really* act on any of them—they're counterfactual, after all.

But in the actual world, the question of which Cauchy surface(s) the FLOTEs act on becomes more pressing: we need an answer in order to understand how the laws are supposed to exert their productive power. So how should we interpret Maudlin's suggestion?

The only structure that is intrinsic to a special relativistic spacetime is given by the Minkowski metric, which determines the distances between events, and thereby also defines the lightcone structure (see Figure 1). Relative to a particular event e, all other events are divided into one of three sets, those that are timelike, lightlike, or spacelike separated from e. Events at timelike separation are in e's future or past; events at lightlike separation lie on the forward or backward lightcones emanating from e; and events at spacelike separation bear no temporal relation to e—i.e. they are neither before, after, nor simultaneous with it. One can *impose* a coordinate system on the spacetime and thereby induce a temporal ordering for all events, even ones that are spacelike separated. But there is no uniquely correct way to do so supported by the underlying geometry;

[7] I'm glossing over some of the details here. For example, to avoid some implausible results in indeterministic settings, Maudlin suggests holding fixed the outcomes of chance processes that are independent of the modifications made in step (2). Edgington (2004) and Dorst (2020) describe this by saying that counterfactuals use "hindsight." See Maudlin (*ibid.*: 21-34) for the full story.

the coordinate system is a human projection, not part of the intrinsic structure of the spacetime.

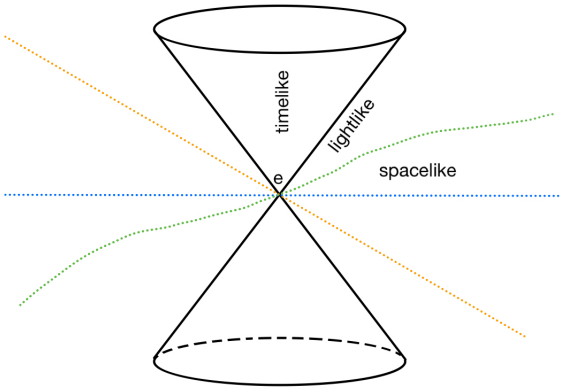

Figure 1: Lightcone structure of Minkowski spacetime. Events at timelike, lightlike, and spacelike separation from e are indicated, as are three Cauchy surfaces that intersect e, represented by dotted lines; note they may be either straight or curved. The Cauchy surfaces have an extra dimension suppressed for ease of representation.

If we are going to respect the resulting democracy of inertial frames, then it seems we cannot privilege a particular Cauchy surface as the one on which the laws act, i.e. the one in which dynamical evolution "really" occurs.[8] So we will have to interpret Maudlin's suggestion as meaning that the FLOTEs act on *every* Cauchy surface. Even still, this is compatible with at least two different ways of construing the input and output *relata* of the production relation.

3.1 Hypersurface-Relative Production

One suggestion is that we take the production relation to obtain on a sort of piecemeal basis, i.e. we make the input any given Cauchy surface, and we make the output the forward evolution of that surface. We then have the following conception of production:

> **Hypersurface-Relative Production:** Production occurs relative to a given foliation of the manifold into hypersurfaces.

[8] I say that *it seems* we cannot do this because, while this is the conventional wisdom about SR, it actually turns out to be a subtle matter whether positing a privileged hypersurface would conflict with SR. For now I'm going to accept this conventional wisdom; we'll return to this issue in §5.

So it is only given a choice of hypersurface that it makes sense to talk about what is produced from what by the operation of the FLOTEs.

The trouble with this proposal is that this production relation is not objective. Traditionally, quantities that are frame dependent are taken not to be fundamental aspects of reality.[9] In discussing the relativity of simultaneity, Maudlin himself suggests as much:

> It is commonly said that in Relativity, the notion of simultaneity is relative to an observer or to a state of motion. We can see the grain of truth in this characterization, but perhaps it also does as much harm as good. The key claim of Relativity is the *nonexistence* of simultaneity as a real physical relation among events. (2012: 92)

For the same reason, he also insists that talk of *speeds* has no place in relativity (2012: 120-121).

Our hypersurface-relative production relation falls victim to the same considerations. From any given frame, it makes sense to talk about which states are produced from which other states: the frame can be taken to fix the Cauchy surfaces required to legitimize talk of production. But there are no *frame-independent* facts about which surfaces production proceeds along. Thus, if we adopt this conception of production, there are no objective production relations in relativity, just like there are no objective velocities or simultaneity relations.

This seems problematic. Remember that the FLOTEs are supposed to furnish robust explanations of events. Now take a particular event e and ask, "Why did e occur?" On the current proposal, we don't yet have the ingredients to supply an answer to this question, for we also need to specify the relevant foliation along which the production relation—which backs the explanation of e—is supposed to proceed. So there *is no* answer to the question of why e occurred *simpliciter*; there is only an answer to the question of why e occurred relative to a particular foliation.

Moreover, the lack of objective production is at odds with the intuitions that motivate Maudlin's Non-Humean Package in the first place. Maudlin himself articulates those intuitions as follows: "Both of the strands of our intuitive picture of the world [i.e. productive laws and a fundamental passage of time] weave together in the notion of a productive explanation, or account, of the physical universe itself. The universe, as well as the smaller parts of it, is *made*: it is an ongoing enterprise, generated from a beginning and guided towards its future by physical law" (2007: 182). On the present proposal, these intuitions do not turn out to be correct. Objectively speaking, the universe, as well as the smaller parts of it, *aren't* made. They are only made relative to a particular foliation into Cauchy surfaces that supports talk of production in the first place. And the world itself doesn't divide the manifold into Cauchy surfaces; that is something we do in our analysis of it.

So it is difficult to see how production relative to an ontologically arbitrary foliation is really what we were after. It looks more like a perspectival sort

[9] Fine's (2005) fragmentalism is a notable exception here. See Hofweber and Lange (2017) and Lipman (2020) for discussion of whether this feature of fragmentalism is problematic.

of production: relative to a particular way of looking at the world, there are facts about what produces what, but from a fully objective perspective, there are none. If so, we are no longer vindicating the intuitions that motivated acceptance of the Package in the first place. When we think that the world is *made* by the laws, we are not thinking that this production is merely relative to a given perspective. Rather, we think of it in fully objective terms—terms which made sense in Newtonian mechanics, but which the present conception of production is not doing justice to. Since those intuitions are supposed to be the primary attraction of the Package, the inability to adequately accommodate them would be a significant blow.

3.2 Pluralistic Production

In attempt to adequately accommodate those motivating intuitions, we can drop the hypersurface-relative notion of production in favor of a more objective one. If we are to avoid privileging a particular Cauchy surface as the true surface of dynamical evolution, then a natural way to proceed would just be to allow that the laws act on all Cauchy surfaces "simultaneously," as it were, giving us the following:

> **Pluralistic Production:** Production occurs along *every* foliation in the forward temporal direction.

Thus, where Σ and Σ' are two cross-cutting Cauchy surfaces, and Σ_{n+1} is the lawful evolution of Σ_n, it is true that Σ_2 is produced by the laws operating on Σ_1, and it is also true that Σ'_2 is produced by the laws operating on Σ'_1. As before, the *relata* of the production relation here are a given Cauchy surface and its lawful evolution. But now we allow that *all* of these production relations obtain from a God's eye perspective.

