Metaphysics and Relativity[1] Katherine Hawley, University of St Andrews

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Isaac Newton gave us a theory about how objects move, forces interact, and gravity operates. Centuries later, Albert Einstein transformed physics, first with his Special Theory of Relativity and then with his General Theory of Relativity. Special Relativity (SR) tells us how objects move when they are unaffected by gravity; General Relativity (GR) generalises the account to include gravity.

According to SR, Newton was more-or-less right about how objects move at ordinary speeds: that's why his theory was successful for so long, and why it continues to be useful. But SR comes into its own when accounting for the surprising behaviour of objects moving near the speed of light (300 000 kilometres per second, or 186 000 miles per second). Despite ignoring gravity, SR in its turn is usually successful: this is because, as GR tells us, over shortish distances gravity has much less influence than other forces. But GR comes into its own when accounting for the surprising nature of the universe on the grand scale, where local forces become negligible, and gravity is crucial.

Why should metaphysicians take a particular interest in all this? Modern physics has many specialist sub-fields, including biophysics, geophysics, quantum cryptography and the study of chaotic systems, but these typically do not feature in a *Companion to Metaphysics*: why do theories of motion and gravity raise distinctively philosophical issues?

The theories of relativity show how motion and gravity are deeply connected with the fundamental nature of space and time. As we will see, SR threatens our ordinary distinctions between past, present and future, whilst GR suggests that space and time are not just the neutral stage upon which events take place, but are themselves actors in the drama. Questions about space and time, and about the persistence and motion of material objects have always been central to metaphysics; many of the great philosophers – Aristotle, Descartes and Leibniz for example – contributed significantly to what we now think of as the science of physics, whilst some of the greatest physicists – including Newton and Einstein – thought deeply and philosophically about the metaphysical nature of space, time, force and motion.

This is a realm in which it can be difficult to draw a sharp distinction between metaphysics and physics. It can be difficult to know what is a matter of straightforward empirical fact, and what is a matter of legitimate philosophical disagreement: how much philosophy is built into the usual understanding of the physics? We are travelling through border country, and will need our wits about us.

1. Special Relativity

1.1 The Relativity of Simultaneity

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From a metaphysical point of view, the most significant consequence of SR is the *relativity of simultaneity*, the idea that, for many pairs of events, there is no objective fact of the matter as to whether the events occurred at the same time, or different times. It is not just that we can't find out whether the events happened at the same time – sometimes there is simply nothing to find out. Or so the usual story goes.

Suppose I am sitting in the middle of a moving single-carriage train, and I throw two balls at the same time with the same effort in two different directions, towards the driver at the front of the train and the guard at the back. We would expect the balls reach the guard and the driver at the same time: after all, they each have the same distance to travel, and I threw them at the same speed.

What does this look like from the ground outside the train? From this perspective, the train carries the guard forward to meet the ball I throw at him. The other ball has further to travel, since the train is carrying the driver away from it. But nevertheless the guard and the driver get bumped on the head simultaneously, because the ball I throw at the driver travels faster than the one I throw at the guard: it is already travelling quite fast in that direction, because of the motion of the train, and my throw only increases its speed. (This addition of velocities explains why jumping from a moving car is more painful than stepping out of a stationary one.)

Commonsense tells us that how fast each ball is moving depends upon our frame of reference: from the frame of reference centred on the train, each ball has the same speed, while from the frame of reference centred on the surrounding countryside, the balls have different speeds. No puzzle there. But experiments show that light violates this commonsense principle: it travels at the same speed with respect to every non-accelerating frame of reference, as does other electromagnetic radiation, like X-rays, infra-red and radio waves.

Suppose I send a radio message to the driver at the front and to the guard at the back. From my perspective – the frame of reference centred on the train – the driver and the guard receive the message simultaneously. After all, their message each have the same distance to travel, and each travels at the same speed.

What does this look like from the ground outside the train? From this perspective, the train carries the guard forward to meet his message, and carries the driver away from hers. But the driver's message doesn't travel any faster than the guard's: like light, radio signals travel at the same speed with respect to every non-accelerating frame of reference. The driver's message travels further, at the same speed, so it arrives after the guard's message.

According to the frame of reference centred on the train, the messages are received *simultaneously*, but according to the frame of reference centred on the surrounding countryside, the guard's message is received *before* the driver's message. (And suppose you are on a train overtaking mine: from your perspective, my train is moving backwards, the driver is moving towards her message and the guard moving away from his, so that the guard's message is received *after* the driver's.) Are the messages received simultaneously? Different frames provide different answers to this question, and SR gives us no reason to take any one frame of reference to be more fundamental than the others.

