What's So Spatial About Time Anyway?

Samuel Baron*[1] and Peter W. Evans†[2]

[1]Department of Philosophy, University of Western Australia
[2]School of Historical and Philosophical Inquiry, University of Queensland

Abstract

Both Skow (2007) and Callender (2008) independently argue that time can be distinguished from space due to the special role it plays in our laws of nature: our laws determine the behaviour of physical systems across time, but not across space. In this work we asses the claim that the laws of nature might provide the basis for distinguishing time from space by looking specifically at the claims of Skow and Callender. We find that there is an obvious reason to be sceptical of the argument Skow submits for distinguishing time from space: Skow fails to pay sufficient attention to the relationship between the dynamical laws and the antecedent conditions required to establish a complete solution from the laws. Callender's more sophisticated argument in favour of distinguishing time from space by virtue of the laws of nature presents a much stronger basis to draw the distinction. We raise, however, the possibility that Callender's account in a certain sense shifts the bump in the carpet: that laws are more 'informative' in the temporal direction seems to call out for an underlying explanation, and whatever this underlying factor is, surely this is the real distinction between time and space.

1 Introduction

It is very natural to suppose that there is a substantial difference between time and space. But what exactly is that difference? Two of our best known models of space and time – the system derived from Newton's theory of gravitation and mechanics, and the system that arises from the special and general theories of relativity, which superseded the former – diverge in the answer they provide to this question. In Newtonian spacetime, time has a clear direction that definitively distinguishes it from the spatial directions, whereas in generally relativistic spacetime temporal and spatial directions are inexorably interwoven. The shift from Newtonian to relativistic mechanics may seem to bring with it the death of difference: time and space appear to be no different in kind. But there is some distinction to be drawn between spacelike and timelike orientations in relativistic spacetime, a distinction that is ultimately encoded within both the mathematical signature of the metric and its causal structure. Despite this,

*email: samuel.baron@uwa.edu.au
†email: p.evans@uq.edu.au

general relativity does not provide a great deal of insight into what that difference ultimately amounts to, metaphysically speaking.

There have been two attempts in recent times to clarify the exact difference between time and space. Both of these accounts, though independent, emphasise the unique role that time plays in the laws of nature: our laws determine the behaviour of physical systems across time, but not across space. The first of these accounts, due to Skow (2007), claims that the reason we never have evolution in a spatial direction is that such a schema would leave us with a paucity of information concerning physical behaviour in a four-dimensional spacetime region. That is, given information at, say, some location in space for all time, any physical laws resembling our current laws will not provide complete information concerning what is going on everywhere else at any time. The second of these accounts, due to Callender (2008), claims that time is the "great informer" in the sense that it discriminates the direction in the manifold of events in which the laws of nature provide maximal determination of the behaviour of physical systems. That is, given certain properties of a large class of our laws, these laws work most informatively in the temporal direction.

In this work we asses the general claim that the laws of nature might provide the basis for distinguishing time from space by looking specifically at the claims of Skow and Callender. After we present Skow's account in §2, we outline in §3 an obvious reason to be sceptical of the argument Skow submits for distinguishing time from space. In short, Skow fails to pay sufficient attention to the relationship between the form of dynamical laws and the dimensionality of the antecedent conditions required to establish a complete solution from the laws. In §4 we turn to Callender's more sophisticated arguments in favour of distinguishing time from space by virtue of the laws of nature. We find these arguments to be a much stronger basis to draw the distinction. However, in §5 we raise the possibility that Callender's account in a certain sense shifts the bump in the carpet: that laws are more 'informative' in the temporal direction seems to call out for an underlying explanation, and whatever this underlying factor is, surely this is the real distinction between time and space. We conclude in §6.

2 Time as the preferred direction of laws

Skow (2007, p.237) outlines the following position concerning the distinction between the spatial and temporal directions in spacetime:

> Timelike and spacelike directions play different roles in the laws of physics... Those laws govern the evolution of the world in timelike directions, but not in spacelike directions.

Skow takes the fundamental difference between time and space to be that the laws of physics determine behaviour by evolution in time, but they do not determine behaviour by evolution in space. This is not supposed to be a trivial claim; evolution is not to be interpreted analytically as evolution *in time*. Rather we are to think of evolution as the determination of physical behaviour in *some* spatiotemporal direction, where that direction is determined by the relation between the laws of physics and the data required by the laws: the antecedent data comprises some subset of the complete information describing physical behaviour in some four-dimensional spacetime region and the laws determine the complete information given this antecedent data. Here is Skow (2007, p.237):

> Roughly speaking, by 'the laws govern the evolution of the world' in some direction I mean that the laws, together with complete information about what is going on in some region of spacetime, yield complete information about (or assign probabilities to complete descriptions of) what is going on in regions of spacetime that lie in that direction from the initial region.