This conception of the production relation appears to do away with the worry about a lack of objectivity that confronted the hypersurface-relative conception. But it does so at the cost of engendering a mysterious sort of overdetermination. Return to our particular event e in the manifold, and our question, "Why did e occur?" On the hypersurface-relative conception of production, we had no answer to that question absent specification of a particular foliation, and this left us thinking that the relevant sense of production was not objective. But on the pluralistic conception of production, we have an *infinity* of answers. Pick any Cauchy surface from which we can draw a continuous timelike curve (in the forward temporal direction) from some point on the surface to intersect e. There will be an infinite number of such surfaces. Consequently, on the pluralistic conception of production the laws will license an infinite number of true explanations of why e occurred.

Granted, something similar is true in Newtonian mechanics. Assuming the temporal order is dense, then for a given event e, we won't be able to pinpoint *the* previous state that the FLOTEs operated on to produce e. Still, there will be a unique total order relation on the set of temporal instants, and it's perfectly intuitive to imagine tracing the productive activity of the FLOTEs

along that order. But in special relativity, there is no total order relation on the set of all Cauchy surfaces that would let us trace the productive activity of the FLOTEs. The best we can do is to have foliation-dependent temporal orders, and thus, according to pluralistic production, an infinite number of distinct histories leading to the production of event e.

Moreover, it's not as though the laws have to work together along all of these paths to produce e. A single Cauchy surface on any *one* of these paths is nomically sufficient for e's occurrence. So this is not like a case in which Simon and Garfunkel together produce an album—where sometimes Paul does the lead vocals and Art does backup, sometimes vice versa, sometimes they sing in harmony—and the result is a product of their combined efforts. Rather, this is more like a case where Paul makes an album by himself, and Art makes an album by himself, and the result is one and the same album (and not two lyrically identical albums either, but numerically the same album). Unlike Simon and Garfunkel's albums, then, our event e is radically overproduced.

So it appears that the kind of production at work here is not the intuitive one we were aiming for. On that intuitive conception of production, it doesn't make sense to say that A produced something all by itself, and B produced something all by itself (where $A \neq B$), and the result was one and the same thing. If this is right, then the pluralistic conception of production cannot be doing justice to the intuitions that were meant to motivate Maudlin's Non-Humean Package.[10]

3.3 Other Conceptions of Production

Neither of the ways we surveyed for understanding the production relation between Cauchy surfaces is able to do justice to the intuitions that are supposed to motivate the Package. That is not to say that they could not be adopted as part of the account. But to do so would be to incur a significant cost, since the resulting Package would be unable to take advantage of what was supposed to be its primary motivation, namely its agreement with the intuitive conception of the world that we begin our investigations with.

A proponent of the Package might thus be motivated to search for other ways of understanding the production relation. And there are *plenty*, especially if we give up on the requirement that the *relata* both have to be Cauchy surfaces. Another way to understand the relation would be to tie it more closely to the lightcone structure. Any cross section of a (back) lightcone is nomically sufficient for the occurrence of the event at its apex. So a different approach would be to regard the output of the FLOTEs as an event, and then try to find something in the back lightcone of that event to serve as the input.

It doesn't seem like this will work, however. For while we now have a natural candidate for the output state, we are going to encounter all the same problems as before with respect to the input state. If we want to pick something that's Lorentz invariant, we should avoid selecting a particular cross section. We thus end up with two familiar options: we can either regard the production of the

[10] See Sebens (ms) for some helpful further discussion of the pluralistic production relation.

apex event as *relative* to a given cross-section of the back lightcone, or we can say that the FLOTEs operate on *every* such cross section. In the former case, we will end up with a perspectival rather than objective notion of production, and in the latter case we'll get a strange sort of overproduction of the apex event. As before, neither of these will do justice to the pretheoretic intuitions we were trying to vindicate.

We might instead take the input to be surfaces of *constant interval* in the back lightcone of our apex event. These surfaces form an expanding set of hyperbolas as the interval between the points on the surface and the apex event e increases. That gives us the following sense of production:

> **Constant-Interval-Surface Production:** Production occurs along surfaces of constant interval from a given event e.

The benefit of this move is that the surfaces of constant interval are Lorentz invariant, and thus there is a unique total order of such surfaces in the past and future lightcones of e. This proposal thus appears to avoid the problems with Hypersurface-Relative and Pluralistic Production: it is fully objective and engenders no obvious overdetermination worries.

Unfortunately, there are a variety of problems with this proposal. For example, it unduly privileges event e. To see this, consider some event d in the past lightcone of e and ask what produced *it*. Event d will lie at some interval Δs from e. If we say that d was produced as the FLOTEs "moved through" the surface of events at Δs separation from e, then e is playing a privileged role in our spacetime. Moreover, there will be events at spacelike separation from e for which d falls in the back lightcone at some constant interval $\Delta s'$. Select one of them and call it e'. How does e' get produced? In the same manner as e? In that case d gets produced as the FLOTEs operate on the surfaces of constant interval from both e and e', and our overdetermination worries have resurfaced.

There are further worries about constant-interval-surface production. For example, it tells us nothing about how the FLOTEs work on events outside of e's lightcone. Moreover, in order for the FLOTEs to produce events in e's future lightcone, they will need input from events at spacelike separation from e. This again requires us to select a spacelike hypersurface intersecting e, which lands us back in our previous troubles.

I do not mean to definitively claim that appropriate *relata* for the nomic production relation cannot be found in a relativistic spacetime. There are plenty of other relativistic structures to explore: null surfaces, the set of all points spacelike separated from a given event ("doughnuts"), Alexandroff intervals ("diamonds"), etc.[11] I cannot hope to survey all such candidate structures, and it may well turn out that there are some plausible candidates that can serve as the *relata* of the production relation employed by the FLOTEs. But let me briefly point out two reasons for skepticism here.

First, any serious candidates for the production *relata* should be subject to two constraints:

[11] See, e.g., Callender (2017: 62-65) for discussion of some of these structures. See Savitt (2009) for more on Alexandroff intervals.

Lorentz Invariance: Candidate *relata* should avoid privileging a particular inertial frame.

Nomic Sufficiency: The input *relatum* should be nomologically sufficient for the output *relatum*.

Together, these two constraints drastically diminish the possibilities. Not just any structure will be Lorentz invariant, and not just any input structure will be nomologically sufficient for any output structure.

Second, if we think carefully about the intuitions we are trying to capture, it looks like the input *relatum* will have to be something like a "present" moment. For our pretheoretic intuition seems to be that the world is made in such a way that the present is the most recently created moment, and that production proceeds from *now* via the laws. If this is right, then we can rely on previous arguments by Callender (2017: 59-66) and Sider (2001: 42-52), both of whom survey a variety of relativistic structures and find that none of them accord well with our manifest conception of a present moment. Callender concludes that "there are not good relativistic candidates for a flowing [or passing] now" (2017: 31). Likewise, Sider maintains that the only candidate for a present in relativity is a privileged foliation of the manifold, and given its lack of Lorentz invariance, such a posit would be scientifically revisionary (2001: 52).