This relativity of simultaneity does not apply to all pairs of events. If two events happen simultaneously at the same place – like the events of my sending a signal to the driver and my sending a signal to the guard – then they are simultaneous with respect to every non-accelerating frame of reference. Moreover, if there is time to send a signal between two events, then their temporal order is fixed: there is no frame of reference according to which the guard receives his message before I send it. Nevertheless, there are plenty of events whose temporal order is frame-dependent.

Pre-relativistic commonsense suggests that we can classify events by the time at which they occurred. In principle at least, I could write down the sequence of events which make up my life history, one on each page of a notebook, then fill up the rest of each page with all the other events which were going on at that time. For example, as I was being born, Elvis was playing Las Vegas, and a Neil Young live album was announced in New York. But the relativity of simultaneity undermines this picture. Although there is a frame of reference according to which all these events occurred simultaneously, there are other frames according to which Elvis's show was over before I was born, and others in which I was born before his show began. SR gives us no grounds for picking one privileged frame, no grounds for preferring one division of events into 'simultaneity groups' rather than another.

1.2 Past, Present and Future

The relativity of simultaneity seems to undermine the distinction between past, present and future. After all, which events are present *now*, as you read this paragraph? Well, all those events, near and far, which are simultaneous with your reading this paragraph. If simultaneity is a frame-dependent matter, then whether some distant event is past, present or future is also a frame-dependent matter.

This poses a problem for metaphysical theories which give particular significance to the distinctions between past, present and future. (Cross-ref chapter on time.) Perhaps the most radical of such theories is *presentism*, the view that only presently existing objects and events are real. For presentists, temporal distance has a significance that spatial distance does not. Spatially distant objects and events on the Moon are less accessible to me than are the ones here in my office, but nevertheless Crater Tycho exists as fully as my desk does. We might say that Crater Tycho does not exist here in my office, as a way of saying that it is not located here, but this doesn't mean the crater is somehow unreal. In contrast, for presentists, temporally distant objects and events which do not exist now simply do not exist at all.

Other philosophers, whilst they accept that past and future objects and events exist, believe nevertheless that there are objective, metaphysical differences between these: events change as they move from the future, through the present, and on into the past.

The relativity of simultaneity looks like a major problem for all these theories, though I shall focus on presentism in what follows. If there is no frame-independent fact of the matter about which events are simultaneous with your reading this paragraph, then there is no frame-independent fact of the matter about which events are now present. So, according to presentism, there is presumably no frame-independent fact of the matter about what exists.

How can presentists respond? The most drastic option is to give up thinking that all present events and objects exist and focus only on I-here-now: after all, there is no indeterminacy about what is happening right here, right now. This is self-centred in the extreme.

A slightly less drastic option is to stick with the idea that only what is present exists, accept that presentness is frame-dependent, and so conclude that which events have the special status is a frame-dependent matter. This might not sound too bad, but it is important to understand how strange this view really is. First, a frame of reference is not a rich conceptual scheme, a culture or worldview, it's just a possible set of coordinates, like latitude and longitude. Second, frames of reference are multitudinous. A frame is often introduced by mentioning an object (e.g. a train) which is stationary with respect to it. But that is just a matter of convenience: there can be a frame of reference even if nothing is stationary with respect to it, just as there can be a viewpoint in the mountains even if nobody is standing there looking out. Right now, you are in many, many, *many* frames of reference, with a different velocity in each (and thus you have many different 'takes' on what's present).

To soften the blow, presentists might argue that, although there's no privileged frame of reference underpinning objective, universal facts about simultaneity, there is at least a privileged frame of reference for you right now – the one according to which you are stationary right now. But even this slightly more modest view has peculiar consequences. Suppose you are on the station platform, and I travel past in a train; our eyes meet, and our hearts flutter. Because we're at rest according to different frames of reference, some events which are present-with your heart flutter are not present-with mine: suppose the bellow of a bison in Boise is one of these events. If presentism is correct, then the bellow exists-with your flutter but does not exist-with mine. So my flutter and the bellow both exist-with your flutter, but my flutter and the bellow do not exist-with each other. This might make you question whether we're still discussing existence: we might have expected existence-with to be *transitive*, to use the jargon.

None of these options for presentism look very promising, especially if presentism is supposed to vindicate our ordinary ideas about the passage of time and the immediacy of the present. (A further option is to look beyond SR for empirical evidence of a privileged reference frame; more on that story later.)

