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Substantivalism vs Relationalism About Space in Classical Physics

Shamik Dasgupta*
Princeton University

Abstract

Substantivalism is the view that space exists in addition to any material bodies situated within it. Relationalism is the opposing view that there is no such thing as space; there are just material bodies, spatially related to one another. This paper assesses this issue in the context of classical physics. It starts by describing the bucket argument for substantivalism. It then turns to anti-substantivalist arguments, including Leibniz's classic arguments and their contemporary reincarnation under the guise of 'symmetry'. It argues that these anti-substantivalist arguments are stronger than is often acknowledged.

Look around you. No doubt you see various material things – cups, tables, chairs – spatially arranged in a certain manner. What is it for them to be spatially arranged? At a minimum, it involves spatial relationships between them: one is three feet from another; one is below another, and so on. But is it also something more than this? Are they also arranged 'within' space, much as goldfish are situated within water?

Substantivalism answers in the positive. It is the view that there really is such an entity as space, in addition to any material bodies situated within it. *Relationalism* is the opposing view that there are just material bodies, standing in various spatial relationships. There is not, on this view, an additional entity in which those bodies are situated.

Which view is correct? This is not a purely philosophical question, for scientific developments – including relativity theory and quantum mechanics – have profoundly impacted the issue. But it is not a purely scientific question either, for the arguments one way and the other quickly lead into difficult questions about realism, explanation, necessity, and knowledge. Indeed, the debate over substantivalism well exemplifies the idea that there is, ultimately, no clear line between science and philosophy.

Here, I outline some of the more philosophical aspects of the debate. To this end, I restrict myself to the debate as it plays out in the context of classical particle mechanics. So, suppose we find out that matter is in fact composed of point particles, with mass and charge, evolving in accordance with Newton's three laws and the familiar force laws (the inverse square gravitational force law and Coulomb's law). Our question is: Should we then be substantivalists or relationalists? The restriction to this sanitized setting is fruitful because it allows us to focus on philosophical issues that also arise almost verbatim in more realistic settings such as General Relativity, but without our having to get sidetracked in various technical complications of the latter. I will indicate how the lessons we learn carry over to more realistic settings as we go along.

After clarifying substantivalism and relationalism in section 1, I discuss arguments for substantivalism in section 2. The rest of the paper focuses on anti-substantivalist arguments, which I believe are a good deal stronger than many contemporary theorists acknowledge. Section 3 introduces Leibniz's classic anti-substantivalist arguments, and sections 4 and 5 discuss their contemporary reincarnation under the guise of 'symmetry'. Sections 6–9 then evaluate these symmetry arguments favorably. But I do not conclude that substantivalism should be rejected, since the pro-substantivalist arguments are also formidable. Instead, I conclude that even in the sanitized setting of classical physics, we have not yet gotten to the bottom of this debate.

1. More on Substanvialism vs Relationalism

I said that relationalism is the view that there is no such thing as space, but that is not entirely accurate. For the relationalist might think that many ordinary statements about space, such as

> The space between the towers of the Golden Gate Bridge is phenomenal to behold.

are true. So she may be said to believe that there is – in a sense – such a thing as space. But still, as a relationalist, she will think that statements like these are ultimately true in virtue of facts about how material bodies, like the towers, are related to one another. Thus, relationalism is more accurately characterized as the view that, insofar as there is such a thing as space, it is 'nothing over and above', or 'dependent on' bodies and their relations to one another. Substantivalism, by contrast, is the view that space 'can be said to exist and to have specified features *independently* of the existence of ordinary material objects', as Sklar puts it (1974, p. 161; my emphasis).[1]

In denying the existence of space as an independent entity, the relationalist does not deny that material bodies are spatially related to one another. Like the substantivalist, she accepts the evident truth that the two towers of the Golden Gate Bridge are 4,200 feet apart. The difference is that, while the relationalist thinks that spatial relations between bodies are basic, the substantivalist thinks that they hold in virtue of where the bodies are situated in substantival space. For the substantivalist, what makes it the case that the towers are 4,200 feet apart is that one is situated in a region of space R_1, and the other is situated in a region R_2, and R_1 and R_2 are 4,200 feet apart. The relationalist, by contrast, offers no such explanation of the fact.[2]

The substantivalist thinks that space exists independently of matter, but it is a further question what the geometric structure of space is – how many dimensions it has, whether it is Euclidean, and so on. Substantivalists can, in principle, offer different answers to these questions. For now, let us focus on the view that space is a three-dimensional, Euclidean object that is infinitely extended in all directions and endures through time. This is known as *Newtonian substantivalism*. Later I will discuss other substantivalist views; until then let us just call this 'substantivalism' for short.

The relationalist faces an analogous question of the geometry of space, though we must take care when asking it. For her, it is not perspicuously formulated as the question of what the geometrical structure *of space* is, but as the question of what geometric patterns can be exhibited by matter. For example, instead of asking a relationalist whether space is Euclidean, we should ask questions like: If one builds a triangle out of three sticks of wood, will its interior angles inevitably add to 180 degrees? The answer 'Yes' corresponds to the substantivalist's view that space is Euclidean. So, a relationalist might *say* that space is Euclidean, but we should understand this as shorthand for a variety of claims about what geometric patterns matter can exhibit. Here, let us focus on the relationalist who says that space is three-dimensional, Euclidean, and infinitely extended (when these claims are suitably interpreted as a shorthand).[3]

2. The Bucket Argument

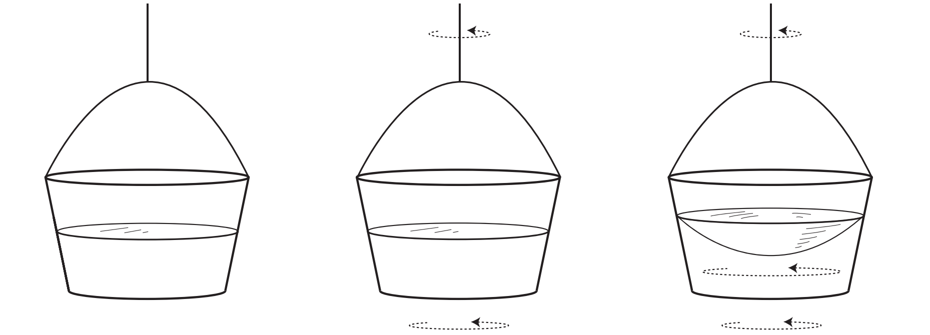
Those are the views. Let us now turn to the arguments, starting with the case for substantivalism.

One argument attempts to read ontology off mathematical physics. Mathematically speaking, the models of classical physical theories consist of a four dimensional set of points, three dimensions for space and one for time, along with various fields or particle trajectories defined on that set. Noticing this, one might conclude that these theories imply the existence of something represented by the points, i.e. substantival space.

This argument presupposes what van Fraassen calls ‘scientific realism’, the view that ‘science aims to give us, in its theories, a literally true story of what the world is like’ (van Fraassen 1980, p. 8).[4] After all, suppose that science just aims to provide useful instruments with which to calculate experimental outcomes, without aiming to state truths about what produces those outcomes. Then it would clearly be a mistake to read ontology off mathematical physics. So, one response to the argument is to reject scientific realism.