If Callender and Sider are right, it apparently follows that *any* conception of relativistic production will fail to do justice to the intuitions about temporal passage and production that are supposed to motivate acceptance of the Package in the first place. As long as those pretheoretic intuitions conceive of production as proceeding from a present moment, no relativistic account of production can capture them.

In sum, we might put the problem as follows. Maudlin's Non-Humean Package is designed to accommodate certain strongly-held pretheoretic intuitions about how the world is produced. But if relativity gives us the correct account of the world's spacetime, those intuitions weren't correct in the first place. Small wonder, then, that we cannot find a technically rigorous, relativistically kosher nomic production relation that does justice to those intuitions. The Package rests on a non-relativistic foundation, and any attempt to modify it to cohere better with relativity forgoes the intuitive advantages the view was supposed to enjoy.[12]

[12]It could be objected that *any* philosophical account of laws will have to forgo some of its intuitive advantages to accommodate current physics. If that's right, then it *might* be unfair to criticize Maudlin's view on the grounds that it loses its intuitiveness in relativity. But this objection is a broad, sweeping claim, and I don't see any shortcuts to establish it. Rather, we have to look at the different views in detail (as it were from close up) to figure out both (a) what their intuitive advantages are, and (b) to what extent those advantages can be maintained in light of current physics. The current paper is a small part of that larger project.

4 The Block Universe

The second major relativistic threat to FLOTEs traces back to an argument originally advanced by Putnam (1967) to the effect that special relativity requires a block universe (or "eternalist") conception of time.[13] Here I will briefly review that argument and then explain why it is problematic for Maudlin's FLOTEs.

The argument is designed as a refutation of the presentist (or growing-blockist) idea that a present moment sweeps through the temporal dimension, separating the real events of the past/present from the as-of-yet unreal events of the future. Consider two reference frames defined via two inertial observers, A and B, in relative motion with respect to each other (see Figure 2). At any given point, each observer will regard certain events spacelike separated from themselves as occurring simultaneously. What will these surfaces of simultaneity look like? The diagram indicates a few of them with dashed lines: in A's frame, the surfaces of simultaneity radiate outward on straight spacelike lines perpendicular to A's worldline. But B's surfaces of simultaneity tilt upward with respect to A's, so B regards events as simultaneous that A does not. Of course, all of this is perfectly symmetric; from B's frame, it's A's simultaneity surfaces that appear tilted.[14]

Note that A and B's worldlines cross at the origin o. Now take an event p on some faraway alien planet that lies on that simultaneity surface of B's that also intersects o. If we regard the simultaneity surfaces as present moments separating the real past/present events from the unreal future events, then at o, p is real for B but unreal for A. If this is nonsense (and surely it is), then it must be wrong to regard these simultaneity surfaces as distinguishing the real from the unreal. Worse yet, consider some inertial observer at p, who has a simultaneity surface that intersects B's worldline at point q, which happens to be B's death. If reality transfers along these simultaneity surfaces (and assuming that no observer is singled out as special, then it's hard to see why it wouldn't), then B's death at q is just as real as the event at p, which is just as real as B's presence at o.[15]

[13] For similar arguments, see Penrose (1989), Rietdijk (1966), and Sider (2001).

[14] I am glossing over a number of issues here. To arrive at these surfaces of simultaneity, typically one imagines sending out a light ray and recording the amount of time it takes to reflect off of some distant object and return. Dividing that time in two then allows one to calculate the distance of the faraway object (given the speed of light), and taking the midpoint of the light's emission and return events gives the time at which it was reflected by the distant object. In this manner one can imagine finding a hypersurface of points in the spacetime simultaneous with the reflecting event. This method is commonly known as Einstein-Poincaré radar synchronization.

It is debated whether Minkowski spacetime underwrites these simultaneity sheets as objectively correct, albeit relative to an inertial frame, or whether there are elements of conventionality in their specification—in other words, whether simultaneity in Minkowski spacetime is merely *relative* or fully *conventional*. We needn't get into the substantial (and fascinating) literature on this issue here. For discussion, see Grünbaum (1973, Chapter 12), Jammer (2006), Janis (2018), Malament (1977), Reichenbach (1958), Rynasiewicz (2000), Salmon (1977), and Sarkar and Stachel (1999). Savitt (2011) provides an accessible review of these debates.

[15] This latter twist follows the presentation in Callender (2017: 54).

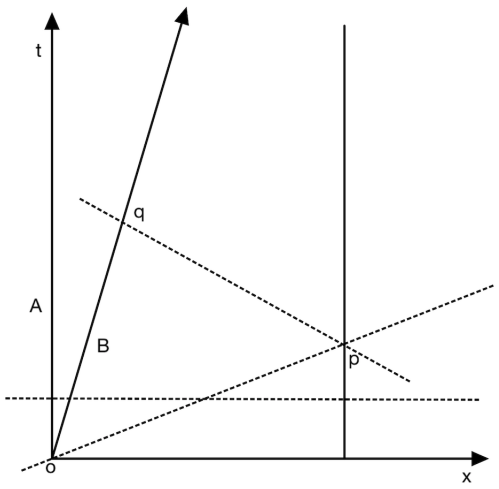

Figure 2: Spacetime diagram of inertial observers A and B in relative motion with cross-cutting simultaneity surfaces. A's surfaces are horizontal in the diagram. In this frame, if the slope of B's trajectory is s, then the slope of B's simultaneity surfaces is $1/s$.

The upshot is that special relativity appears to refute the presentist (or growing-block-ist) view of time in favor of a block universe ("eternalist") view. As Sider (2001: 42) puts it, the argument constitutes "the fatal blow to presentism." In common terms, it forces us to accept that the future is just as real as the present.

This conclusion is widely (though not universally) endorsed by philosophers of physics. In addition to the authors already cited in footnote 13, others who accept the argument include Gibson and Pooley (2008), Hoefer (2011), Monton (2006), Saunders (2002), and Savitt (2000) (though Savitt appears less sanguine about it in his (2011)). Callender calls it "utterly convincing" (2017: 53). Maudlin (2002: 260; 2007: 109, 115) also appears to endorse the block universe view, though he doesn't say whether Putnam's argument played a role in that endorsement. A notable exception is Zimmerman's (2011) tour de force, which gives a compelling defense of presentism in the context of special relativity. Zimmerman argues in favor of privileging a particular foliation, and tries to minimize the conflict with special relativity that appears to result.[16] We'll return to this strategy in the next section, but for now, I want to consider the implications for FLOTEs if the conventional wisdom about Putnam's argument is correct.

Those implications are straightforwardly problematic. If eternalism is the

[16]Hinchliff (2000) also endorses this "neo-Lorentzian" approach.

right view of time, then every event that will ever occur is "there already" in the spatiotemporal manifold. Fundamentally, then, there is nothing for the FLOTEs to produce; all of it already exists. The FLOTEs are just idle wheels.[17]

To be clear, I am not objecting to Maudlin's taking the laws as ontologically primitive, nor to the idea that one can simply stipulate that these primitive entities play certain roles (cf. Schaffer, 2016). What I'm objecting to is the idea that the role that's been stipulated for the FLOTEs is there to be played in the first place.