Thus, given an amount of information concerning some subset of spacetime that corresponds to the data required to provide a well-posed initial value problem for some physical laws, we can produce enough information to describe physical behaviour in some four-dimensional spacetime region, and the direction from the initial region to the complete region is the direction of evolution. This is straightforwardly the case when the direction of evolution coincides with the direction of time. We take initial data on some spacelike surface and employ physical laws that require such data in order to determine the behaviour of some system throughout some four-dimensional region that includes the spacelike surface as an initial temporal boundary, so long as the initial data and the laws comprise a well-posed initial value problem. The laws thus govern evolution from one time to another. This is precisely the structure we take to be typically characteristic of physics.

Skow's claim, then, is that the distinction between time and space consists in physical laws evolving in the direction of time, but never in the direction of space; we always take spacelike surfaces (data at a time) as initial data, our laws always govern evolution in directions normal to these surfaces, and thus evolution always occurs in the direction of timelike vectors. Skow (2007, p.237) says as much:

> Now, timelike vectors are not tangent to any time, on any way of partitioning any given spacetime into times [spacelike surfaces]. Rather, no matter which partitioning of spacetime into times you use, timelike vectors point from one time toward others. So timelike vectors point in the directions in which the laws govern the evolution of the world.

And then continues:

> The same is not true of points of space. If I know what is going on right here (at this location in space) for all time, the laws do not give me complete information about (or assign probabilities to complete descriptions of) what is going on anywhere else at any time.

According to Skow, the reason we never have evolution in a spatial direction is that such a schema would leave us with a paucity of information concerning physical behaviour in a four-dimensional spacetime region. Skow is correct to point out that given information at some location in space for all time, any physical laws resembling our ordinary laws will not provide complete information concerning what is going on everywhere else at all times. There is a very good reason for this. Ordinarily our laws strike two practical balances to achieve a complete specification of physical behaviour in a four-dimensional spacetime region. The first is between the number of variables constituting the antecedent conditions and the order of the dynamical law; and the second is between the number of dimensional components of these variables and the corresponding dimension of the law. As a quick illustration we can consider second-order dynamical equations, which comprise a large portion of our known physical laws. Second-order equations require the antecedent conditions to be constituted by two dependent variables; we ordinarily take these to be the position and velocity initial conditions. Since we ordinarily take initial data to extend across three spatial dimensions in our actual physical laws, these laws must be three-dimensional, relating three components of each of the dependent variables to the independent variable (which we ordinarily take to represent time).

It is usually trivial to add or subtract components to a dynamical equation to ensure the dimensionality of the equation and the initial data match. However, it is important for our present purposes to note that the operation of the laws that we take to govern evolution in our world is to extend the initial conditions across one further dimension that we call time (in a sense that produces 'dynamics') – taking three-dimensional initial conditions to a four-dimensional dynamical solution, or n-dimensional antecedent conditions to an $n+1$-dimensional solution. Thus, if one of these laws (of appropriate dimensionality) took as its antecedent conditions information at some location in space for all time (a simple line through four-dimensional spacetime), the most that law could tell us would be information on some spatiotemporal plane to which the initial line is parallel. This is not complete information concerning a four-dimensional region of spacetime. Hence such a schema would not provide evolution in a spatial direction and this would leave us with a clear distinction between timelike and spacelike directions.

Given Skow's criteria for evolution in some spatiotemporal direction, information concerning some location in space for all time will never succeed in providing a system wherein the laws govern the evolution of the world in a spacelike direction.

3 Dynamical laws and antecedent conditions

Having elucidated Skow's position, we will now outline a difficulty for his account. Let us consider in more depth the relationship between laws and antecedent conditions. If we want to take some law to give us a representation of physical behaviour throughout a four-dimensional region of spacetime, then there had better be a correspondence between the dimensionality of the antecedent conditions and the dimensionality of the law. Given that the role of many of our current physical laws is to extend antecedent data through one further dimension, in order for the combination of the laws and the antecedent conditions to result in a description of physical behaviour throughout a four-dimensional region of spacetime we require our antecedent conditions to describe complete information across a three-dimensional sub-region of spacetime (such as a spatial configuration at some time).

It is thus obvious why information concerning a single location in space at all times, combined with our ordinary laws, will not result in a description of physical behaviour throughout a four-dimensional region of spacetime: that information is incomplete. For any case in which the antecedent conditions fail to yield complete information about a four-dimensional sub-region, there are two possible modifications that we could make so as to achieve such complete information. One way would be to keep the antecedent conditions as they are and apply them to more wide-reaching laws. To illustrate such a law, imagine the following highly simplified scenario.