But even granting scientific realism, the argument should not convince as it stands. When mathematics is used in physics, we should distinguish those aspects of the mathematics that are genuinely representational from those that are mere artifacts of the formalism. Consider our representation of temperature. If A is 100°C and B is 50°C, we should not infer that A is twice as hot as B, since in the Fahrenheit scale their ratio is different: A is 212°F and B is 122°F. The ratios between real numbers do not signify anything here; they are mere artifacts of the mathematics. The lesson is that even the scientific realist should not naively read reality off the mathematics of a scientific theory, since some of the mathematics may not be genuinely representational. This lesson applies equally to questions of ontology: even if the models contain a set of points, it is a further question whether those points genuinely represent substantival space.[5]

How then should a realist argue that some part of the mathematics represents something real? A typical strategy is to show that, if it did, this would best explain some observed phenomena.[6] The most influential line of argument for substantivalism, devised by Newton, takes exactly this form. The observed phenomena are the behaviors of *accelerating* bodies. Newton illustrated this behavior by hanging a bucket of water on a rope, winding the rope up, and then letting it go. If you do this, the bucket starts spinning, and after a bit the water spins too. As the water spins, it climbs the sides of the bucket and takes on a concave shape – see Fig. 1.[7]



State 1: The bucket and water are both at rest. The rope is wound up, ready to be released.

State 2: The rope is released and the bucket starts spinning. The water remains at rest.

State 3: The water starts spinning with the bucket, and goes concave.

Fig. 1. The Bucket Argument.

Why does the water go concave in State 3? Because it is *spinning*; or, more precisely, because it is *accelerating* – its velocity is changing over time (in this case, its velocity is changing *direction* over time).[8]

But what does this explanation amount to? It appeals to the *acceleration* of the water, but what is acceleration? For the substantivalist, the answer is clear. Motion, on his view, is motion *through substantival space*. To be moving just is for one’s position *in substantival space* to be changing over time. Acceleration is then a particular kind of motion through space, defined in the standard way as the second derivative of position.

But the relationalist has difficulty making sense of this. For what, on her view, is motion? Not motion through substantival space. Instead, motion for her is motion *relative to other material bodies*: to be moving just is for one's distance to those other material bodies to be changing over time. But which other material bodies? Which bodies are such that motion relative to *them* explains why the water goes concave in State 3? Descartes said that motion is motion relative to whatever is adjacent, in this case the bucket.[9] But this does not work, for in State 3 the water is at rest relative to the bucket, just as it was in State 1, when the water was not concave. Moreover, the water is in motion relative to the bucket in State 2, yet the water is not concave. Clearly, motion relative to the bucket does not explain the phenomena.

What about motion relative to *the walls of the room*? Could this explain why the water goes concave in State 3? No, as is demonstrated by another experiment: put the walls on wheels and spin them around a bucket of water, and the water will not go concave even though it is accelerating relative to the walls.[10]

This then is the so-called 'bucket argument' for substantivalism. The observed phenomenon is the water going concave. And the idea is that the best explanation – perhaps the only explanation – is that the water is accelerating *through substantival space*. Note that the observed phenomenon here consists in relational matters of fact: the distances between bits of water and bits of the bucket changing over time. So the relationalist cannot complain that we have characterized the phenomenon in terms that already favor her opponent, for it has been characterized in terms that are, by her own lights, in good standing. Note also that the scope of the argument is not limited to water in buckets. For the kinds of effects experienced by the water are ubiquitous: cyclones form due to the earth's rotation, galaxies form their distinctive spiral shape due to their rotation round a center, and so on. These are all so-called 'inertial effects', and the argument is that they are all best explained (in classical physics, at least) by the fact that the bodies in question are *accelerating* through substantival space.[11]

Relationalists have, of course, contested the argument; here let me describe two kinds of response. The first tries harder to find some special body, such that acceleration relative to *it* is what explains inertial effects. We saw that the special body cannot be the bucket, nor the walls, but is there something else that could play this role?

It is not at all obvious that there is. For suppose we say that acceleration relative to a particular body B is what explains inertial effects. Then B had better not exhibit inertial effects, since B cannot accelerate relative to itself! Given how widespread inertial effects are, this makes the search for such a body difficult (to put it mildly).

Ernst Mach noticed that the system of distant stars and galaxies, considered as a system, is not rotating relative to the Earth. He called them the 'fixed stars', and proposed that acceleration relative to *them* explains inertial effects. This requires that there are forces that correlate with acceleration relative to these fixed stars. Mach assumed that there are such forces, but did not provide a workable physical theory describing their behavior. Whether such a theory can be given is a question of physics that I will not attempt to address here. Suffice it to say that the consensus is pessimistic.[12]

Moreover, one might object to this Machian strategy by arguing that the water would go concave even if spinning in a bucket in an otherwise empty world. But this argument is importantly weaker than the original bucket argument. For the original bucket argument was that the relationalist is unable to explain an *actual observation*, whereas the current argument consists of a thought experiment about what would happen in an untestable counterfactual scenario. Thus, Mach would not be moved: as a positivist, he would say that what a theory predicts in untestable scenarios is of questionable relevance. Still, others with less positivistic inclinations might find this kind of thought experiment compelling.[13]

So much for this first kind of relationalist response, which tries to explain inertial effects in terms of motion relative to some special body. A second kind of response concedes defeat on that front, and instead attempts to explain inertial effects in a more deflationary manner.

Sklar (1974) proposed one such deflationalist response. He pointed out that we do not *directly* observe whether something is accelerating; at best, we just see the effect of that motion (for example, the water going concave). What then *do* we observe directly? Sklar suggests this: '(1) that objects in relative motion vary in the inertial forces they suffer and that (2) objects in uniform motion with respect to one another suffer similar inertial forces' (p. 230). What Sklar means, presumably, is that we directly observe *instances* of these generalizations, and that (1) and (2) are inductive generalizations from those instances. Sklar's idea is then to stop here and propose (1) and (2) as one's final theory. On this view, the concavity of the water in the bucket is explained by the fact that the water is moving uniformly relative to other bodies that suffer similar inertial effects, but we do not further explain why all those bodies suffer those inertial effects. As Sklar puts it:

> 'But why do some systems suffer no inertial forces, whereas others do? I offer no explanation. This is just a brute, inexplicable fact about the world. It seems clear that if one adopts this stance there is nothing incompatible with accepting… that some systems are acted upon by forces that others do not experience, accepting that the *variation* in the force suffered is a function of the *relative* motion of the varying systems, and maintaining a pure-relationalist account of space, time and spacetime. What we give up is the hope of "explaining" the occurrence of the forces in terms of some state of motion of the system suffering the forces.' (pp. 230–1).

In response, the susbtantivalist may boast that she *can* explain why some systems suffer no inertial forces while others do: only the latter are accelerating through substantival space. And, in reply, Sklar may complain that this explanatory advance comes at the cost of the ontological extravagance of positing substantival space. So the question is which explanation of the water in the bucket is better overall: the ontologically economic one that stops at (1) and (2), or the ontologically extravagant one that goes further. As Sklar notes, this is now a philosophical question: the idea that one or other explanation is best 'can only be philosophically justified, and hardly empirically confirmed or unconfirmed' (p. 231). Indeed, Sklar says that his view fits best with a positivist view of science, which puts less value on explaining principles like (1) and (2) in terms of theoretical posits like substantival space. Thus, as anticipated earlier, the arguments for and against substantivalism – even 'scientific' arguments such as Newton's – quickly bleed into deep philosophical waters![14]

Sklar also discusses a second relationalist view on which material bodies, in addition to standing in spatial relations, have primitive, intrinsic properties of acceleration. While the substantivalist takes acceleration to consist in the *relation* that the body bears to space, this relationalist view claims (somewhat ironically) that acceleration is not relational at all. On this view, some bodies have the primitive property of zero acceleration, others have the primitive property of $5\,\mathrm{m/s^2}$ acceleration to the north, and no analysis of these properties is given. Inertial effects are then explained by appealing to the possession of these properties.[15]

Is this second relationalist view of Sklar's promising? Field (1984) argues that it is not. He asks whether the view really quantifies over this new domain of acceleration *properties*, or whether the idea is that we introduce new primitive *predicates* like 'is accelerating at $1\,\mathrm{m/s^2}$ to the north', 'is accelerating at $2\,\mathrm{m/s^2}$ to the north', and so on. On the second option, Field argues that the resulting theory will be ungainly in the extreme: it will contain infinitely many primitive predicates and will not be finitely or even recursively axiomatizable. And on the first option, Field asks why positing a domain of acceleration properties is any better than positing substantival space – indeed he goes so far as to suggest that the two theories are notational variants.