I know of nowhere that Maudlin explicitly addresses this worry. The closest he gets is in his rebuttal to Gödel's (1949) argument that relativity undermines the idea of an "objective lapse of time." Gödel claimed that such a lapse implies the existence of a privileged foliation of "nows," and that this is incompatible with relativity. Maudlin (2002: 265-266) objects that a foliation is irrelevant to the lapse of time, and that what's really needed is an *orientation*.[18] However, elsewhere Maudlin seems to be committed to the idea that the passage of time requires *more* than just an orientation. Recall his claim in §2 that a generic temporal asymmetry would not underwrite talk of temporal *passage*, and that we needed to add the productive activity of the FLOTEs along that asymmetry for such talk to make sense. But if the entire manifold is already there, what could the productive activity of the FLOTEs possibly amount to? Even if we allow that an orientation by itself would be sufficient for temporal passage (and that a foliation would not), the crucial point is that it is *not* sufficient to legitimize talk of production. A complete manifold equipped with an orientation is no more hospitable to FLOTEs than is a complete manifold equipped with a preferred foliation. As long as the manifold is complete, there is nothing for the FLOTEs to do.

It is somewhat surprising that no one has yet made note of this objection. My own diagnosis is sociological: aside from some noteworthy exceptions[19], philosophical work on the metaphysics of laws and the metaphysics of time seems to proceed relatively independently of one another. It may be that disciplinary boundaries are the culprit, as philosophy of time is typically a topic in metaphysics proper, whereas the metaphysics of laws is more frequently discussed in philosophy of science. This may contribute to a sort of compartmentalization, where questions about time and questions about laws tend to get addressed in relative isolation from each other.[20]

[17] Of course, this is true whether or not Putnam's argument succeeds in showing that special relativity requires eternalism. As long as eternalism is correct, FLOTEs apparently have no role to play.

[18] A relativistic manifold is temporally orientable iff it admits a continuous non-vanishing timelike vector field. Whenever it admits one such field, it also admits a complementary one in which all of the vectors point in the opposite direction. To specify an orientation is to fix one of these vector fields as containing the future-pointing vectors. (See Bielińska and Read (2023) for a helpful discussion of orientability.)

[19] E.g. Adlam (2022), Builes and Impagnatiello (forthcoming), Callender (2017), Chen and Goldstein (forthcoming), Loewer (2012), Maudlin (2007, Chapter 6), Sebens (ms), and Skow (2007).

[20] Hoefer (2011) argues that propensity theories of objective chance also presuppose a tensed/presentist metaphysics of time, and that "once we force ourselves away from that

An alternative explanation is that I have misunderstood Maudlin's position: perhaps he is really an advocate of the *growing block* view of time. This is a subtle interpretive issue, and the best I can do is point the reader to the quotations cited above. Maudlin states his position most explicitly on page 109 of *The Metaphysics within Physics* (2007): "I am one of those unusual defenders of the block universe who does not deny that there is any objective flow of time. The four-dimensional universe is a single entity of which the *passage* of time, in one particular direction, is an ingredient." Given that by "temporal passage" he means a fundamental asymmetry in the temporal dimension, (*ibid.*: 108) the picture one gets here is of a four-dimensional block with fundamental "arrows" pointing toward the future in the temporal dimension (this is Loewer's interpretation of Maudlin in his (2012)). But one might argue that this should really be interpreted as commitment to a four-dimensional *growing* block where the temporal arrows indicate the direction in which the FLOTEs produce growth. In that case, the leading edge of the growing manifold would play the role of the present moment, so we would again be faced with the task of identifying a relativistically kosher present. The prospects of a relativistic growing manifold are considered in §5.

Given a commitment to a (non-growing) block universe, I am not sure exactly how a proponent of the Package might try to respond to the objection that the FLOTEs have no role to play. One possibility would be to try to shift to a more deflationary conception of production to accommodate the fact that the output *relata* already exist. Callender (2017: 157), for example, talks of production occurring whenever the laws license inferences about one hypersurface given information about another: "[T]o the extent that one can speak of the physical state in a region of spacetime 'determining' another, one can often show that the state of the universe at one of these 'times' produces the next." If Maudlin were to avail himself of this sense of production, presumably he would want to add that it only occurs along the future direction in the manifold, to avoid countenancing production (and hence explanation) in both temporal directions. We might call this the "oriented inferential conception" sense of production:

> **Oriented Inferential Production:** A set of laws is productive in the oriented inferential sense if they permit nontrivial inferences about the content of later hypersurfaces given information about the content of earlier hypersurfaces.

This is a thin and yawn-inducing sense of production[21] that could be adopted even by a Humean (as Callender himself is). All it requires of the laws is that they can amplify information in a particular direction, and this is purely a

perspective, the notion of chance propensities loses most, if not all, of its intuitive content" (p. 69). (Similar points are made by Maxwell (1985) and Shanks (1993).) So his basic contention is very similar to my own in the present section. As with laws, objective chance is frequently studied in philosophy of science rather than metaphysics proper, so this may be further evidence that the sociological/compartmentalization explanation is on the right track.

[21] I borrow the phrase from Earman (2008: 159), who uses it in a similar context to describe a sense of temporal becoming that merely amounts to the happening of events in their temporal order, and is thus compatible with a block universe.

matter of the laws' formal structure, not their metaphysical status.[22] But if so, then it becomes unclear what is gained by Maudlin's primitivism. FLOTEs were taken as primitive because they function not just to specify but to *produce*—in a robust, unanalyzable, yet intuitive sense—later states on the basis of earlier states. This robust kind of production was also supposed to underwrite the ability of the FLOTEs to furnish genuine explanations of natural phenomena. Maudlin explicitly takes it to be a serious advantage of his view that it can provide an explanation of how the manifold ("Humean mosaic") comes to be.[23] Now, under pressure from the block universe of relativity, we are trying to say a bit more to clarify the nature of the production relation. If it really just amounts to a sort of directed implication relation, then what has ultimately been bought by primitivism about the laws? Humean laws can likewise "produce" states in this sense, so if that relation allows FLOTEs to explain the mosaic, it also allow Humean laws to explain the mosaic. Not only is the resulting account not doing justice to the intuitions that motivate it, but everything it *can* do can also be done by Humean laws.

It might be objected that Humean laws couldn't play this explanatory role because of circularity worries. If the laws themselves are determined by the mosaic, then how can they turn around and explain it? This worry has been pressed by a number of authors, including Maudlin himself (2007: 172).[24] If it were right, then primitivism about FLOTEs would still have an explanatory advantage over Humeanism.

But two points deserve mention about this idea. First, this would be a rather hollow victory. It maintains that FLOTEs can explain the mosaic because they have a primitive status that endows them with such explanatory power. It is hard to see that much has been accomplished here.