We have a universe in which each location in spacetime is simply a single many-valued property. We could think of this property as, say, colour; each location in spacetime is green, or red, or blue, and so on. Information concerning a single location in space for all time would consist in a linear series of colours. We could now imagine a law that took this information as an antecedent condition and determined the value of this property throughout four-dimensional spacetime. For instance, the universe is a single colour at each time. Thus, given a linear series of colours at a single location in space, and the law stipulating uniform colour at each time, we have complete information concerning four-dimensional spacetime.

A second way that we might achieve complete information is to keep our ordinary laws and expand the scope of the antecedent conditions instead, by feeding in more information. In the case where we take our laws to give evolution in time, we expect our antecedent conditions to contain total information about three spatial dimensions at some part of the manifold (such as a total spatial configuration at some time). Similarly, equivalent laws evolving in space would also require antecedent conditions that are three-dimensional – in this case, we would need complete information concerning two dimensions of space and one dimension of time at some part of the manifold. Given such information and the requisite laws, we could compute complete information concerning four-dimensional spacetime.

We are now in a position to see why Skow's account is deficient. When discussing the evolution of our ordinary laws over time, Skow feeds in total information about the three spatial dimensions that correspond to a particular time. Which is to say that, for some time, t_p, a complete three-dimensional specification in the spatial dimensions comprises the antecedent conditions. This yields total information for all $t < t_p$ and $t > t_p$. He argues that the analogous operation in the spatial case does not yield total information. The analogous operation in the spatial case, however, would be this: for some spatial location, say, z_q, a complete three-dimensional specification consisting of information about the remaining two spatial dimensions plus information about the temporal dimension would constitute the antecedent conditions. The laws should then enable one to extrapolate information for all $z < z_q$ and $z > z_q$ (see Fig.1 for a representation of the two cases). In short: in the temporal case, we extrapolate from information about all three spatial dimensions at a time. In the spatial case, we extrapolate from information about two spatial dimensions and all of time at a point in space.

But the spatial extrapolation represented in Fig.1(ii) is not the kind of operation that Skow considers. Rather, Skow considers cases in which one takes partial information about some part of space, which may or may not include information about time, and then one attempts to extrapolate across all of spacetime (see Fig.2 for a representation). Consider, for instance, Skow's fourth (and most realistic, because it uses actual quantum laws) example of using laws to extrapolate information across space, rather than time (Skow, 2007, p.246):

> **Example 4:** In this world, the laws of quantum mechanics govern the world. In an EPR-type experiment, there are two particles some distance apart, and if we measure the spin on one of them in some direction, we know with certainty the outcome of a measurement of spin of the other particle in that same direction, even if the measurement of events are spacelike separated. So these laws govern the evolution of the world in a spacelike direction.

Skow concedes that one can gain information about one part of spacetime based on information about a measured particle in another part of spacetime plus the laws, but goes on to argue