This completes my outline of the bucket argument. In a classical setting, it is the main argument in favor of substantivalism. In other settings (e.g. General Relativity) the arguments are somewhat different, but I believe the best ones resemble the bucket argument in being arguments to the effect that substantival space(time) enters into the best explanation of some observed phenomena. So, like the bucket argument, we can expect them to lead quickly into difficult philosophical questions about what constitutes a good explanation.

3. Leibniz's Arguments

What about arguments against substantivalism? The main arguments in the context of classical mechanics, as well as in more realistic contexts such as General Relativity, are made in the language of 'symmetry'. But these symmetry considerations can be traced back at least as far as Leibniz, in his correspondence with Clarke.[16] So let us begin there, before discussing their contemporary re-incarnation in terms of symmetry.

Leibniz's idea was that substantivalism implies a *proliferation of possibilities*, and that this is problematic. But he distinguished different ways in which the possibilities proliferate, and different reasons for thinking that the proliferation is problematic, resulting in a number of related arguments.

Start with the claim that substantivalism implies a proliferation of possibilities. Imagine a world W just like ours with the *one* exception that the entire material history of the world is unfolding three feet to the right of where it actually unfolds. W is just like the actual world with regards to spatial relations between bodies, so according to the relationalist there is no real distinction between the two worlds. But for the substantivalist there is a real difference: in W, every material body is situated in a *different* region of space than it actually is. More generally, a *shifted world* is one in which the entire material history of the world is uniformly shifted over by some distance in some direction. Substantivalism, but not relationalism, appears to imply that there are infinitely many distinct shifted worlds.

Or imagine a world W* just like ours with the *one* exception that the entire material history of the world is drifting through space at a uniform velocity – say, 5 mph in the direction from London to Paris. W* is just like the actual world with regards the spatial relations between all bodies at any given time, so (again) according to the relationalist there is no real distinction between the worlds. But for the substantivalist there is a real difference: in W*, every material body is moving through substantival space at a *different* rate. Call worlds that differ in this way *boosted worlds*. Substantivalism, but not relationalism, appears to imply that there are infinitely many distinct boosted worlds.

So, substantivalism implies a proliferation of possible worlds. But why is this problematic? Leibniz offered two reasons. First, he said that if these possibilities were genuinely distinct then God would have no reason to create the world one way rather than the other; which is, as he put it, 'against my axiom'. The axiom in question was the Principle of Sufficient Reason (PSR), which he expressed as the idea that God had a reason to create the world exactly as it is. Leibniz expressed the resulting argument thus:

> 'Now from hence it follows, (supposing space to be something in itself, besides the order of bodies among themselves,) that' 'tis impossible there should be a reason, why God, preserving the same situations of bodies among themselves, should have placed them in space after one certain particular manner, and not otherwise.' (Leibniz's third letter)

The second reason Leibniz gave for thinking that the proliferation of possibilities is problematic is that the resulting possibilities are all *indiscernible*. And this goes against another of his principles, namely that 'there is no such thing as two individuals indiscernible from each other'. This is now known as the Principle of the Identity of Indiscernibles (PII):

$$\text{PII} : (\forall x)(\forall y)(x \text{ and } y \text{ are indiscernible} \longrightarrow x = y)$$

Now, the PII admits of different readings depending on what the quantifiers range over. For Leibniz's current argument, we must read them as ranging over *possibilities*, not worldly objects, so that the PII here says that indiscernible *possibilities* are identical. Since shifted and boosted possibilities are indiscernible, it follows from the PII that they are not distinct, *contra* substantivalism. As Leibniz put it:

> 'To say that God can cause the whole universe to move forward in a right line, or in any other line, without making otherwise any alteration in it; is another chimerical supposition. For, two states indiscernible from each other, are the same state; and consequently, 'tis a change without any change.' (Leibniz's fourth letter)

In sum, we have two kinds of possibilities – shifts and boosts – and two principles that those possibilities violate – the PSR and the PII – giving four arguments altogether. They can be schematically represented thus:

(1) If Newtonian substantivalism is correct then [boosted / shifted] possible worlds are genuinely distinct.
(2) A proliferation of such possible worlds violates [PSR / PII].
(3) The [PSR / PII] is correct.
(4) Therefore, Newtonian substantivalism is false.

These arguments are valid, but are they sound? Contemporary theorists are likely to see Premise 3 as the weakest link. Few accept the PSR these days, and Leibniz' theological gloss on it only makes it that much more controversial. And why must we accept the PII? Leibniz himself derived it from his PSR: if there were indiscernible possibilities, God would have no reason to choose to actualize one rather than the other. But then the PII is no more plausible than his PSR.

What about the other premises? Premise 1 is plausible, regardless whether it concerns shifts or boosts. We will later discuss views on which it fails with regards to shifts, but let us grant it for now.

That leaves Premise 2. And indeed it has been questioned, at least in some of its incarnations. For example, Maudlin (2012) argued that it is false when understood as saying that the proliferation of *boosted* worlds violates the *PSR*. Why? His thought is that if God were faced with a choice of which boosted world to actualize, she could avoid an arbitrary decision about the *direction* of the world's motion through space by choosing the unique world in which the center of mass of the universe is *at rest*. So God has a reason to choose *that* world, and hence the proliferation of boosted possibilities does not violate the PSR, says Maudlin.

Whether Maudlin is right here depends on subtle questions about what could constitute a reason for God. On one view – arguably Leibniz's view – God is choosing the 'best of all possible worlds', where a world W is better than W* if W has more of some morally good-making feature (such as pleasure, or welfare, or what have you) than W*. On this view, God has a reason to choose W over the alternatives if W is better than the alternatives in this moral sense. But a world in which the universe is at rest is no better than the boosted alternatives in this moral sense, and so the proliferation of boosted alternatives does violate the PSR after all, *contra* Maudlin. Maudlin seems to be working with a different view, on which God has a reason to choose W over the alternatives if choosing W lets her avoid an arbitrary choice. As the case of velocity shows, these two views about God's reasons come apart.

One can also question Premise 2 when understood as saying that the proliferation of *boosted* worlds violates the *PII*. For consider two possibilities that are boosted versions on one another – are they indiscernible? It depends what 'indiscernible' means. On one interpretation, worlds W and W* are indiscernible if they are alike in their distribution of qualitative properties. More fully, say that a property or relation is qualitative if it does not concern a particular individual. For example, the property of being green is qualitative, but the property of being identical with Obama is not. Then the idea is that W and W* are indiscernible if there is a 1-1 function f from individuals in W to individuals in W*, such that for all x in W, x and $f(x)$ have the very same qualitative properties and stand in the very same qualitative relations. If this is what 'indiscernible' means, then boosted worlds are *discernible*: for the property of being at rest is qualitative, but boosted worlds (by definition) are not alike in their distribution of this property.[17]

Still, boosted worlds look and taste and smell the same. So if *this* is what it is for worlds to be indiscernible, then the proliferation of boosted possible worlds *does* violate the PII, just as Premise 2 states.