Second, and more significantly, if the relevant kind of explanation is backed by production, and the production relation is to be understood in this oriented inferential sense, then the circularity worry appears to lose traction. What the laws are really doing here is *licensing* the inference from a given hypersurface to a later hypersurface, but they arguably aren't directly involved in the explanation. Hicks (2021) argues that it is indeed a mistake to think of laws as figuring directly into explanations of their instances; rather, one can instead conceive of them as backing the explanation of the *explanandum* state on the basis of the *explanans* state.[25] On this view, there is no explanatory circularity for Humeanism, since the laws are not directly part of the *explanans*. Hicks's conception of the explanatory role of laws squares quite well with a conception of explanation according to which it is ultimately a matter of Oriented Inferen-

[22]Indeed, a number of recent developments of the Lewis's Humean Best Systems Account of laws (1973, 1986, 1994) have emphasized the need for systematizing standards that select laws with this kind of "amplifying" power. See, for example, Hicks (2018), Dorst (2019a), Jaag and Loew (2020), and Loewer (2020).

[23]See especially Maudlin (2007: 174).

[24]Also see Emery (2019), Lange (2013, 2018), and Shumener (2019). A wide variety of Humean responses have been developed, including e.g. Loewer (2012), Hicks and van Elswyck (2015), Miller (2015), Marshall (2015), Dorst (2019b), and Bhogal (2020).

[25]A view like this is also suggested in Skow (2016).

tial Production—i.e. a matter of what can be inferred, in a temporally oriented manner, on the basis of what. If this is right, why should it matter what the metaphysical status is of the entity licensing that inference?

None of this is meant to endorse Oriented Inferential Production. I only mean to point out that *if* a proponent of FLOTEs were to adopt this conception in response to the worries about eternalism, their account would lose its explanatory advantage over Humeanism.

In short, Maudlin's Non-Humean Package faces a dilemma: either the productive activity of the FLOTEs is ontologically robust, in which case it looks incompatible with eternalism (and, via Putnam's argument, with relativity), or it is ontologically innocent, in which case the view has no clear advantage over Humeanism. Perhaps there is some other notion of nomic production that we can use to navigate this strait, but if so I am not aware of it, nor do I see how it could maintain the intuitive advantages of the view.

By now this is a recurring theme. In modifying our conception of FLOTEs to be compatible with relativity, in one way or another we forgo what was most compelling about them. There is an alternative, however. Instead of modifying FLOTEs to be compatible with the traditional understanding of relativity, we might instead modify our understanding of relativity to be compatible with FLOTEs. The next section considers the merits of this strategy: can it be done consistent with the letter of special relativity, and how scientifically revisionary would it be?

5 Privileging a Foliation

Essentially all of the problems that we've encountered to this point could be solved by positing a privileged foliation along which FLOTEs operate. We would then have natural candidates for the *relata* of the production relation, namely the successive leaves of the privileged foliation, giving us the following conception of production:

> **Privileged Hypersurface Production:** Production occurs only along a privileged foliation of the manifold into spacelike hypersurfaces.

With Privileged Hypersurface Production, we have a notion that is objective (i.e. not hypersurface-relative) and yet it does not result in radical overdetermination of the produced events. Essentially it is the intuitive notion of production from Newtonian Mechanics.

With respect to Putnam's argument, positing a privileged foliation along which FLOTEs operate would allow us to maintain that the future is *not* (yet) real, and that the FLOTEs are literally producing the manifold along an empirically inaccessible hypersurface, in line with a growing block view of time. This *might* coincide with some particular inertial frame's simultaneity surfaces, though in principle it need not (if the privileged hypersurface is curved). The empirical inaccessibility of which hypersurface is privileged would also allow us to explain why we might have found Putnam's argument compelling.

The main issue here is that the existence of a preferred foliation is typically regarded as inconsistent with the content of special relativity. As Maudlin himself puts it: "If a preferred family of hyperplanes is part of the intrinsic structure of spacetime then the fundamental postulate of the Theory of Relativity is false" (2011: 185). But as he also points out, it is a subtle issue identifying exactly what counts as part of the intrinsic structure of spacetime, and there are ways of privileging a particular foliation without appealing to anything in spacetime's intrinsic structure.

For example, Zimmerman (2011: 209) imagines a physical theory according to which a particular kind of particle is of singular importance, and then a manifold in which it just so happens that all such particles are inertially comoving. Since the particles are privileged, there is some sense in which the frame in which they are all stationary is also privileged. But its privileged status has nothing to do with the intrinsic structure of spacetime; it is, rather, a matter of the contingent initial conditions of the universe. There is no inconsistency with special relativity here.

So some ways of privileging a foliation are relativistically kosher, while others are not. To decide whether a privileged foliation along which FLOTEs exert their productive power is inconsistent with special relativity, we need some criterion for when a foliation is privileged in a way that depends on the intrinsic structure of spacetime. Zimmerman (2011) seeks the same sort of criterion, though with slightly different goals in mind. He is trying to argue that presentism is consistent with special relativity, and wants to maintain that there are ways of privileging a foliation that are consistent both with the content of SR and with varieties of presentism. Drawing on Maudlin's (2011) discussion of which versions of quantum mechanics are inconsistent with special relativity, the criterion Zimmerman ultimately arrives at is that a theory is inconsistent with SR if it postulates laws that directly appeal to intrinsic spacetime structure beyond the Minkowskian metric (*ibid.*: 216). He elaborates the idea as follows:

> What is inconsistent with merely Minkowskian intrinsic structure is to explain some fact about the contents of spacetime as being due to the special nature of one foliation, and then not be able to appeal to any deeper laws that fail to mention that foliation. If the laws of a theory merely pick out the relevant frame of reference in terms of contingent material contents, and the contents merely *happen* to pick out that frame; then it is the material contents that are doing the work. But if a theory's most basic laws (whether they govern physical or metaphysical features of the manifold) must invoke one inertial frame of reference or foliation "by name", as it were; then there is something special about the frame or foliation itself, quite apart from the manifold's content. The law is an indication that the manifold includes built-in "rails", directing things in a certain way: some structure that is part of spacetime itself is doing the work. (*ibid.*: 213).

Zimmerman's idea is that if the fundamental laws directly reference the mate-

rial contents of spacetime—and only pick out a particular frame indirectly by reference to those contents—that foliation may be privileged, but not in a way that is inconsistent with SR. So if we return to his special particle theory where they are all stationary in an inertial frame, whether or not we have an inconsistency with SR will depend on whether the laws refer to the material contents such as the particles, or whether they refer to successive leaves of the foliation themselves.

What is it for the laws to *reference* material constituents of spacetime as opposed to spacetime structure itself? Zimmerman acknowledges that this idea is somewhat vague, but presumably it cannot merely be a matter of how the laws are commonly *expressed* in our physical theories. As Hicks and Schaffer (2017) point out, physicists often use context sensitive pragmatic criteria to decide how to write down equations, so it would seem unwise to try to read off deep metaphysical structure directly from the equations found in physics texts and papers.