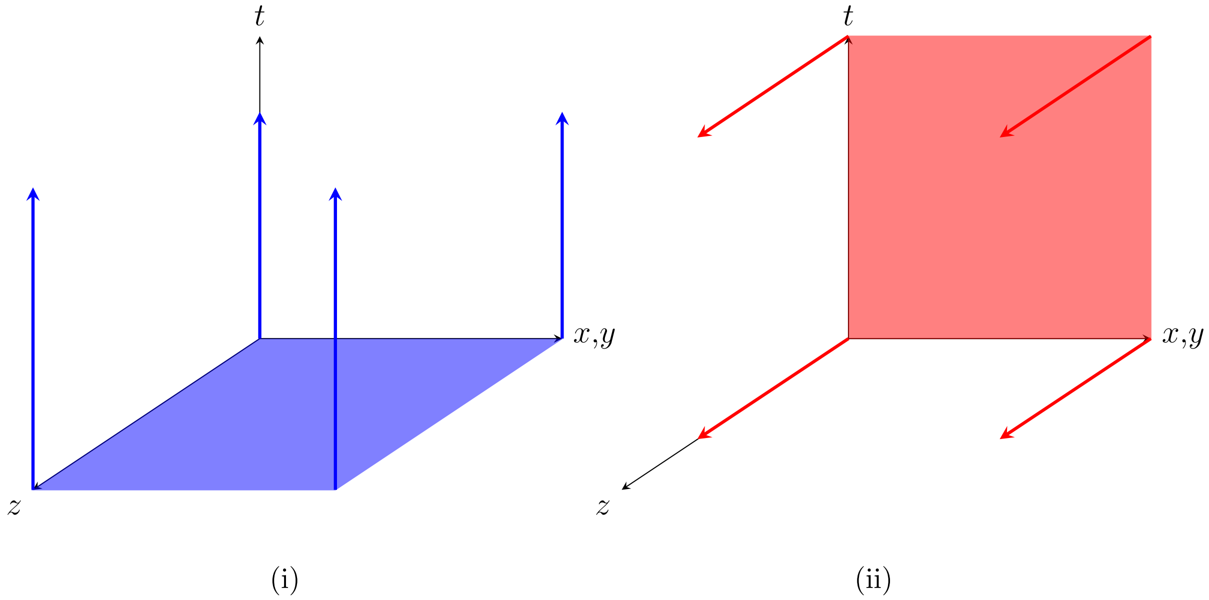

Figure 1: A representation of temporal and spatial evolution: (i) represents an extrapolation through time via the laws; (ii) represents the analogous extrapolation through space.

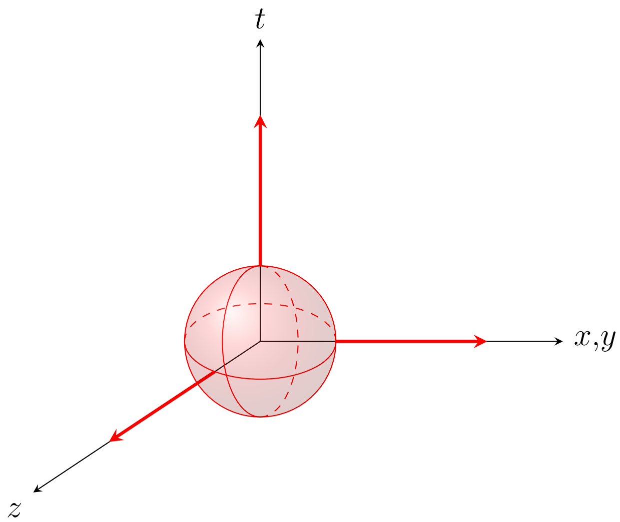

Figure 2: Skow's proposed extrapolation through space.

that there is no way to use the same laws in such a case to extrapolate all of the information about the entire four-dimensional manifold. He extends precisely the same reasoning to each of the three cases of a law governing the evolution of the world across space that he considers. In each case he admits that some information about another region of spacetime may be gained via the relevant laws, but denies that information about the whole manifold can be gathered.

Each of the cases that Skow considers can be represented by Fig.2. Limited information about a particular spatial region is used to try and gain information about all of spacetime. The crucial missing ingredient is time: in order to extrapolate all of the information about a complete four-dimensional spacetime from two dimensions of space, full information about the temporal dimension is needed. In the cases he presents, no temporal information is used. It is unsurprising, then, that only limited information about spacetime is yielded. In essence, the cases that Skow considers are the wrong cases to be focusing on. What we need to look at are cases that are like those represented by Fig.1(ii). Because Skow does not consider any of those cases, he has failed to show what he sets out to prove in §8 of his paper: namely that it is *impossible* for there to be laws that govern the evolution of the world across space in the same way that the laws govern the evolution of the world across time. The relevant impossibility result is crucial to Skow's account of the difference between the spatial and temporal directions of spacetime. For, as he notes, his "view entails that it is not possible that there be laws that govern the evolution of the world [in] a spacelike direction". Given this entailment, if it is possible that the laws govern the evolution of the world across space in exactly the manner in which they govern the evolution of the world across time, then that is sufficient to show that the essential difference between time and space cannot be to do with the fact that the laws can govern the evolution of the world across the former but cannot across the latter.

Of course, all we have shown is that Skow has not yet addressed an objection he thought he had put to rest. It is therefore interesting to inquire as to whether there are any plausible cases of spatial evolution in the sense of Fig.1(ii). For it is one thing to note that Skow has failed to rule such cases out as being impossible, quite another to show that there are such cases in the offing. If there are no such cases, then that would seem to strengthen Skow's conviction that the distinction between time and space ultimately resides with the manner in which the laws govern evolution across spacetime, even if his way of developing that distinction is ultimately too strong. In order to make our point more forcefully, then, let us consider an example that looks to be evolution in space of the kind that we deem to be acceptable, and the kind that we believe Skow has failed to take into consideration.