Clearly, what this discussion shows is that one must take care in clarifying the content of the PSR and the PII when assessing Premise 2. But perhaps this is all moot, since as I said most contemporary theorists reject Premise 3. So are there other arguments against substantivalism?

4. *Symmetry Arguments*

There are, and they can be seen as contemporary descendants of Leibniz's arguments. They typically appeal to the *symmetries* of classical mechanics. And what are symmetries of a theory? As Baker puts it, the 'symmetries of a theory are transformations that preserve its laws' (Baker 2010, p. 1057).

Let us unpack this. We are all familiar with symmetries of *shapes*. For example, rotation by 90 degrees is a symmetry of a square because rotating a square by 90 degrees yields a figure that exactly coincides with the original. More generally, symmetry is an operation (e.g. rotating the square) that preserves something (e.g. the square's extension through space). So generalized, we can consider the symmetries of a law: *as a first approximation*, a symmetry of a law L will be a way of altering a physical system (this is the operation) that preserves the truth-value of L (this is what is preserved). We can represent a way of altering a physical system with a function on possible worlds. A symmetry of a law then becomes a function on possible worlds that preserves the truth-value of L (i.e. it maps worlds in which L is true to worlds in which L is true, and worlds in which L is not true to worlds in which L is not true). I stress that this is only a first approximation: ultimately, the symmetries of L must preserve more than *just* the truth-value of L, else symmetries become too cheap (see Belot 2013). But precisely what else must be preserved is a matter of some controversy, and it will not matter greatly for our purposes, so in this survey paper I will bracket this issue.[18]

To illustrate, let CM be the laws of the classical mechanics that we are assuming for the sake of argument (see the introduction). The symmetries of CM are then (at a minimum) functions on worlds that preserve the truth-value of CM. The shifts and boosts discussed earlier are symmetries of CM: if one takes a world that consists of particles evolving in accordance with CM, and then considers the world in which everything is uniformly shifted or boosted, it is straightforward to show that the resulting world will also consist of particles evolving in accordance with CM.

Now, how can symmetries be used to adjudicate issues such as substantivalism vs relationalism? As Baker puts it, the idea is that '[worlds] related by a symmetry transformation must share identical values of all fundamental quantities' (Baker 2010, p. 1158). To see what this means, say that F is an *invariant* feature of a law L if any two worlds related by a symmetry of L agree on all values of F. For example, position in Newtonian space, and velocity through it, are *not* invariant features of CM, since worlds related by boosts and shifts disagree on their values. Then Baker's idea is that (all else being equal) we should think that a given feature is real only if it is an invariant feature of the laws. Thus, his idea is that the following is a reasonable (though not valid) line of inference, *ceteris paribus*:

(1) Laws L are the true and complete laws governing our world.

(2) Feature F is not an invariant feature of L (or wouldn't be, if it were real).

(C) Therefore, F is not real.

Insofar as we are assuming that CM are the true and complete laws, the idea is that we can examine its symmetries, notice that position and velocity through substantival space are not invariant features, and then infer (ceteris paribus) that they are not real features – which they would be if substantivalism were true. That is the 'symmetry argument' against substantivalism.

5. *The Relevance of Symmetry*

This kind of symmetry argument has been used against substantivalist views in the context of other theories such as General Relativity. So it is worth examining the argument more closely. In particular, what justifies it? What is it about features that are not invariant – like position and velocity in Newtonian space – in virtue of which there is reason to think they are unreal?

Opinions are divided. One idea is that such features are *redundant* or *superfluous* to the physics. The idea is that they 'make no difference' to the mechanical laws: there are systematic ways to alter their values and yet preserve the truth of the laws, so those laws 'don't care' what their exact values are. Thus on this first approach, the symmetry argument boils down to the idea that (ceteris paribus) we should not believe in features that are not needed for the mechanics.

Another idea is that features that are not invariant are *undetectable*. On this second approach, the symmetry argument boils down to the empiricist idea that (ceteris paribus) we should not believe in that which we can never see or detect.[19]

Which approach is preferable? This is an under-explored question. To be sure, there are instances of each approach in the literature. One sees the first approach played out in Earman's discussion of symmetry and spacetime structure (1989, chapter 4), North's discussion of symmetry in Lagrangian and Hamiltonian mechanics (2009), and Baker's discussion of symmetry reasoning (2010). And the second approach is exemplified in Maudlin's discussion of substantivalism in classical physics (2012, chapters 2 and 3). But there is little explicit discussion about whether the respective approach taken is preferable to the other.[20]

In (Dasgupta, forthcoming) I defend the second approach, so let me focus on it here. It assumes that features are not invariant are undetectable, but is this true? It is widely assumed among physicists that it is. As Feynman puts it, 'the laws of Newton are of the same form in a moving system as in a stationary system [that is, boosts are symmetries of CM], and therefore it is impossible to tell, by making mechanical experiments, whether the system is moving or not' (1963, p. 15). Feynman does not elaborate on why this is, but there is an argument that supports his claim, developed by Roberts (2008). The idea is that to measure the value of a quantity is to set up a situation in which the value has some observable effect on, say, how far a needle swings or what is written on a computer printout. But if boosts are symmetries of CM, then the particular velocity of a given body through Newtonian space cannot have such an effect. Why not? Well, consider a boosted world W. In W, the body has a *different* velocity, but the *same* observable effects (since W will look and taste and smell just like the actual world). Since boosts are symmetries of CM, W is a world in which CM is true; and so it follows that W represents what observable effect we *would* see, according to CM, *were* everything systematically boosted. So it is impossible to set up a situation in which the particular velocity of a given body will produce a particular observable effect. An analogous argument can be run with regards to position in Newtonian space.

This is no ordinary skeptical argument. To be sure, we are given a number of different hypotheses – that the body is moving at 1 mph, that it is moving at 2 mph, etc – and, according to the above argument, each hypothesis is consistent with the evidence. To that extent, it resembles an ordinary skeptical argument, where we also have a number of different hypotheses – that I am dreaming, that things are as they appear – each consistent with the evidence. But in ordinary skeptical arguments, different considerations can be advanced in favor of each hypothesis. One might say that the hypothesis that I am dreaming is more ontologically parsimonious, whereas the hypothesis that things are as they appear is closer to common sense, more explanatory, is 'given in experience', and so on. The anti-skeptic thinks that these differences favor the second hypothesis; the skeptic disagrees. But in the current case, there is nothing that can be said in favor of one hypothesis about the velocity of a given body that cannot equally be said in favor of an alternative, boosted hypothesis. All hypotheses are equally simple, equally explanatory, and so on. Thus the two hypotheses are 'evidentially equivalent' in a *much* stronger sense than the hypotheses under consideration in ordinary skeptical arguments.