What the laws "refer to" is ultimately going to depend not just on the physical theory in question, but also on the metaphysics of laws. In particular, we need to ask what the *role* of the laws is according to a given philosophical theory of lawhood. If the role of the laws is to relate properties—as it would be according to necessitarians like Armstrong (1983), Dretske (1977), and Tooley (1977), or (rather differently) according to dispositional essentialists like Bird (2007)—then we need to know the nature of the properties that the laws relate: are they best understood as properties of occupants of spacetime, or of spacetime itself? If the role of the laws is to summarize particular matters of fact—as on Humean Best System views—then we need to know the nature of the particular facts they are summarizing. In other words, we need to look to the metaphysical form of the laws, not merely the form of their equations, to decide whether they are referencing intrinsic spacetime structure.[26]

On some views of laws, it may require quite subtle analysis—of both the physical theory in question and the metaphysical account of laws on offer—to determine whether or not the laws reference intrinsic spacetime structure. Fortunately, the analysis is rather straightforward when it comes to the conception of FLOTEs currently under consideration. The *relata* of FLOTEs, on this view, are particular spacelike hypersurfaces of the spacetime manifold; the FLOTEs function to produce later such hypersurfaces from earlier ones. It seems clear here that the laws "reference" intrinsic spacetime structure, namely the privileged hypersurfaces of the manifold upon which they operate. Remember how Loewer suggested we understand this: the fundamental arrows of time—which we are now positing to exist along a privileged hypersurface—determine the direction in which the laws operate. The job of the FLOTEs is to look for the leading edge of the manifold and evolve it in the direction indicated by the arrows thereon. If so, the manifold has "built-in 'rails', directing things in a certain way," as Zimmerman puts it. The verdict, then, is straightforward: if

[26]If this is right, it implies that Zimmerman's verdict, namely that presentism is compatible with SR, likewise depends on the metaphysical nature of the laws.

our criterion of inconsistency with SR is that the laws refer to intrinsic spacetime structure beyond the Minkowski metric, then the current conception of FLOTEs is inconsistent with SR.

How damning is this result? One option for a proponent of FLOTEs would be to search for an alternative criterion of inconsistency with SR on which there is none here. Surely there are candidate criteria that would render a friendlier verdict about the present proposal (namely, a FLOTE-directed privileged foliation), though admittedly the verdict of inconsistency *seems* quite plausible here—if this isn't a case of inconsistency, then what is?—so any alternative criterion that reaches the opposite verdict would have to explain away that plausibility.

Probably a better option would just be to own up to the inconsistency. Though inconsistency with a physical theory as well-confirmed as relativity is a serious worry for a philosophical account of laws, as I mentioned in the introduction, there already exist first order physical theories that are likewise inconsistent with it, e.g. Bohmian mechanics.[27] Moreover, this inconsistency *might* go away in some general relativistic spacetimes, where the spacetime geometry itself could privilege a particular foliation.[28] And lastly, we know that general relativity is not the final word: someday it will probably be replaced by a more successful theory of quantum gravity, and at this point it is anyone's guess whether the spacetime structure of that theory will turn out to be as inhospitable to FLOTEs as those of SR and GR.

So the proponent of FLOTEs can take some solace in the fact that the spacetime structure of relativity may yet be replaced by better physics. But we ought not overstate this. Conflict with relativity is conflict with one of the most highly confirmed physical theories ever. Insofar as there are reasons to think that the world is relativistic—and there are plenty—there are reasons to think that FLOTEs are an inaccurate picture of the nature of laws.

6 Conclusion

When Pierre-Simon Laplace famously articulated the idea of causal determinism, the picture was at once metaphysical and epistemological:

> We may regard the present state of the universe as the effect of its past and the cause of its future. An intellect which at a certain moment would know all forces that set nature in motion, and all positions of all items of which nature is composed, if this intellect were also vast enough to submit these data to analysis, it would embrace in a single formula the movements of the greatest bodies of the universe and those of the tiniest atom; for such an intellect

[27] Cf. Maudlin (2011: 173-202).

[28] There is a fair amount of debate about this question. Callender (2017, Chapter 3) provides a helpful summary, as well as a negative appraisal of the idea that general relativity is more hospital than special relativity to presentism or the growing block.

> nothing would be uncertain and the future just like the past would be present before its eyes. (1814 [1902])

What starts here as a metaphysical picture about the present state of the universe being the cause of its future becomes an epistemological picture about the intelligence's ability to predict the future on the basis of the present. Maudlin's FLOTEs are essentially a precisification of the vague metaphysical picture articulated by Laplace. I have argued that relativity undermines that metaphysical picture, though it's worth noting that it does not touch the epistemological one. Given complete information about a Cauchy surface, a Laplacean intelligence could still predict the entire future, and what relativity teaches us is that it doesn't matter which Cauchy surface the intelligence knows about; complete information about any one of them would allow the intelligence to infer the rest of the manifold.[29]

It is rare that a philosophical view of laws sticks its neck out far enough to be so seriously tested by actual physics. Some philosophers, e.g. Lange (2012: 185), argue that philosophical accounts of laws ought to be general enough that they are compatible with all theories that physicists (rightly) take seriously. But Maudlin is explicit about his disagreement with this position. As just one example, he observes that FLOTEs cannot abide closed timelike curves, for if they existed then the productive activity of FLOTEs would operate in a circle around them—but production cannot operate in a circle.[30] In Maudlin's words, "the existence of closed timelike curves would imply the non-existence of this sort of productive explanation, and might suggest that a Humean account is the strongest that can be had" (2007: 175). My basic suggestion has been that even without CTCs, relativity *already* implies the non-existence of the sort of productive explanations that Maudlin seeks.

In a sense, my objection here is an instance of a broader dialectical trend. Non-Humeanism is sometimes characterized, rather generally, by its commitment to the idea that laws "govern" the particular matters of fact. And if you spend enough time with Humeans, you will hear the complaint that this notion of *governance* is opaque: it is unclear just what is being asserted by the claim that laws govern—unclear what role is thereby being ascribed to the laws—and correspondingly it is unclear how we are to evaluate it.[31]

I think this complaint is fairer against some accounts than others, and at first glance Maudlin's account avoids it entirely. In contrast with the obscurity of "governance," Maudlin's notion of *production* seems entirely straightforward:

[29] Two caveats: First, I am assuming here that the spacetime is globally hyperbolic. If it is less well behaved, e.g. if it contains closed timelike curves, prediction would become more difficult. (See the discussions in Arntzenius and Maudlin (2000) and Thorne (1994) for more on the difficulties of prediction in the presence of CTCs.) Second, some have argued that the lightcone structure makes it impossible for any embedded agent to achieve knowledge, or at least absolute certainty, about future events. (See e.g. Geroch (1977), Ismael (2019), and Manchak (2008).)

[30] Moreover, CTCs would preclude the existence of Cauchy surfaces, so even if a proponent of FLOTEs decided to bite the bullet and admit circles of production, they would still need to find different *relata* for the production relation.

[31] See, e.g., Shumener (2022) and the references therein for further discussion.

here we *can* see what role is being ascribed to the laws, and correspondingly we can see what it would take for the view to be true or false.

