432018 PHILOSOPHY OF PHYSICS (Spring 2002)

Lecture 17: Substantivalism *vs.* relationism

Preliminary reading: Sklar, pp. 69-82.

We will now try to assess the impact of Relativity Theory on the debate between Leibniz and Newton about the nature of space. Recall that Newton postulated an absolute space that was (in some sense) 'out there' waiting to be filled by material bodies, whereas Leibniz maintained that space was merely inferred from the collection of all possible spatial relations between material bodies. Of these two positions, 'substantivalism' and 'relationism' respectively, the former seemed to be most plausible at the end of our earlier discussion due to the 'bucket argument'.

But clearly, in order to utilise Relativity Theory and its implications in such a discussion, we now have to talk about *space-time*. As such, we now have to see whether space-time is something which is (in some sense) 'out there' waiting to be filled by *events*, or whether it is merely something that is inferred from the collection of all possible spatiotemporal relations between such events. In particular, we should be wary of prematurely inferring a metaphysical view about the existence and nature of space-time from a scientific theory.

1 Substantivalism *vs.* relationism

Generally, the initial reaction to the Special Theory of Relativity was that Einstein had succeeded in vindicating the relationist. But, this claim should be treated with at least some scepticism and so we start with a warning. Then we shall go on to see what sort of impact Relativity Theory has had on this debate.

Don't confuse 'relativistic' with 'relationist'!

And you shouldn't do this, at least *prima facie*, since all we can really say is:

> In Newtonian physics there are certain features of the world that are 'absolute' which are 'relative' STR.

For example, on Newton's view there is a definite, non-relative, spatial and temporal separation between any two events whereas in STR such spatial and temporal separations can only be defined relative to an inertial frame of reference and they will differ depending on which inertial frame of reference is chosen. Clearly, although this forces us to revise our physical understanding of spatial and temporal separations, relativity in this sense has little to do with the metaphysical question concerning the nature of space and time, or indeed space-time. That is, it is quite clear that the question which concerns us, namely

> In order to account for observable phenomena, must we posit an independently existing space-time, i.e. a structure which exists over and above the material things and the relations between them?

is more subtle than the question being addressed when we consider the kind of 'relativity' indicated above. And, to make this point especially clear, it should be noted that even though some previously 'absolute' quantities become 'relative' in STR, this theory introduces new 'absolute' (i.e. observer independent) features of its own such as the space-time interval which separates two events and the proper time elapsed along a specific path connecting two events.

The 'bucket argument' and absolute accelerations

Earlier we saw that the 'best' argument that was provided for a substantival space was the 'bucket argument'. Indeed, according to Newton, this argument establishes that the *observable* non-inertial effects of rotation could only be explained by positing the existence of an absolute space. Now, we can ask:

> How does this argument fare when we move to a world described by STR? Does it retain its force and lead us to view space-time as substantival or does the problem that it poses for the relationist 'disappear' in this new theory?

Recall that in Newton's argument, the key distinction was between systems which were moving inertially (relative to absolute space) and those that were absolutely accelerated. And, it is quite clear that this distinction also holds in STR where the inertial frames are, as they were in Newton's theory, those in which no inertial forces are experienced. And, they are further distinguished by being the reference frames in which experiments, like the one performed by Michelson and Morley, give null results. As such, in STR it is still possible to decide whether or not a given frame of reference is 'really' accelerating or not, and so it would appear that Newton's argument retains its force in STR.

Is it that simple?

Does this mean that if we accept STR we must adopt the metaphysical position advocated by Newton, i.e. substantivalism, but with Newton's absolute space replaced by a substantival Minkowski space-time? Do we really need a 'space-time itself' relative to which acceleration is absolute and whose existence is postulated as part of the 'best' explanation of the existence of inertial forces and the optical effects that can be used to detect absolute acceleration? Again, we must be wary of jumping from a scientific theory to a metaphysical conclusion. Maybe we could find some way of reconciling STR with a relationist account of space-time.

A relationist response

Newton's 'bucket experiment' can be seen as an inference to the best explanation and relationists have challenged the conclusion Newton drew by questioning whether absolute space adequately plays the required explanatory role. In particular, arguments have been proposed to show that when a substantivalist posits space-time as an entity needed to *explain* the distinction between absolutely accelerated and absolutely non-accelerated motions,

- his approach to the problem is *flawed*, and
- his offered explanations are *spurious*.

Specifically, the substantivalist argues that inertial forces and the optical effects of accelerations can be explained in terms of the acceleration of a system with respect to the 'inertial reference frames' of *space-time itself*, the special relativistic analogue of Newton's space itself. But, as before, these space-time structures are not directly observable and so we only infer their existence from the causal effects associated with motion relative to them. As such, in order to succeed, the relationist only needs to explain all that is to be explained without positing the space-time itself.