The argument that velocity through Newtonian space is undetectable (from two paragraphs back) assumed that velocity boosts are symmetries of the laws. As presented there, the assumption was important: if the laws were not symmetric under boosts, the boosted world W may not be a world in which CM is true, in which case W would not represent the observable effect we *would* observe if everything were boosted. But one might argue that the assumption is not essential, that we can we also establish the same conclusion with something weaker. For suppose there were a velocity-dependent law. To take a very simplistic example, suppose there were some material whose color depends on its velocity through Newtonian space: if it is at rest, it is green; if moving, it takes on other colors. This law is clearly not symmetric under boosts, so now our assumption does not hold. But does this mean that we could tell whether a given sample of the material is at rest, just by looking to see whether it is green? Not necessarily. Having observed that it is green, one can infer that it is at rest only on the basis of a theory, namely that green correlates with rest. Call this theory T_1. According to a rival theory T_2, yellow correlates with rest instead. Thus, if T_1 is true, then green indicates *rest*; if T_2 is true, then green indicates *motion* instead. So, having seen that the material is green, one can infer that it is at rest only if one knows that T_1, and not T_2, is true. But can one ever discover whether T_1 or T_2 is true? If one sets up the case so that T_1 and T_2 are empirically equivalent, then experiment alone cannot decide the matter. If T_1 and T_2 also score equally with regards to other theoretical virtues – if they are equally simple and so on – then there will be nothing we can say in favor of the one theory that cannot also be said in favor of the other. In that case, even though the laws are not symmetric under boosts, it remains the case that it will be 'impossible to tell, by making mechanical experiments, whether the system is moving or not', as Feynman put it.[21]

The point is that a mechanical experiment is an attempt to figure out (i) the value of the quantity under investigation, on the basis of (ii) the observed outcome of the experiment, and (iii) the laws governing the process by which (i) caused (ii). If one does not know (iii), one will not know what value of the quantity is indicated by (ii). In the example above, there are velocity-dependent laws, and so being at rest in Newtonian space gives rise to an observably different experimental outcome than being in motion does; but since you do not know which outcome is caused by which state of motion, you are not in a position to know what each outcome indicates.

This suggests that we can argue that velocity is undetectable without assuming that the laws are symmetric under boosts, and with some weaker assumption about the laws in its place (I leave it for further work to establish exactly what this weaker assumption is). This is not to say that there is anything wrong with the original argument that velocity is undetectable. It is just to say that there may be a stronger argument, with weaker premises, for the same conclusion.

6. Galilean Substantivalism

What is the rational response to these symmetry arguments against Newtonian substantivalism? The question is underspecified, for we have four distinct arguments:

(1) The **boost argument from redundancy**, which says that *velocity* through Newtonian space is *redundant*.
(2) The **boost argument from undetectability**, which says that *velocity* through Newtonian space is *undetectable*.
(3) The **shift argument from redundancy**, which says that *position* in Newtonian space is *redundant*.
(4) The **shift argument from undetectability**, which says that *position* in Newtonian space is *undetectable*.

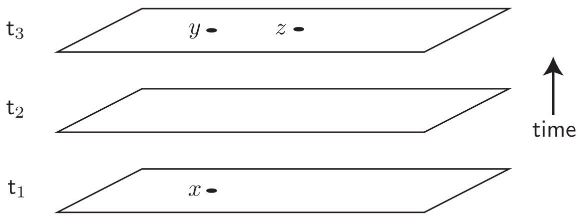
As we will see, many theorists think that the different arguments deserve different responses, so these distinctions are important to keep track of. Let us start by considering the boost arguments, and then turn to shift arguments.

The consensus, with which I agree, is that at least one of the boost arguments is compelling and should move us to reject Newtonian substantivalism. But what view of space should we believe instead? Perhaps relationalism, though the bucket argument suggests not (see section 2). That argument, remember, purports to show that there must be a quantity of *absolute* acceleration – acceleration that is not defined relative to a given body – to explain inertial effects, and relationalism does not yield such a quantity.

We find ourselves in a pickle. If we accept the bucket argument, we must recognize such a thing as absolute acceleration. But acceleration is typically defined as the rate of change of velocity. Thus, if there is such a thing as absolute acceleration, there must also be such a thing as absolute velocity too–that is, velocity that is not defined relative to a material body. But the boost arguments show that absolute velocity is redundant and/or undetectable. So, it appears that we must either reject the bucket argument, or else be lumbered with a redundant and/or undetectable feature in absolute velocity.

As it turns out, this is a false dilemma. There is a view that recognizes such a thing as absolute acceleration, but rejects the definition of acceleration as the rate of change of velocity, and so avoids commitment to absolute velocity. Thus, if one is impressed by the bucket argument, and also by the boost arguments against absolute velocity, one can have one's cake and eat it too!

To see what the view is, it helps to think four-dimensionally. I said earlier that Newtonian substantivalism is the view that space is a three-dimensional (3D) Euclidean object that endures through time, but let us revise this and think of the view four-dimensionally instead. To this end, imagine a stack of 3D Euclidean spaces, one for each moment of time, making up a 4D space-time structure. The 3D spaces are temporally ordered, and there is a temporal distance between any two of them: one might be 1 minute before another, and so on. This induces a temporal distance between any two *points* in the 4D structure. The temporal distance between any two points in the same 3D space will be 0; that is, they are simultaneous. Call this a 'Euclidean Stack'; see Fig. 2.[22]



t_1 is a 3D Euclidean space, represented here as a 2D Euclidean plane, similarly for t_2 and t_3. Temporal order is represented by the arrow on the right: t_1 is earlier than t_2, which is earlier than t_3. There is also a measure of temporal distance between each Euclidean space. In these diagrams, let the temporal distance between t_1 and t_2 and between t_2 and t_3 be 1 minute. Thus, the temporal distance between point *x* and point *y* is 2 minutes and the temporal distance between point *y* and point *z* is 0 minutes (they are simultaneous points).

Fig. 2. A Euclidean Stack

We can then understand Newtonian substantivalism as adding the following posit: that there is a spatial distance between *any* two points in the stack. Of course, there already was a spatial distance between any two *simultaneous* points—this follows from calling each of the 3D spaces making up the stack 'Euclidean'. The current posit is that there is a spatial distance between any two *non-simultaneous* points too. Let us understand the posit as implying that, given a point *x* in one 3D space, any other 3D space contains a point that is 0 meters from *x*. The result is known as 'Newtonian space-time', and we can now understand Newtonian substantivalism to be the view that Newtonian space-time exists, and has this structure, independently of its material constituents. See Fig. 3a.

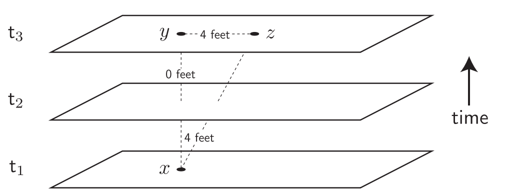


Fig. 3a. In Newtonian space-time, there is a spatial distance between any two points in the stack. Thus, even though *x* and *z* are in distinct Euclidean spaces (t_1 and t_3, respectively), we can nonetheless say that *x* is 4 feet from *z*. Note that *x* is 0 feet from *y*; in effect, *x* and *y* are the "same place" at different times.

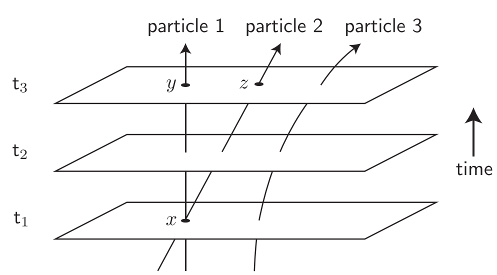


Fig. 3b. Particle 1 is at rest, because its location in t_3 is 0 feet from its location in t_2 and t_1. Particle 2 is moving at constant velocity: its location in t_3 is 4 feet from its location in t_1 and its location in t_2 was exactly halfway between. Particle 3 is accelerating: it travels further between t_2 and t_3 than it did between t_1 and t_2.