Faced with these problems, some presentists have questioned whether their metaphysical claims can be really be refuted by a scientific theory. SR tells us that simultaneity is frame-relative, and that the laws of physics do not pick out one frame as being more fundamental than all the others. We could accept this yet still wonder whether there might nevertheless be a privileged frame of reference, one which is undetected by the laws of physics. This frame would have no empirical, scientific significance, but could be the ground of unique, objective simultaneity, and thus, for the presentist, unique, objective facts about what exists.

Accepting SR does not logically compel us to give up the idea of a privileged frame of reference. But many people – both philosophers and physicists – think that the philosophical reasons to believe in such a frame are far outweighed by our empirical grounds for thinking it does not exist. Why? First, there is the idea that if there were

a privileged reference frame, this would show up in our best scientific theories: unlike, perhaps, God, beauty or morality, this is just the sort of thing you'd expect science to tell you about. Second, there is the idea that an empirically undetectable distinction between past, present and future, whilst not incoherent, cannot form the basis of a philosophical theory which is supposed to explain or vindicate our pre-theoretical ideas about time and existence. To this, presentists may respond that worries about the relativity of simultaneity only arise over very long distances or very short periods, so it is no wonder that our pre-theoretical ideas about time and existence are not sensitive to these concerns.

The relationship between presentism and special relativity is fraught but fascinating. The nature of time and existence are themselves central philosophical concerns, of course, but this debate is also a battleground for methodological issues about human knowledge: what is the relationship between science and philosophy, between the empirical and the *a priori*? Above all, can we infer that something – like a privileged reference frame – does *not* exist from the fact that it is *not* mentioned in a successful scientific theory?

1.3 Persistence and the Relativity of Simultaneity

How do material objects persist through time? (cross-ref chapter ##) Or, as it is often put, how can a single object exist at several different times? Perdurantism is the view that material objects persist through time by having different temporal parts at different times, just as they extend through space by having different spatial parts in different places. In contrast, endurantism is the view that material objects persist through time by being wholly present at each of several times. For endurantists, temporal persistence is quite different from spatial extension.

In their standard formulations, both perdurantism and endurantism presuppose that persistence is a matter of existing – somehow or other – at more than one moment in time. But what is a moment in time? Commonsense suggests that we can divide history into groups of simultaneous events, events which happen at the same moment. Yet the relativity of simultaneity undermines this picture, and thus the very notion of a moment: the grouping (or 'foliation') of events differs according to different frames of reference. How does this affect perdurantism and endurantism?

As usually formulated, perdurantism invokes a distinction between spatial and temporal parts, a distinction which is undermined by the relativity of simultaneity. But the theory is also a species of 'four-dimensionalism', the view that objects are stretched out through the four dimensions of spacetime, not just the three dimensions of space. Given relativity, the claim that persisting objects are four-dimensional becomes more fundamental than the claim that they have temporal parts. Talk of temporal parts and spatial parts can be replaced by talk of spatiotemporal parts, and then the claim that a persisting object has a different temporal part at every time at which it exists can be replaced by the claim that it has a different spatiotemporal part for each part (or 'subregion') of the whole region it occupies. Which of these are temporal parts – rather than spatial parts – is a frame-dependent question.

What about endurantism? It certainly looks as if, unlike perdurantism, endurantism presupposes a significant distinction between space and time, a presupposition which is threatened by the relativity of simultaneity. But philosophers have disagreed about

whether this is a fatal problem for endurantism, or whether there is a way of adapting the theory to fit with special relativity.

Endurantism is a 'three-dimensionalist' theory: it claims that objects are stretched out in the three dimensions of space, but move in their entirety through time. The pre-relativistic picture is that an enduring object 'sweeps out' a four-dimensional region by being successively wholly present at each momentary subregion of it; in contrast, a perduring object would simply fill up the whole four-dimensional region. In this respect, enduring objects are like universals (cross ref ###), which are wholly present in each of several different locations.

The difficulty is to specify what counts as a 'momentary' subregion of an enduring object's four-dimensional region, given the relativity of simultaneity. One promising option is to acknowledge that which subregions are momentary is a frame-dependent matter, but claim nevertheless that an enduring object is wholly present at any subregion which is momentary according to some frame of reference or other. On this account, an enduring object is not wholly present at every subregion of its four-dimensional region: some subregions will be temporally extended according to every frame of reference. Other subregions will be momentary according to some frame of reference, yet, intuitively, be occupied by a spatial part of the enduring object, not by the whole object itself.