Let's see how the relationist's argument could run:

- So, given what we have just said, the relationist wants to explain the difference in observed inertial effects in two different laboratories by only referring to their acceleration relative to one another.
- But, the substantivalist retorts that the relationist can *not* explain why in one such set of frames *no* inertial effects are observed, whereas in other sets they are. That is, why are there some *preferred* laboratories where *no* inertial effects are observed? If the accelerations are just relative, surely we should observe inertial effects in all such accelerating laboratories and not just those which are accelerating relative to the preferred ones? Indeed, the substantivalist can explain the difference, he just takes the preferred frames to be those that are not accelerating with respect to space-time itself!
- But, the relationist can counter this argument by claiming that although he can't explain why one such set of inertial frames is preferred, he can take it to be a 'brute fact'. That is, surely there must be some set of frames where all the effects of acceleration just happen to cancel out, and it just happens to be this one. Indeed, in nature, there are always going to be *some* brute facts and so why can't this be one of them?

- Now, the substantivalist can't reply that he doesn't like brute facts since he utilises them to. For instance, for the substantivalist, it is a brute fact of nature that acceleration with respect to the inertial geodesics of space-time causes the inertial effects. So, the substantivalist seems to be stuck.

- Moreover, at this point, the relationist can reinforce his position with the following points:
  - The substantivalist is no better off in explanatory terms than the relationist. And moreover, the substantivalist needs to posit a mysterious 'space-time itself' which, on the account just given, seems to do no explanatory work at all!
  - Following Leibniz, the relationist can produce a series of arguments to show that the substantivalist view entails other facts (e.g. the [absolute] location in space-time at which a particular event occurs) which have no observable consequences whatsoever. And, recall that such 'differences in theory which give rise to no observational differences' were one of the puzzling features of Newton's original account of space.

However, it is by no means clear exactly who has the upper hand here. Indeed, we can ask ourselves:

- Do we really understand what the substantivalist is claiming we must postulate in order to explain the observable phenomena?

- Do we really understand what the relationist is denying and what he is putting in its place?

In particular, do we really understand the issues on which these two positions differ?

2 Mach's proposal and the General Theory of Relativity

In the nineteenth century, Ernst Mach attempted to reconcile the results of Newtonian physics with the relationist view of space and time. In particular, he noted that:

- the rotation rate of the Earth determined by observing the fixed stars, and

- the absolute rate of rotation of the Earth as determined by purely mechanical experiments that relied on the forces generated by rotation,

were the *same*. This prompted Mach to suggest that the inertial forces might originate from the *relative* acceleration of different material bodies. Obviously, if such a force is to come about due to the relative acceleration of the Earth and the distant fixed stars,[1] it would have to be [pretty much] independent of the distance between the bodies in question and [highly] dependent on their masses. But, if such a force existed, it would provide an alternative explanation of the phenomena which Newton explained in terms of the causal interaction between material bodies and space itself. Indeed, recall that in the bucket argument, which contains an instance of such a phenomenon in need of explanation, one of Newton's premises is that there can be *no* 'action at a distance' force such as the one Mach is proposing. Thus, if such a Machian force existed, then the relationist would be able to deny the conclusion of Newton's most persuasive argument.

However, STR doesn't provide a suitable context for discussing such a suggestion and so we must turn instead to GTR. In this new theory, where gravity[2] is explained in terms of curved space-time, maybe the curvature of the universe as a whole will allow us to develop a Machian theory. That is, a *relationist* theory in which inertial effects can be explained in terms of the *relative* accelerations of material bodies. Indeed, Einstein was certainly motivated by Machian ideas when he began his development of GTR. We shall now consider some of the consequences of a Machian account and then we shall consider whether GTR has the required features.

[1]More specifically, this force is to come about not due to accelerations with respect to the 'fixed stars' *per se*, but with respect to the 'smeared out' (read 'averaged') distribution of the remaining matter of the universe which is approximated by the distribution of the fixed stars.

[2]Note: It is quite clear that gravity can *not* play the role of the Machian force since, at least in its Newtonian form, the gravitational force has little effect over large distances.

(I) Newton's one-body universe — Is a relative acceleration view tenable?

One of Newton's early arguments for the existence of absolute space involves a universe which contains a single material object. Now, let us ask whether this object is rotating or not. Clearly,

- On Newton's view, even though there is no other matter in the universe, we can still determine whether the object is rotating relative to absolute space. Indeed, such rotation would reveal itself due to the inertial effects experienced by this object due to its absolute motion. Thus, there is still a distinction between rotating and non-rotating bodies in a Newtonian one-body universe.
- On Mach's view, there is no other matter for this object to rotate relative to and so there can be no rotation. Furthermore, in the absence of this 'other matter' there is no way to account for any inertial forces that may be experienced. Thus, no distinction can be drawn between rotating and non-rotating bodies in a Machian one-body universe.

However, Mach objects to this argument since the universe is given to us only once 'complete with fixed stars intact'. This is a bit vague and may be expressing:

- the **weak** claim that we have *no way of inferring* what would be the case in a universe radically different from our own, or
- the **strong** claim that the laws of nature are merely 'summaries' of what occurs in this world *as it is* and, as such, it is *meaningless* to talk about universes that are radically different from it.