Consider classical electromagnetism. Classical action principles of the sort found in electromagnetism generally require that the field boundary is fixed on a closed hypersurface, wherein the timelike parts of the boundary are just as important as the spacelike parts. Determining physical behaviour as a solution to the action integral involves integrating over the spacetime region enclosed by the boundary. It is interesting to note that neither the integral over space nor over time has any precedence over the other: the solution will comprise the same action for the same field in the same spacetime region regardless of whether we represent the integral as 'evolving' a spacelike hypersurface in time or a timelike hypersurface in space. If we imagine an electromagnetic system consisting of a perfect conductor at some location which constrains some of the electric and magnetic field components to be zero, so long as there are no other boundary conditions, an analysis of the fields near the conductor might appear as though the field is 'evolving' in a spatial direction away from the conductor, à la Fig.1(ii).

While we take this example from electromagnetism to provide a clear counterexample to Skow's arguments regarding the distinctiveness of time, we do not wish to argue that this sort of example provides good evidence for a strong nomic symmetry between space and time (for reasons to which we will return in the context of the discussion in §5). But we do hope to have shown that this is the kind of spatially directed law that Skow needs to take into account to make his arguments at all convincing. Let us now turn to a second attempt to differentiate time from space, an attempt that lies in a similar vein to Skow's but that does not face the difficulty we have outlined in this section.

4 Time as the "great informer"

Callender (2008) makes a closely related but much more robust attempt to address the fundamental difference between time and space; similarly to Skow, Callender identifies the laws of nature as the key to understanding the distinction. The feature that differentiates time from space, according to Callender, is that time is the "great informer": time is the direction in the manifold in which the greatest amount of information can be generated by the smallest set of antecedent conditions. This sort of informativeness – "generating some pieces of the domain of events given other pieces" (Callender, 2008, p.3) – is a hallmark of a good balance between strength and simplicity in a best systems theory of laws, where the goal is to provide as accurate a description of as much of the world as possible in the most succinct manner.[1] Thus, for Callender, "time is that direction in spacetime in which we can tell the strongest or most informative stories" (Callender, 2008, p.4).

To understand how effective Callender's maxim is at distinguishing time from space, we can consider these notions of strength and informativeness in terms of how much of the actual world some system of laws manages to imply. While a deterministic system (i.e. one that generates the world completely) is the strongest such system, indeterministic systems can be strong too (in particular, Markovian systems of laws). But, as Callender points out, a formal characteristic of a system of laws that turns out to be even stronger *for us* than determinism is that the system comprises a 'well-posed Cauchy problem'. Let us be explicit about what this means.

Cauchy problems are characterised by seeking out a solution to a dynamical equation (usually a partial differential equation (PDE)) given antecedent data (so-called Cauchy data) specified on a hypersurface in the domain of the solution (in our case, the manifold). The problem is 'well-posed' if a solution (i) exists for any possible antecedent conditions, (ii) is unique, and (iii) changes continuously with the antecedent conditions. This latter condition is relevant for understanding the qualifier '*for us*': small errors in specifying the antecedent conditions lead only to small errors in our determination of the subsequent dynamics. So, for creatures such as us with the sorts of practical concerns we have regarding what sort of information we are interested in, plus the limitations we are under with respect to the information we are capable of gathering, the most informative dynamical laws appear to be well-posed Cauchy problems. Thus, for us, well-posed Cauchy problems tell the most informative stories.

The next step in Callender's argument is that, given that very many of our most important dynamical laws are second-order linear PDEs, only a specific subclass of second-order linear PDEs admit well-posed Cauchy problems – hyperbolic PDEs. This is important for Callender's argument because, mathematically, hyperbolicity places certain restrictions on the kind of boundaries that can be used to solve such differential equations. Part of the reason for this is

[1] See Lewis (1983, 1994) for an outline of the best systems approach. Note that Cohen and Callender (2009) have recently offered a new version of the theory (see also Schrenk (2014)), according to which there are many best systems, each indexed to a particular use of expressive resources (which, in turn, is linked to the domain of science in which the best system is being developed). The possibility of multiple best systems may make Callender's position hard to sustain, since there may be a best system in which space and not time is the great informer. Presumably, however, Callender will maintain that the best system associated with fundamental physics is the system that should tell us the fundamental difference between time and space, if there is one.

that any physical signals that emerge from the solution to a Cauchy problem must propagate in accordance with the hyperbolic dispersion relations of the relevant differential equation, and doing so endows the solution with a causal structure (in a sense, solutions 'evolve causally' from the antecedent boundary). Accordingly, physical solutions to well-posed Cauchy problems must respect this causal structure and thus only certain types of antecedent conditions will be able to accommodate such solutions. It just so happens that the appropriate antecedent conditions that respect this structure, and thus admit solutions to well-posed Cauchy problems, are *spacelike* hypersurfaces. So only hyperbolic PDEs admit well-posed Cauchy problems, and hyperbolic PDEs pick out a causal structure such that their admissible antecedent conditions are spacelike, and thus what we interpret as evolution must happen in a direction normal to these surfaces.