But clarity is both a virtue and a risk. Insofar as I can see what it might mean to say that the laws produce later states of the world from earlier states, the truth of that claim would require the falsity of relativity. At the very least, if one wants to maintain that the idea of FLOTEs still makes sense in relativistic spacetimes, then it's no longer clear what the production relation is supposed to be. Presumably it's something *extra*, something that Humean laws don't do. But what that extra thing is, and why it is aptly called "production," I do not know.[32]

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References

[1] Adlam, Emily. (2022) "Laws of Nature as Constraints." *Foundations of Physics.* 52: 1-41.

[2] Albert, David. (2000) *Time and Chance.* Cambridge, MA: Harvard University Press.

[3] Armstrong, David. (1983) *What is a Law of Nature?* Cambridge: Cambridge University Press.

[4] Arntzenius, Frank, and Tim Maudlin. (2000) "Time Travel and Modern Physics." *The Stanford Encyclopedia of Philosophy.* Zalta, E. (ed.) https://plato.stanford.edu/entries/time-travel-phys/

[5] Bhogal, Harjit. (2020) "Nomothetic Explanation and Humeanism about Laws of Nature." In Bennett, Karen and Dean W. Zimmerman (eds.), *Oxford Studies in Metaphysics, vol. 12.* Oxford: Oxford University Press: 164-202.

[6] Bhogal, Harjit and Zee Perry. (2017) "What the Humean should say about entanglement." *Noûs.* 51: 74-94.

[7] Bielińska, Marta and James Read. (2023) "Testing Spacetime Orientability." *Foundations of Physics.* 53.8: 1-25.

[8] Bird, Alexander. (2007) *Nature's Metaphysics.* New York: Oxford University Press.

[9] Builes, David and Michele Odisseas Impagnatiello. (forthcoming) "An Empirical Argument for Presentism." In Bennett, Karen and Dean W. Zimmerman (eds.), *Oxford Studies in Metaphysics.*

[10] Callender, Craig. (2017) *What Makes Time Special?* Oxford: Oxford University Press.

[11] Chen, Eddie Keming and Sheldon Goldstein. (forthcoming) "Governing Without a Fundamental Direction of Time: Minimal Primitivism about Laws of Nature." In Yemima Ben-Menahem (ed.), *Rethinking Laws of Nature.* Springer.

[12] Dorst, Chris. (2019a) "Towards a Best Predictive System Account of Laws of Nature." *British Journal for the Philosophy of Science.* 70: 877-900.

[13] Dorst, Chris. (2019b) "Humean Laws, Explanatory Circularity, and the Aim of Scientific Explanation." *Philosophical Studies.* 176: 2657-2679.

[14] Dorst, Chris. (2020) "Why do the Laws Support Counterfactuals?" *Erkenntnis.* https://doi.org/10.1007/s10670-019-00207-1

[15] Dretske, Fred. (1977) "Laws of Nature." *Philosophy of Science.* 44: 248-68.

[16] Earman, John. (2008) "Reassessing the Prospects for a Growing Block Model of the Universe." *International Studies in Philosophy of Science.* 22: 135-64.

[17] Edgington, Dorothy. (2004) "Counterfactuals and the Benefit of Hindsight." In Dowe, P. and Noordhof, P. (eds.), *Cause and Chance: Causation in an Indeterministic World*, pp. 12-27. New York: Routledge.

[18] Emery, Nina. (2019) "Laws and their Instances." *Philosophical Studies.* 176: 1535-61.

[19] Fletcher, Samuel C. and James Owen Weatherall. (forthcoming a) "The Local Validity of Special Relativity. Part 1: Geometry." *Philosophy of Physics.*

[20] Fletcher, Samuel C. and James Owen Weatherall. (forthcoming b) "The Local Validity of Special Relativity. Part 2: Matter." *Philosophy of Physics.*

[21] Fine, Kit. (2005) "Tense and reality." In Kit Fine (ed.), *Modality and Tense: Philosophical Papers.* Oxford: Clarendon Press: 261-320.

[22] Geroch, Robert. (1977) "Prediction in General Relativity." In Earman, J., Glymour, C., and Stachel, J. (eds.) *Foundations of Space-Time Theories*, Vol. 8, pp. 81-93. Minneapolis: University of Minnesota Press.

[23] Gibson, Ian and Pooley, Oliver. (2008) "Relativistic Persistence." *Philosophical Perspectives.* 20: 157-98.

[24] Gödel, Kurt. (1949) "A Remark about the Relationship between Relativity Theory and the Idealistic Philosophy." In Schilpp, P. (ed.), *Albert Einstein: Philosopher-Scientist*, pp. 555-62. La Salle, IL: Open Court.

[25] Grünbaum, Adolf. (1973) *Philosophical Problems of Space and Time.* Second Edition. Dordrecht: D. Reidel Publishing Company.

[26] Healey, Richard. (2008) "Review of *The Metaphysics Within Physics.*" Notre Dame Philosophical Reviews. Accessed at: https://ndpr.nd.edu/reviews/the-metaphysics-within-physics/

[27] Hempel, Carl and Paul Oppenheim. (1948) "Studies in the Logic of Explanation." *Philosophy of Science.* 15: 135-175.

[28] Hicks, Michael and Peter van Elswyck. (2015) "Humean Laws and Circular Explanation." *Philosophical Studies.* 172: 433-43.

[29] Hicks, Michael and Jonathan Schaffer. (2017) "Derivative Properties in Fundamental Laws." *British Journal for the Philosophy of Science.* 68: 411-450.

[30] Hicks, Michael. (2018) "Dynamic Humeanism." *British Journal for the Philosophy of Science.* 69: 987-1007.

[31] Hicks, Michael. (2021) "Breaking the Explanatory Circle." *Philosophical Studies.* 178: 533-57.

[32] Hinchliff, Mark. (2000) "A Defense of Presentism in a Relativistic Setting." *Philosophy of Science.* 67: S575-S586.

[33] Hoefer, Carl. (2011) "Time and Chance Propensities." In Callender, Craig (ed.) *The Oxford Handbook of Philosophy of Time*, pp. 68-90. New York: Oxford University Press.

[34] Ismael, Jennan. (2019) "Determinism, Counterpredictive Devices, and the Impossibility of Laplacean Intelligences." *The Monist.* 102: 478-98.

[35] Jaag, Siegfried and Christian Loew. (2020) "Making Best Systems Best for Us." *Synthese.* 197: 2525-2550.

[36] Jammer, Max. (2006) *Concepts of Simultaneity: From Antiquity to Einstein and Beyond.* Baltimore: The Johns Hopkins University Press.

[37] Janis, Allen. (2018) "Conventionality of Simultaneity." In E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy.* Accessed at: https://plato.stanford.edu/entries/spacetime-convensimul/.

[38] Lange, Marc. (2012) "'There Sweep Great General Principles which All the Laws Seem to Follow.'" In Bennet, Karen and Dean Zimmerman (eds.), *Oxford Studies in Metaphysics, vol. 7*, pp. 154-86. New York: Oxford University Press.

[39] Lange, Marc. (2013) "Grounding, Scientific Explanation, and Humean Laws." *Philosophical Studies.* 165: 255-61.

[40] Lange, Marc. (2018) "Transitivity, Self-Explanation, and the Explanatory Circularity Argument against Humean Accounts of Natural Law." *Synthese.* 195: 1337-53.