If we adopt this notion of endurance, enduring objects are wholly present at very, very many different subregions of their four-dimensional region, and many of those wholly-occupied subregions will intersect with one another. This picture does not seem incoherent, but it does raise questions about the initial motivations for endurantism, just as relativity-friendly versions of presentism raise questions about motivations for that theory. Endurantism begins with an apparently natural picture of spatially-extended objects sweeping majestically through time, and it can be hard to recognise that natural picture in this story of multi-location.

2. General Relativity

Gravity is what makes the apple fall down from the tree, what enables us to step outdoors without flying off into space. Magnetic forces draw the compass needle towards the pole, and we might think of gravity as a force which draws material objects towards each other, affecting the way they move. Newton told us that the strength of the gravitational attraction between two objects depends upon how much mass each has, and how far apart they are (the less their mass, or the further apart they are, the less the mutual attraction).

This pre-relativistic story takes gravity to be a kind of direct connection between spatially-distant objects, a connection which is somehow generated by their mass, and which pushes or pulls the objects in one direction or another. Einstein's General Theory of Relativity (GR) replaces this picture with one according to which an object's mass has an impact on the shape of space itself, and thus, indirectly, on the ways in which other objects move about in space.

It can be difficult to imagine space itself having a shape, partly because 'shape' often means 'outline', and it is hard to see how something could have an outline unless it is an element of a bigger system. But we can begin to grasp the idea by thinking about

the shape of a two-dimensional surface, like a trampoline. Initially, the trampoline is flat, with two parallel lines running from one end to the other. If we mark three different points on the trampoline, and connect each point to the other two using straight lines, the resulting figure is an ordinary triangle, with internal angles adding up to 180°. If we place lightweight table-tennis balls at random onto the trampoline, they will lie scattered across the surface. Now suppose we place a heavy bowling ball onto the trampoline, stretching out the material and creating a deep well. What happens? The lightweight balls roll down into the well, gathering together at the bottom. The triangle is distorted, and its angles no longer add up to 180°. The parallel lines are no longer parallel; the one nearer the well is more severely affected than the other.

We observers see this as a change in the three-dimensional shape of the two-dimensional trampoline. But the change would also be apparent to creatures living on the surface itself. Having been surprised by a sudden convergence of table-tennis balls, an ant would find that parallel lines now look divergent, that it has further to travel to get from one side of the trampoline to another, and that what used to be a detour may now be the shortest path (one which avoids the bottom of the well)

In respect of our own four-dimensional spacetime, we are like ants, not trampolinists: we cannot step outside and observe the varying shape of spacetime, but we can observe how objects move, and make other measurements which confirm Einstein's theory of gravity.

2.1 Relativity of Simultaneity Again

Faced with the fact that SR does not isolate a privileged perspective on simultaneity, some presentists have hoped to find a privileged reference frame in GR. (Endurantists who are uncomfortable with the 'relativistic' version of their view might share this hope.) Cosmologists using GR believe that the universe is expanding, and that the distribution of matter everywhere is becoming less dense as a result of this expansion. This seemingly-inexorable move from denser to less dense gives us the option of taking events to be simultaneous if they occur in regions of equal density.

This strategy for rescuing presentism and straightforward endurantism raises two important issues. First, the expansion of the universe is thought to be a contingent fact. There are other ways things might have turned out – consistent with GR – according to which the universe is in a 'steady state'. Are presentism, endurantism and absolute simultaneity therefore contingent facts about the world, not even physically necessary? Or is the expansion perhaps a contingent empirical sign of an underlying necessity? Second, it is not clear whether this highly-sophisticated idea from fundamental physics can really vindicate the commonsense ideas about time and persistence upon which presentism and endurantism are supposed to be built. (This is very like the question I raised at the end of section 1.)

2.2 Substantivalism and Relationalism

Metaphysicians have long argued about whether space and time are entities in their own right, or whether they are mere abstractions from concrete objects and events. Could there be space and time if there were no objects and nothing ever happened? There is consensus that, given relativity, we can no longer talk about three-dimensional space and one-dimensional time, and must instead talk about four-

dimensional spacetime. But there is no consensus about whether GR favours substantivalism, the view that spacetime is a genuine entity, or relationalism, the view that spacetime is nothing over and above the events occurring in it. (cross-ref chapter on space)

As we have just seen, GR invokes the shape of spacetime itself to explain why objects move as they do, why the apple falls, why we can walk around on the surface of the Earth. Spacetime is no longer just an inert, neutral backdrop against which objects and forces interact, it is an element in that interaction. In this way, GR points towards substantivalism about spacetime.

Yet, as we shall shortly see, the 'hole argument' points in the opposite direction, indicating that substantivalists are committed to the existence of physical facts which go beyond anything required by GR. (In this respect, the hole argument is like the argument against presentism from the relativity of simultaneity, according to which presentists are committed to facts which go beyond anything required by SR.)