When we put all this together we see that, since well-posed Cauchy problems tell the most informative stories, the most informative stories are told in a direction normal to spacelike hypersurfaces. Since we have identified time here as the direction in which we tell the most informative stories, time must be the direction normal to spacelike hypersurfaces. Thus, "well-posed Cauchy problems pick out temporal directions" (Callender, 2008, p.7).

While we are largely in agreement with Callender's account concerning the distinction between time and space, we would like in the next section to identify and discuss what we take to be places of potential weakness.

5 'Drawing' a distinction?

It seems that Callender has managed to provide a much stronger connection than Skow between the laws of nature and the distinction between time and space. According to the best systems account of laws, the laws of nature are those that satisfy the trade-off between simplicity and strength. While it may certainly be possible that there are dynamical laws that are informative in a spatial direction, Callender's claim is that such laws simply would not be included in the best systems account since they could not be as simple or as strong as well-posed Cauchy problems (which pick out the temporal direction as the direction of evolution). So for Callender the difference between time and space is that time, as opposed to space, can be used to build simpler laws of nature that give maximal information about spacetime. Thus the first minor point that we would like to make is that Callender's position is not quite that time is the 'great informer' – it is not implausible that space be just as great an informer but still not be included in the best systems account – his claim is that time is the simplest or most efficient way of informing via law.

So the key to Callender's argument is that there cannot be laws that inform across space that are more simple (and just as informative) than our laws that inform across time. Put this way, one can see an area of overlap between Callender's account and Skow's. Given scant antecedent data of the sort that would be required for laws to inform across space (such as is depicted in Fig.1(ii), for instance), it seems likely that strong informative laws would need to be overly complex. If there were to be spatially directed laws simple enough to compete with temporally directed laws on a best systems account, then it had better be the case that antecedent data of a similar dimensionality to a spacelike hypersurface be required to make the spatially directed laws maximally informative. But *we* rarely (if ever) have access to this sort of antecedent data, so in this sense spatially directed laws will in all likelihood be less simple than temporally directed laws *for us*.

The question remains, however, whether this distinction between time and space with regards to the simplicity and strength of laws in each of the directions indicates a fundamental difference between time and space themselves, or simply reinforces that we have a vastly different relationship to the two directions in our experience of the world. There are two points that we would like to make in accordance with this question. The first concerns the possibility that we already have at least some laws that look to be spatially directed – for instance, the example from classical electromagnetism from the end of §3. While we noted there that this case provides a clear counterexample to Skow's arguments, there is good reason to be sceptical of grounding a strong nomic symmetry between space and time on cases like this one. Even for classical action principles of the sort found in electromagnetism, time and space cannot be treated as identical. The reasons for this are essentially those given by Callender (2008, p.9). For a start, the metric signature of time differs from that of space, and we can take this to be an expression of the hyperbolicity of field theories like electromagnetism. And, as we noted above, hyperbolic equations pick out a causal structure wherein the admissible antecedent conditions are spacelike. When we further note that there is no general theory for existence and uniqueness of solutions to boundary value problems with timelike antecedent conditions (which, recall, are two of the conditions for well-posedness), the possibility for timelike Cauchy data looks rather slim.[2]

Be that as it may, there is no reason yet to suppose that the lack of well-posed Cauchy problems with timelike antecedent boundary data is due to some deep mathematical asymmetry between time and space. At least, if there is such a deep asymmetry, it has not been discovered. The lack of existence and uniqueness theorems in particular may be entirely due to the manner in which the antecedent data available to us is impoverished in important respects: it is not usually the case that we have timelike antecedent boundary data available to us and this could very be why no existence or uniqueness theorems for Cauchy problems across space have been produced. If we were in a position to have access to the right sort of data more generally, those theorems may indeed be forthcoming.

In light of this, there is a possible, albeit somewhat speculative, critique that might be levelled at Callender's position concerning the distinction between time and space. Callender repeatedly refers to creatures like 'us' when discussing the strength and simplicity of temporally directed dynamical laws. We have seen that this strength and simplicity is closely connected to the nature of the antecedent conditions needed by the laws. One might therefore argue that the distinction between time and space based on informativeness has more to do with the availability of information for us, rather than any deep fundamental difference between time and space themselves. The story would look something like the following. Due to some feature about ourselves, we live and have access to data exclusively on spacelike hypersurfaces, one at a time. Since we are constrained to such hypersurfaces we can only hope to predict

[2]Although, see Weinstein (2008) for an exploration of existence and uniqueness of solutions to boundary value problems with timelike boundaries.