However, even granting this, we can ask of a theory like GTR, which *does* describe gravity in many different kinds of universe, whether its predictions agree with Newton or Mach on this issue.

(II) Dependence on the matter distribution — Are Machian interactions tenable?

In a Machian universe, the inertial effects are the result of an interaction which depends on the relative acceleration between a system and the matter distribution that surrounds it. As such, a Machian should expect the following effects:

1. The inertial effects experienced by a system will vary if the distribution of matter surrounding the system is radically modified.
2. It should make no difference if we speak of the system rotating and the surrounding matter not rotating, or *vice versa*.
3. It should be absurd to speak of the matter of the universe as being in a state of absolute rotation.[3]

So, does GTR agree with any of these Machian predictions?

GTR — Points for Mach

Einstein's intentions when formulating GTR and early work on this theory indicated that it had Machian aspects. In particular, looking at the questions in (II), it was found that:

1. In GTR, what a system in accelerated motion experiences will be dependent on the general distribution of matter in the universe.[4] As such, radically changing the the amount or distribution of the matter in space-time will have an effect on the inertial forces generated by local motion.

[3] For, if the effects of rotation *are* due to rotation relative to the matter of the universe, then the effects of rotation on the matter of the universe itself should be due to its rotation relative to itself, but this is absurd since nothing can rotate relative to itself.

[4] This is because, in GTR, absolute acceleration is deviation from the *local* curved timelike geodesics of the space-time and this, in turn, is dependent on the *global* curvature of space-time which is correlated with the distribution of matter in the space-time.

2. In GTR, an 'object which is itself at rest surrounded by matter which is rotating' and an 'object which is itself rotating surrounded by matter which is at rest' experience 'similar' forces.

which are in good agreement with our Machian predictions.

GTR — Points against Mach

But, further work on GTR established that it wasn't quite as Machian as the relationist might desire. In particular, even though the inertial effects experienced by an object are modified by changing the distribution of the surrounding matter, it is as though there was a *basic* inertial effect due to absolute rotation to which the 'new' modifying effects were added. That is,

- even in a universe devoid of other matter, GTR predicts a distinction between being in absolute rotation and not.[5]

which goes against what Mach predicted in (I). Furthermore, looking at the questions in (II), we have:

2. Although, as we have seen above, the inertial effects experienced by an 'object at rest surrounded by rotating matter' and the inertial effects experienced by a 'rotating object surrounded by matter at rest' are 'similar', this does not mean that inertial effects are always due to relative rotations as a relationist may desire. For example, in GTR, if we consider the situation in Figure 1 it turns out that, contrary to what Mach and the relationist want, the

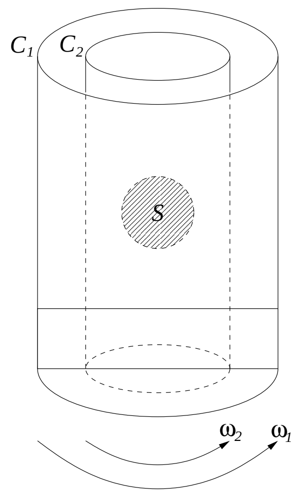

Figure 1: *Consider two cylinders, C_1 and C_2, which are rotating at rates given by ω_1 and ω_2 where $\omega_1 \neq \omega_2$. In turn, these two cylinders are rotating about a material body denoted by S. In GTR, and contrary to our Machian predictions, the inertial effects experienced by S depend on which of these two cylinders is 'really rotating' rotating and not just on their relative rotation.*

forces experienced by S depend on *both* the relative rotation of the two cylinders *and* which cylinder is 'really rotating'.

3. In GTR, we can have the Gödel universe, a situation where *all* the matter in the universe is in rotation. But, the Machian thinks that this is absurd.[6]

So, we can see that these points disagree with our Machian predictions.

[5]This occurs because, in order to determine what space-time is like in a universe described by GTR, we have to specify boundary conditions for it. When considering open universes, the usual boundary condition is that space-time which is far removed from any matter is 'flat' (i.e. not curved). But, flat space-time is Minkowskian (i.e. the space-time of STR), and this is a reasonable space-time for an 'empty' universe. However, as we saw earlier, in Minkowski space-time the Newtonian distinction between absolute and relative rotations still holds!

[6]For more information about the Gödel universe, see Sklar, pp. 78-9.

Who wins?

Consequently, there seem to be a similar number of points for and against Mach in the context of GTR. So, what should we do? Well,

- the Machian can claim, following the gambit discussed in (I) above, that the points against seem to involve the consideration of universes which are radically different from our own. And, as such, they are 'irrelevant'.
- the anti-Machian can claim that physical considerations based around the general applicability of GTR have shown the Machian view to be untenable.

But, this looks suspiciously like stalemate. So, in the next lecture, we shall look at another approach to settling the debate between the substantivalist and the relationist.

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