Suppose you had to describe the room you're in right now. You could describe the various objects in the room, and then describe how they are related to each other ('there's a monkey and a toy car, and the monkey is sitting in the car'). Asked to describe the whole universe, we could say 'there's a bunch of spacetime points, they have such-and-such spatiotemporal arrangement, and matter and energy are distributed amongst them thus-and-so'. The bunch of points is the 'manifold', their spatiotemporal arrangement is the 'metric', and the distribution is the 'matter field'. GR tells us how the metric is related to the matter-field, how the shape of spacetime is related to the distribution of objects.

Now, how does the traditional substantivalism-relationalism debate translate into these terms? What do substantivalists affirm and relationalists deny? Perhaps substantivalists should claim that the manifold of points exists independently of the events happening at those points, whereas relationalists should deny this.

If substantivalists rashly accept this characterisation of their position, then relationalists can pounce. Suppose we have the manifold of points, arranged with their metric and their matter-field. Would things have been different if the points had been reshuffled, keeping the metric and the matter field constant? If the points are independently-existing entities, as substantivalists think, then presumably any reshuffle makes a difference. But GR tells us that many reshuffles make no detectable difference at all. The points themselves don't seem to differ in their intrinsic properties: they don't have tiny labels that would enable us to keep track of them if they were switched around. So substantivalists are committed to facts in addition to those recognised by GR – facts about which points are where.

(This criticism of substantivalism is known as the 'hole argument' because, as a special case, the points in a given region – known as the 'hole' – could be reshuffled without affecting what happens before, after or around that region.)

Substantivalists need to reconsider what they are substantivalists about. If they take spacetime to be just the manifold, the bare collection of points, they will be committed to undetectable facts, but they may be on safer ground if they take

spacetime to be the manifold together with the metric, i.e., the collection of points together with the way in which they are arranged with respect to one another. If this more complex entity is replaced by an alternative manifold-plus-metric, this would certainly make an empirical difference.

What sort of entity is a manifold-plus-metric? Different 'sophisticated substantivalists' have developed this idea in different ways, but one option is to think of each spacetime point as having its relations to other points essentially, so that the points exist together in a web of mutual dependence. It seems clear that substantivalists can escape the hole argument in this way.

What's not so clear is whether sophisticated substantivalism is really distinct from relationalism. The more that GR gives a quasi-causal, dynamical role to the manifold-plus-metric, the more difficult it is to draw a line between material things (which relationalists accept) and spacetime itself. What's so special about the spatiotemporal properties of a point, in contrast to its other properties, like those which fix how much mass or charge is there? Why think the spatiotemporal properties of a point are essential to it, whilst its other properties are not?

As we saw with the debate surrounding SR, presentism and endurantism, the collision of ancient metaphysical problems and modern scientific theories can be highly fruitful, even though science rarely gives us a straight answer to a metaphysical question. Substantivalists, presentists and endurantists are all forced to rethink their theories, to consider what motivates them, what is central and what is peripheral to their views. If this rethink does not kill the theories, it may make them stronger.

Further Reading

The *Stanford Encylopedia of Philosophy* (http://plato.stanford.edu/) is a very useful online resource. Relevant articles include 'Being and Becoming in Modern Physics' by Steven Savitt, 'Time' by Ned Markosian, 'Temporal Parts' by Katherine Hawley, 'The Hole Argument' by John Norton, 'Newton's Views on Space, Time and Motion' by Robert Rynasiewicz, and 'Space and Time: Inertial Frames' by Robert DiSalle. Some of these articles are more introductory than others, but all provide useful references both to the general literature and to other articles in the Encylopedia.

Bourne, Craig (2006): *A Future for Presentism*, Oxford: Oxford University Press. Defends presentism, considering both the objection from the SR and the possible impact of GR.

Dainton, Barry (2001): *Time and Space*, Chesham: Acumen Publishing. Introduces a wide range of issues about time and space, including the impact of relativity.

Gibson, Ian and Pooley, Oliver (2006): 'Relativistic Persistence', *Philosophical Perspectives*, 20, pp. 157-198. A comprehensive study of the impact of relativity theory on theories of persistence, with useful references.

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Sartori, Leo (1996): *Understanding Relativity*, Berkeley: University of California Press. A gentle introduction to the physics of relativity.

Saunders, Simon (2002): 'How Relativity Contradicts Presentism', in Callender (ed.) *Time, Reality and Experience*, Cambridge: Cambridge University Press, pp. 277-92. Clear statement of the case against presentism.