data on other spacelike hypersurfaces, and we have developed scientific practices that reflect this. It then turns out that the best, most efficient, and most informative models developed by these scientific practices admit only antecedent data on spacelike hypersurfaces. We might conclude that there is something fundamentally special about the direction normal to this antecedent data, that singles it out from amongst the other directions. But we might also conclude that what makes this direction special is not fundamental at all, but is a function of our special epistemic vantage point from within the manifold. Because we have exclusively spacelike information available to us, then for us limited beings the laws that are simpler for us are the ones that inform in what we call the temporal direction. (And it would be no coincidence that this aligns with the metric signature of time, since this is part of the same scientific model expressing the casual structure that we see from our limited vantage point.) We simply do not have access to the sort of information that would allow us to build models that inform in some spatial direction. Perhaps if we had greater access to timelike information then we could develop dynamical laws in a spatial direction that were just as simple and strong as our current laws in the temporal direction. There would then be no deep difference in complexity between the two kinds of law, and no deep difference between time and space.

In short, the difference between time and space that Callender has isolated may be merely perspectival; a function of the epistemology of beings like us. The fact that timelike Cauchy data appears hard to come by may be nothing more than a reflection on the way in which we gather information, and the way in which we exist. For one of Kurt Vonnegut's Tralfamadores – four-dimensional beings who see the past as a valley to descend into and the future as a mountain to climb – timelike Cauchy data may be commonplace. There is pressure on Callender to rule out the perspectivel interpretation of his account. There are many differences between time and space that are merely perspectival: we arguably experience time, and not space, as flowing; it seems to us as though other places exist, but not other times; we cannot experience everything in space at a time but we can experience everything in time at a particular spatial location (longevity permitting); and so on. Each of these might mark a difference between time and space, but each is due to our epistemic limitations as beings, or due to contingent facts about our psychology. Because many differences between time and space are merely perspectival in this manner, we need some assurance that the difference Callender identifies is not just one more.

To sharpen the problem somewhat, consider that there could be beings who live under the following epistemic limitation: they are just like us except that they do not have, available to them, all of the information about space at a time. In other words, the spatial information available to them is impoverished in a manner that is analogous to the way in which the temporal information available to us is impoverished. Suppose that such beings go on to try to formulate dynamical laws of nature. They would presumably not be able to come up with much. According to whatever they do come up with, however, space and time are likely to be equally poor informers. That is because well-posed Cauchy problems that enable extrapolation across time would be just as hard to come by as well-posed Cauchy problems that enable extrapolation across space. Such beings, then, would conclude that there is no difference between time and space, at least if they accept Callender's account of the difference between the two.

Now, Callender's view has to be that these beings are mistaken. That they see no difference between time and space is merely a function of the epistemic limitations under which they labour. But if that criticism is on target, then we need to know why *we* are not also mistaken. What reason do we have for thinking that our apparent detection of a difference between time and space is not merely a function of the epistemic limitations under which we labour? Callender does not appear to supply one. Of course, he might conclude that such beings are not mistaken. They are correct to believe that, in their world, time is no different from space. But this raises another problem. Plausibly, if time is different from space in a certain respect, then *necessarily* time is different from space in that respect. After all, what we are trying to do is come up with a plausible conceptual analysis of the difference between the two. That analysis should tell us the necessary features of that difference. If, however, we conclude that the beings under consideration – who have poor information about space available to them due to epistemic limitations – are equally correct in their assessment about the difference between time and space, then it is possible that time does not differ from space with respect to the informativeness of the dynamical laws. This is possible, because such beings are clearly possible.

In order to rule out the case just considered, we would need some reason to think that beings who labour under the relevant epistemic limitations are impossible. Rather, all beings, regardless of their epistemic situation, will always come up with a system of laws in which time, and not space, is the great informer. Moreover, notice that such an explanation cannot appeal to necessary facts about epistemic agents, for this certainly will collapse the distinction between time and space being offered into something that is merely perspectival. If the reason why time is always the great informer is ultimately to be explained in terms of necessary limitations on epistemic beings, then it is clear that the difference between time and space being identified has more to do with beings like us than anything else.

This last point raises a further issue for Callender, which is the second point we wish to raise concerning the question of the fundamentality of the difference between time and space. Suppose that the laws that inform across space are indeed more complex than the laws that inform across time, as Callender claims should be the case. One is left to wonder why this should be so. There appear to be two candidate explanations. First, the difference in complexity could be entirely due to the antecedent data being fed into the laws; there is no deep mathematical asymmetry between time and space that underwrites the difference. If that's the right explanation, however, then it really does look like the difference between time and space is due to the availability (or lack thereof) of certain information to us. Given the right information, well-posed timelike Cauchy problems across space should be statable. Or, at least, we have no reason yet to think that this is not so, and thus that the difference between time and space that Callender points to would persist were our epistemic situation to be massively enriched with timelike data. Second, the difference in complexity could be due to some hitherto unknown deep asymmetry in the mathematics. This is better: it would rule out the epistemic interpretation. But it faces a further concern: whatever that asymmetry consists in, surely *that* is the thing that's marking the difference between time and space. For whatever that asymmetry is, it ultimately explains why time and not space is the great informer.