Fig. 3. Newtonian space-time.

In section 2, I said that, according to the Newtonian substantivalist, a body is at rest if it occupies *the same place* over time, and is moving if it occupies *a different place* at different times. We can now reinterpret this as follows. All bodies occupy different regions of the 4D stack at different times, since each moment of time is a different 3D Euclidean space. Still, we can say that a body is at rest if the spatial distance between its current location and its earlier one is 0, and moving otherwise. In effect, we are defining a 'place' to be a straight vertical line through the 4D stack that connects points that are 0 meters from one another. Velocity can then be defined as distance traveled over time, and acceleration can be defined as the rate of change of velocity, as normal. Note that these are *absolute* notions of velocity and acceleration: a body's velocity and acceleration are not defined in terms of its relations to other material bodies, but rather in terms of its trajectory through Newtonian space-time. See Fig. 3b.

We can now define the intermediary view that yields a notion of absolute acceleration but not absolute velocity, as follows. Start with a Euclidean Stack, but do not make the Newtonian posit that there is a spatial distance between any two events in the stack. So, given any two *non-simultaneous* points, there is no fact of the matter as to the spatial distance between them. It follows that there is no fact of the matter as to how far a given body is *now* from where it was *then*, and so no fact of the matter as to its distance traveled over time. Thus, we have dispensed with the notion of absolute velocity that we had in Newtonian space-time.

How then can we secure a notion of absolute acceleration? By distinguishing between *straight* and *curved* vertical lines through the stack. As we can see from Fig. 3, there is a distinction between straight and curved vertical lines in Newtonian space-time too: the straight lines are the trajectories of constant absolute velocity. But, on the current view, we cannot define the distinction between curved and straight lines like this because the notion of absolute velocity is not well defined. So instead, we take the distinction to be primitive. The result is known as 'Galilean space-time', and we can let Galilean substantivalism be the view that Galilean space-time exists, and has this structure, independently of its material constituents. See Fig. 4a.

According to Galilean substantivalism, a body is accelerating if it makes a curved trajectory through the stack. This is an absolute notion of acceleration, since whether a body is accelerating is defined not in terms of its relations to other bodies, but rather in terms of its trajectory through the stack. The Galilean substantivalist then explains inertial effects, such as the water going concave in the spinning bucket, by saying that they are effects felt by bodies that are accelerating *in this sense*. Thus, since her view recognizes a notion of absolute acceleration, she claims that her view has all the explanatory virtues of Newtonian substantivalism. And yet, since she defines absolute acceleration *without* appeal to absolute velocity, she is rid of that bit of redundant and/or undetectable structure. See Fig. 4b.

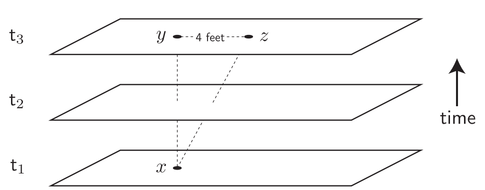


Fig. 4a. In Galilean space-time, the spatial distance between non-simultaneous points is undefined. So, there is no fact of the matter as to the spatial distance between *x* and *y*, or between *x* and *z*. Instead, there are facts about which vertical trajectories through the stack are straight and which are curved. The dotted lines between *x* and *y*, and between *x* and *z*, represent straight trajectories.

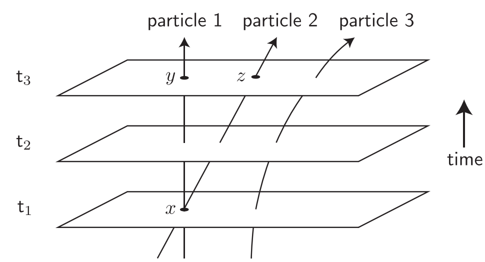


Fig. 4b. Particle 1 is in unaccelerated, or 'inertial', motion, because it makes a straight trajectory through the stack. Particle 2 also makes a straight trajectory and so is also in unaccelerated motion. Because there is no spatial distance between *x* and *y*, or between *x* and *z*, there is no fact of the matter as to which particle is at rest and which is moving; in contrast to the situation in Newtonian space-time (compare Figure 3b). Particle 3 makes a curved trajectory through the stack and so is accelerating.

Fig. 4. Galilean space-time.

For these reasons, it is widely thought that Galilean substantivalism is a vast improvement on Newtonian substantivalism.[23]

7. *Problems for Galilean Substantivalism*

Are we now done? Can we conclude that Galilean substantivalism is the correct view of space-time, at least in a classical context? Many theorists think so.[24] But it is not clear that they are right, for even if it is an improvement on Newtonian substantivalism, Galilean substantivalism appears to contain lots of remaining redundant and/or undetectable structure.

For one thing, we still have the *shift* arguments to contend with. After all, Galilean substantivalism appears to recognize a real difference between shifted worlds, since in a shifted world bodies make trajectories through *different* bits of Galilean space-time than they actually do. Thus, even if the Galilean substantivalist is rid of *one* kind of redundant and/or undetectable structure, namely absolute velocity, she is still lumbered with *another*, namely position in Galilean space-time. This is not to deny that Galilean substantivalism is an improvement; it is just to say that it is, perhaps, not the final view on the matter.

This issue is well known and much discussed, and I will address it further below. But before that, let me outline two less discussed respects in which Galilean substantivalism might be accused of harboring redundant and/or undetectable structure.

First, consider a world W with bodies making trajectories through Galilean space-time, and now imagine a world W* that differs only in the fact that all the trajectories are uniformly 'tilted over' in the stack. In Newtonian space-time, the result of tilting the trajectories over would be a boosted world in which everything has a different absolute velocity. In Galilean space-time, we cannot *describe* W* like that, since absolute velocity is not well defined. But still, W* is *distinct* from W, since bodies make *different* trajectories through Galilean space-time in W* than they do in W; see Fig. 5. Thus, Galilean space-time still has enough structure to make sense of differences between these worlds; it is just that we must now label them 'tilted' worlds, not 'boosted' worlds. And, the argument goes, this change in labels is irrelevant: differences between tilted worlds are redundant and/or undetectable if differences between boosted worlds were. So, just as we had two boost arguments against Newtonian substantivalism – from redundancy and undetectability, respectively – we have two corresponding *tilt arguments* against Galilean spacetime.[25]

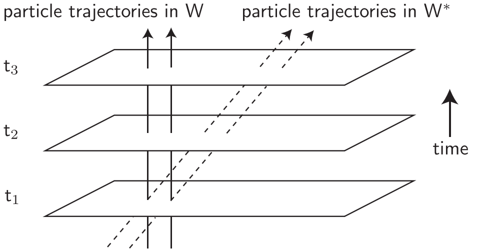


Fig. 5a. In Newtonian space-time, we can distinguish worlds that differ only in a uniform velocity boost. Worlds W and W*, illustrated here, are an example. In W, the two particles are at rest. In W*, they are both moving at constant velocity in the same direction. So, W* is 'boosted' relative to W.

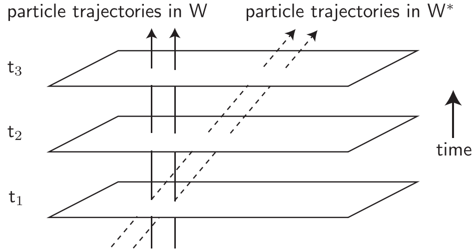


Fig. 5b. In Galilean space-time, we can distinguish worlds that differ only in a uniform tilt. Worlds W and W*, illustrated here, are an example. Unlike in Figure 5a, we cannot say that in W the particles are at rest and in W* they are in uniform motion, for the distinction between rest and uniform motion is not well-defined in Galilean space-time. So we cannot describe W* as boosted relative to W. Still, the worlds are distinct insofar as the particles make a different trajectory through Galilean space-time in each one. So, we can describe W* as 'tilted' relative to W.