[41] Laplace, Pierre-Simon. (1814 [1902]) *A Philosophical Essay on Probabilities,* trans. Truscott, F. and Emory, F. New York: John Wiley and Sons.

[42] Lewis, David. (1973) *Counterfactuals.* Malden: Blackwell.

[43] Lewis, David. (1986) *Philosophical Papers, Volume II.* New York: Oxford University Press.

[44] Lewis, David. (1994) "Humean Supervenience Debugged." *Mind.* 103: 474-90.

[45] Linneman, N., Read, J. and Teh, N. J. (ms) "The Local Validity of Special Relativity from an EFT-inspired Perspective.' doi.org/10.48550/arXiv.2305.01534

[46] Lipman, Martin. (2020) "On the fragmentalist interpretation of special relativity." *Philosophical Studies.* 177: 21-37.

[47] Loewer, Barry. (1996) "Humean Supervenience." *Philosophical Topics.* 24: 101-127.

[48] Loewer, Barry. (2007) "Counterfactuals and the Second Law." In Price, Huw and Richard Corry (eds.), *Causation, Physics, and the Constitution of Reality: Russell's Republic Revisited*, pp. 293-326. Oxford: Clarendon Press.

[49] Loewer, Barry. (2012) "Two Accounts of Laws and Time." *Philosophical Studies.* 160: 115-37.

[50] Loewer, Barry. (2020) "The Package Deal Account of Laws and Properties." *Synthese.* https://doi.org/10.1007/s11229-020-02765-2

[51] Malament, David. (1977) "Causal Theories of Time and the Conventionality of Simultaneity." *Noûs.* 11: 293-300.

[52] Manchak, John. (2008) "Is Prediction Possible in General Relativity?" *Foundations of Physics.* 38: 317-21.

[53] Marshall, Dan. (2015) "Humean Laws and Explanation." *Philosophical Studies.* 172: 3145-65.

[54] Maudlin, Tim. (2002) "Remarks on the Passing of Time." *Proceedings of the Aristotelian Society.* 102: 259-74.

[55] Maudlin, Tim. (2007) *The Metaphysics within Physics.* New York: Oxford University Press.

[56] Maudlin, Tim. (2011) *Quantum Non-Locality and Relativity, Third Edition.* Malden: Wiley-Blackwell.

[57] Maudlin, Tim. (2012) *Philosophy of Physics: Space and Time.* Princeton University Press.

[58] Maxwell, Nicholas. (1985) "Are Probabilism and Special Relativity Incompatible?" *Philosophy of Science.* 52: 23-43.

[59] Miller, Elizabeth. (2014) "Quantum entanglement, Bohmian mechanics, and Humean supervenience." *Australasian Journal of Philosophy.* 92: 567-583.

[60] Miller, Elizabeth. (2015) "Humean Scientific Explanation." *Philosophical Studies.* 172: 1311-32.

[61] Monton, Bradley. (2006) "Presentism and Quantum Gravity." In Dieks, Dennis (ed.), *The Ontology of Spacetime*, pp. 263-80. Amsterdam: Elsevier.

[62] Newton, Isaac. (1689) *Philosophiae Naturalis Principia Mathematica*, Book 1, trans. Andrew Motte (1729), rev. Florian Cajori, Berkeley: University of California Press, 1934.

[63] Penrose, Roger. (1989) *The Emperor's New Mind: Concerning Computers, Minds, and the Laws of Physics.* New York: Oxford University Press.

[64] Price, Huw. (2011) "The Flow of Time." In Callender, Craig (ed.), *The Oxford Handbook of Philosophy of Time*, pp. 276-311. New York: Oxford University Press.

[65] Putnam, Hilary. (1967) "Time and Physical Geometry." *The Journal of Philosophy.* 64: 240-7.

[66] Reichenbach, Hans. (1958) *The Philosophy of Space and Time.* New York: Dover Publications, Inc.

[67] Rietdijk, C. W. (1966) "A Rigorous Proof of Determinism Derived from the Special Theory of Relativity." *Philosophy of Science.* 33: 341-4.

[68] Roberts, John. (2016) "Laws of Nature." In Humphreys, Paul (ed.), *The Oxford Handbook of Philosophy of Science*, pp. 337-55. New York: Oxford University Press.

[69] Rynasiewicz, Robert. (2000) "Definition, Convention, and Simultaneity: Malament's Result and its Alleged Refutation by Sarkar and Stachel." *Philosophy of Science* 68: S345-57.

[70] Salmon, Wesley. (1977) "The Philosophical Significance of the One-Way Speed of Light." *Noûs.* 11: 253-92.

[71] Sarkar, Sahotra and Stachel, John. (1999) "Did Malament Prove the Non-Conventionality of Simultaneity in the Special Theory of Relativity?" *Philosophy of Science.* 66: 208-20.

[72] Saunders, Simon. (2002) "How Relativity Contradicts Presentism." In Callender, Craig (ed.), *Time, Reality and Experience*, pp. 277-92. Cambridge: Cambridge University Press.

[73] Savitt, Steven. (2000) "There's No Time Like the Present (in Minkowksi Spacetime).' *Philosophy of Science.* 67: S563-74.

[74] Savitt, Steven. (2009) "The Transient *Nows*." In *Quantum Reality, Relativistic Causality, and Closing the Epistemic Circle.* Western Ontario Series in Philosophy of Science, pp. 349-62. Springer, Dordrecht.

[75] Savitt, Steven. (2011) "Time in the Special Theory of Relativity." In Callender, Craig (ed.), *The Oxford Handbook of Philosophy of Time*, pp. 546-67. New York: Oxford University Press.

[76] Schaffer, Jonathan. (2016) "It is the Business of Laws to Govern." *dialectica.* 70: 577-588.

[77] Sebens, Charles T. (ms) "How do Laws Produce the Future?"

[78] Shanks, Niall. (1993) "Time and the Propensity Interpretation of Probability." *Journal for General Philosophy of Science.* 24: 293-302.

[79] Shumener, Erica. (2019) "Laws of Nature, Explanation, and Semantic Circularity." *British Journal for the Philosophy of Science.* 70: 787-815.

[80] Sider, Ted. (2001) *Four-Dimensionalism: An Ontology of Persistence and Time.* New York: Oxford University Press.

[81] Skow, Brad. (2007) "What Makes Time Different from Space?" *Noûs.* 41: 223-42.

[82] Skow, Brad. (2016) *Reasons Why.* New York: Oxford University Press.

[83] Shumener, Erica. (2022) "The Power to Govern." *Philosophical Perspectives.* 36: 270-291.

[84] Thorne, Kip. (1994) *Black Holes and Time Warps: Einstein's Outrageous Legacy.* W. W. Norton.

[85] Tooley, Michael. (1977) "The Nature of Laws." *Canadian Journal of Philosophy.* 7: 667-98.

[86] Zimmerman, Dean. (2011) "Presentism and the Space-Time Manifold." In Callender, Craig (ed.), *The Oxford Handbook of Philosophy of Time*, pp. 163-244. New York: Oxford University Press.