Either way, Callender has not identified a fundamental difference between time and space. Either he has identified a difference that can be sheeted home to our epistemic situation or he has identified a difference that can be sheeted home to some more fundamental mathematical asymmetry, an asymmetry that deserves to be drawn out, explored and understood. In other words, it is difficult to see what basis there could be for the conjecture that time is the great infomer except thinking that there is some fundamental difference between time and space that forces the increased nomic complexity of laws that govern the evolution of the world over space. But then that factor – whatever it is – is the true difference between time and space; the complexity of the most informative laws is just a symptom of that underlying factor.

Callender might respond by maintaining that it is just a brute fact that time is the great informer and not space; there is no further explanation to be had. This might even be expected: after all, if Callender has highlighted a fundamental difference between time and space, then we should not expect there to be an answer to the question of why this difference holds. Our point, however, is that Callender has *not* highlighted a fundamental difference between time and space. He has, rather, highlighted a difference between various types of laws. But what is it about time and space in virtue of which the laws display this type of difference? The worry may be drawn out as follows: a fundamental difference between time and space should be such that it holds even if the laws of nature are different. The difference that Callender has highlighted, however, does not cohere with this basic thought. For if the laws of nature were such that time and space were equally good informers, then the difference claimed between the two would disappear. Of course, Callender might just maintain that it is impossible for time and space to be equally good informers. But then we want to know why this is impossible: what is it about time and space that rules this out? Nothing in Callender's account seems to answer this question. Moreover, any answer to this question would seem to be a better candidate for being the fundamental difference between time and space than Callender's own proposal.

We recognise, however, that there are really two ways of thinking about the relationship between time, space and law. First, it might be thought that time and space exist independently of the laws, and are such that the laws operate *on* time and space. Second, one might claim that all there is to time and space is whatever is enshrined within the laws of nature. If one adopts the second account, then the difference that Callender has isolated will be a merely contingent feature of time and space. For the laws could be different, and if the laws could be different then so too might the difference between time and space. If one adopts the first account, by contrast, then any difference between time and space that appears in the laws of nature will not be a fundamental difference. Rather, that difference will be a symptom of a metaphysically prior difference between time and space themselves. But then it is that difference that we want to know more about.

6 Final thoughts

If one is of an optimistic bent, then perhaps what we have said can be seen as providing a way forward for Callender. He might simply maintain that time and space are nothing over and above the laws of nature and just accept that the difference between time and space is a contingent difference. Time and space possibly differ from one another in other ways or not at all. While the position is certainly a coherent one, we are doubtful that it is the position that Callender was aiming for and, as already noted, it is not in line with the goal of conceptually analysing time and space. A better solution, perhaps, is to maintain that time and space are distinct to the laws, and then give some explanation for why it is that time is the greater informer, and not space. What is difficult about this task – and may even render it impossible – is the onus to provide an explanation that unbinds the features of time that make it the great informer from those features that are merely a function of our special epistemic vantage point in spacetime.

References

Callender, C. (2008). What Makes Time Special. Foundational Questions Institute *The Nature of Time* Essay Contest. fqxi.org/data/essay-contest-files/Callender_FQX.pdf.

Cohen, J. and Callender, C. (2009). A Better Best System Account of Lawhood. *Philosophical Studies* **145**: 1–34. doi:10.1007/s11098-009-9389-3.

Lewis, D. (1983). New work for a theory of universals. *Australasian Journal of Philosophy* **61**(4): 343–377. doi:10.1080/00048408312341131.

——— (1994). Humean Supervenience Debugged. *Mind* **103**: 473–490. www.jstor.org/stable/2254396.

Schrenk, M. (2014). Better Best Systems and the Issue of CP-Laws. *Erkenntnis* **79**: 1787–1799. doi:10.1007/s10670-014-9642-9.

Skow, B. (2007). What Makes Time Different from Space. *Noûs* **41**(2): 227–252. doi:10.1111/j.1468-0068.2007.00645.x.

Weinstein, S. (2008). Many Times. Foundational Questions Institute *The Nature of Time* Essay Contest. fqxi.org/data/essay-contest-files/Weinstein_FQXI2.pdf.