Fig. 5. Boosts and tilts.

Second, one might even try to argue that whether a body is making a curved or straight trajectory through Galilean space-time is undetectable. This might sound odd. Can we not detect this by seeing whether the body is experiencing inertial effects, like the water in the bucket going concave? After all, the Galilean substantivalist told us how such forces relate to trajectory: she said that bodies under the influence of no force make straight trajectories through space-time, and bodies under the influence of force make curved trajectories (where the degree of curvature is proportional to the force). So, if we see that a body is free of force – e.g. if we observe no inertial effects – can we not conclude that it is making a straight trajectory?

Not quite. Call this theory about how force relates to trajectory T_1. In effect, T_1 picks out the *straight* trajectories as being 'privileged'; that is, as being those trajectories that are followed by bodies in the absence of force. But now pick a curved trajectory, and take the set of all trajectories that are unaccelerated relative to it. According to T_2, *they* are the privileged trajectories followed by bodies in the absence of force, and bodies under the influence of force follow trajectories that are curved relative to those privileged ones (where the degree of curvature is again proportional to the force). Now, imagine that we see a body free of force. What does this indicate? According to T_1, it indicates that the body is making a straight trajectory; according to T_2, it indicates that it is making a certain kind of curved trajectory. So, if one does not know whether T_1 or T_2 is true, and all one sees is a body free of force, one will not know whether it is moving along a straight or curved trajectory! Assume now that we *cannot* know whether T1 or T_2 is true. Then, we cannot detect whether a body is moving along a curved or straight trajectory. The situation is similar to the discussion of color at the end of section 5: it may be that making a straight trajectory is observably different than making a curved trajectory, but if we do not know which observation correlates with which trajectory, we are not in a position to know what each observation indicates. Call this the 'curvature' argument.[26]

This argument rests on the idea that we cannot know whether T_1 or T_2 is true. Is this correct? They are empirically equivalent, so data are never going to refute one but not the other. Any reason to believe one over the other must therefore be based on some criteria other than empirical adequacy, such as simplicity. And, though T_1 is easier than T_2 to write down, it is not clear whether that is the kind of simplicity that yields an epistemic reason to believe T_1. Clearly, the issue depends on epistemological issues regarding what kinds of criteria yield reasons for belief. I will not try to settle these issues here.

To sum up: We have the shift arguments, the tilt arguments, and the curvature argument, all purporting to show that Galilean substantivalism harbors redundant and/or undetectable structure. If these arguments succeed then, while Galilean substantivalism is an improvement on Newtonian substantivalism, it is far from ideal and should not be considered a stable resting point.

Do the arguments succeed? Set aside the curvature argument, since it is somewhat speculative, and focus on the shift and tilt arguments. Are they compelling?

There is a growing consensus that they are not. Specifically, the consensus I have in mind makes the following two claims:

(i) The shift arguments *do not* make a compelling case against Galilean substantivalism.

(ii) Nonetheless, the boost arguments *do* make a compelling case against Newtonian substantivalism, and in favor of Galilean substantivalism.

So the consensus is that there is a problem with the shift arguments specifically, a problem that the boost arguments do not share. Moreover, it turns out that if the shift arguments have this problem, the tilt arguments have it too. Thus, according to this consensus, Galilean substantivalism is a stable resting point after all (in a classical context).

I think that this consensus is a mistake: *if* the boost arguments made a compelling case against Newtonian substantivalism, *then* the shift and tilt arguments also make a compelling case against Galilean substantivalism. In which case, Galilean substantivalism is not a stable resting point, just as we suspected. I will finish by discussing this issue.

8. *Boosts vs shifts I: modality*

What is the difference between the boost and shift arguments, according to this consensus? Two differences have been emphasized: a *modal* difference, and an *epistemic* difference.

Start with the modal difference. As presented above, the shift arguments against Galilean substantivalism make a modal assumption, namely that Galilean substantivalism implies

> (Shift) There are many possible worlds that differ from actuality only in a uniform shift of all matter.

The analogous assumption in the boost arguments is that Newtonian substantivalism implies

> (Boost) There are many possible worlds that differ from actuality only in a uniform boost of all matter.

No one has questioned this latter assumption that Newtonian substantivalism implies (Boost). But many Galilean substantivalists have argued that their view does not imply (Shift), and indeed that (Shift) is false, so that the shift arguments fail.

Why do they think that (Shift) is false? Well, the shifted worlds are qualitatively alike, in the sense defined in section 3. They agree on the truth of all statements that make no reference to any particular region of Galilean space-time; for example, that two bodies x and y are 2 meters from each other. They differ only with regards to which particular region of space-time each body is located at: in one world, the body is located at *this* region (demonstrating a bit of substantival space-time) while in the other it is located at *that* region (demonstrating another). Now, a view in modal metaphysics known as 'anti-haecceitism' states that there is no difference between possible worlds without a qualitative difference. So, if anti-haecceitism is true, then (Shift) is false. And anti-haecceitism is reasonably popular: some take it to be an axiom in their theory of necessity, others take it to follow from some theory about the workings of *de re* necessity such as counterpart theory. But, either way, a Galilean substantivalist might endorse anti-haecceitism, and thereby reject (Shift), and so conclude that the shift argument fails. This response is known as 'sophisticated substantivalism', and has been pursued (in the context of an analogous debate about substantivalism in General Relativity) by Brighouse (1994), Butterfield (1988), Caulton and Butterfield (2012), Hoefer (1996), Maidens (1992), and Pooley (2006, manuscript), among others.

A sophisticated substantivalist will say the same thing about the tilt arguments. As presented above, the tilt arguments assumed that Galilean substantivalism implies

> (Tilt) There are many possible worlds that differ from actuality only in a uniform tilt of all matter.

But tilted worlds are qualitatively alike too, so a sophisticated substantivalist will say that their view does not imply (Tilt), and indeed that (Tilt) is false.

Is this a reasonable response to the shift and tilt arguments? I think not. To see why, consider an analogy with boosts. Imagine a Newtonian substantivalist who, faced with the boost argument, makes the following speech:

> 'Your argument assumes that my view implies (Boost). But your assumption is incorrect, and indeed I claim that (Boost) is false. Why? Because I believe, with Spinoza, that all truths flow from the essence of God, and hence that all truths are necessarily true. So, I believe that (Boost) is false simply because there are no non-actual worlds at all! Hence I reject your assumption that my view implies (Boost), and so I reject your boost argument against my view.'

We should all agree that this Spinozist response is no good. It is not that Spinoza's view – that all truths are necessary – is false (if indeed it is false). Rather, it is the wrong *kind* of response. For suppose that Spinoza was right that every truth is necessary, so that (Boost) is false. Does this mean that we can happily retain our belief in Newtonian substantivalism? Surely not! Even if

Spinoza is right, it remains the case that absolute velocity is redundant and undetectable, just as the boost argument concludes. It's just that, when arguing the point to a Spinozist, we should not do so in terms of the framework of metaphysically possible worlds. Our reasoning about detectability and redundancy, and hence the boost arguments, should be couched in other terms (we can leave it to the Spinozist to tell us how to do this).

The right response to the boost argument, as we know, is to reject Newtonian substantivalism and endorse Galilean substantivalism instead. This position agrees with the Spinozist that (Boost) is false, but it offers a different explanation of *why* (Boost) is false. According to Galilean substantivalism, (Boost) is false *because of the structure of space-time*: the pared-down structure of Galilean space-time is enough on its own to guarantee that (Boost) is false.[27] In contrast, the Spinozist above thinks that (Boost) is false for some other reason, specifically, because of the nature of God.

The lesson is this. The right response to the boost argument rejects (Boost). But not any view that rejects (Boost) is the right response. What distinguishes the right response is that it rejects (Boost) *for a particular reason*: it offers a new view about the structure of space-time that implies that (Boost) is false.

Go back to the shift argument against Galilean substantivalism. The 'sophisticated substantivalist' response maintains that Galilean substantivalism is true, and yet insists that (Shift) is false, and so thinks that the shift argument fails. But why, on this view, is (Shift) false? Not because of the structure of space-time. For Galilean substantivalism – at least, as described above – is the view that there is a *physical entity*, substantival space-time, that exists independently of the matter situated within it. So I can denote different parts of this entity by demonstration: there is one part *here* (pointing at my desk), another part *there*, and so on. And a shifted possible world can then be described as one in which my desk is located *there* rather than *here* (and so on for other material bodies). Nothing *about the structure of space-time*, according to Galilean substantivalism, rules out the possibility of matter being arranged like that.[28] If it turns out that such a world is impossible, that must be because of something else: perhaps because of an axiom in one's theory of necessity that implies anti-haecceitism, or perhaps because of some counterpart theory about *de re* modality that implies anti-haecceitism, or perhaps some other reason. At any rate, these are the kinds of explanations that the sophisticated substantivalists mentioned earlier offer as to why (Shift) is false.

I claim that this is no better a response to the shift argument than the Spinozist response was to the boost argument. Admittedly, the sophisticated substantivalist might appeal to a *reputable* modal thesis, such as counterpart theory, to explain why (Shift) is false, while the Spinozist appeals to a *unreputable* thesis to explain why (Boost) is false. But the fact that counterpart theory is more reputable or plausible than Spinozism is neither here nor there: the point is that they are both the wrong *kind* of response. The charge against Galilean substantivalism is that it has redundant and/or undetectable structure. Typically, one makes this charge using the framework of metaphysically possible worlds, by meditating on the proliferation of shifted worlds mentioned in (Shift). But this is just one (particularly vivid) way to make the charge, and if one's interlocutor has idiosyncratic views about metaphysical possibility that preclude one from making the charge in those terms, then one must make the charge somehow else. So, one misses the point of the charge if one responds by wheeling some modal theory on which (Shift) is false – however plausible that theory may be – just as one misses the point if one wheels in Spinozism as a response to the boost arguments.

Instead, the right response to the shift argument is to propose some new theory about the structure of space-time that is enough by itself to guarantee that (Shift) is false. What would this new theory be like? This is an open area of current research. The obvious starting point is to say that space-time is not fundamentally an *entity*. So, one might propose some kind of 'qualitativist' view of space-time, on which the fundamental facts about space-time are purely qualitative. They would make no mention of entities, such as regions of space-time that stand in geometric relations; rather, they would just describe a patchwork of purely qualitative geometric relations. For example, one might try applying a 'bundle theory' to space-time regions (see O'Leary-Hawthorne and Cover (1998), and L.A. Paul (2014)). Or one might try a kind of 'generalism' (see Dasgupta (2009), (2011); and Russell (manuscript)). But it is fair to say that we do not yet know how best to develop this qualitativist view of space-time. Here, it suffices to say that, on any qualitativist view, there would not be enough structure at the fundamental level to generate shifted worlds, in just the same sense that in Galilean space-time we do not have enough structure to generate boosted worlds.

If this is right, then the consensus described earlier – that the shift arguments fail in a way that the boost arguments do not – is a mistake. Just as the boost arguments motivate a move from Newtonian to Galilean substantivalism, so the shift arguments should motivate a move from Galilean substantivalism to some qualitativist view about space-time.

Of course, if a qualitativist held that space-time (understood qualitatively) had the same geometric structure as Galilean space-time, one could *call* her view a version of 'Galilean substantivalism'. And then one would say that the shift arguments do not make a compelling case against Galilean substantivalism after all, just as the consensus said. I do not mind talking that way, but it is just a verbal maneuver. The point remains that the shift arguments make a compelling case for a change in view, away from the idea that space-time is an *entity* and toward the idea that it is, ultimately, a purely qualitative structure. This is contrary to the consensus, according to which the shift arguments *fail* and no change to a qualitativist view is necessary.[29]

9. Boosts vs Shifts II: Epistemology

Put aside anti-haecceitism: let us assume that Galilean substantivalism implies (Shift), just as the shift argument says. Still, Maudlin (1993) argued that there is another difference between boost and shift arguments. His focus is on the *undetectability* versions of both arguments. He argued that while velocity through Newtonian space is undetectable, location in Galilean (or Newtonian) space is *not* undetectable. For this reason, he thinks that while the undetectability argument from *boosts* makes a compelling case against Newtonian substantivalism, the undetectability argument from *shifts* fails to make a compelling case against Galilean substativalism.

Of course, this would be moot if you thought that the *redundancy* arguments did all the work. But Maudlin thinks that the *undetectability* arguments are more important. So he concludes, with the consensus, that Galilean substantivalism is a stable resting point.

What, according to Maudlin, is the difference between the case of velocity and location? In the case of velocity, he says:

> The universe as a whole may be at rest, or traveling uniformly five meters per second due north, or 888 meters per second in the direction between Earth and Betelgeuse, and so on. According to Newtonian dynamics *no possible observation* can reveal its actual state of motion. (1993, pp. 189–90).

But the case of location, he says, is different:

> Various positional states of the universe as a whole are possible: It could be created so my desk is *here*, or three meters north of here, or 888 meters from here in the direction from Earth to Betelgeuse, and so on. Which is the actual state of the world? Now the answer is easy: In its actual state, my desk is here,

> not three meters north or anywhere else… To even formulate the appropriate question in the [shift argument] one must indexically pick out a spatiotemporal location, and it is then no great trick to observe what material body that location actually contains. (1993, p. 190).

The idea is this. Suppose that Newtonian substantivalism is true. And suppose that (Boost) is true: there are many distinct possible worlds that differ only in a uniform velocity boost. Then, we can formulate a question about which of this world we inhabit, for example:

> 'Is the universe as a whole at rest?'

And the reasoning in section 5 purports to show that we cannot answer this question. But now suppose that Galilean substantivalism is true, and that (Shift) is true: there are many distinct worlds that differ only in a uniform shift. Maudlin's idea is that we *cannot* formulate an analogous, unanswerable question about which of these worlds we inhabit. For example, we might try asking:

> 'Is my desk here or three meters north of here?'

But we know the answer: My desk is right here! The difference, according to Maudlin, is that the only ways we have of denoting a given region of substantival space – demonstrating it, or describing its relations to material bodies – are such that, having asked a question about what is located there, the question is easily answerable.[30]

This shows that there is an *expressive difference* between velocity and location: we can formulate unanswerable questions about the former, but not the latter. What follows? Maudlin thinks it follows that 'the static shift [i.e. (Shift)] does not… imply that there are any real but empirically undeterminable spatiotemporal facts about the world' (p. 191). So, the idea is that the expressive difference shows that we can detect – and, more generally, know – where we are in Galilean space-time. We can display the argument like this:

(1) We cannot formulate an unanswerable question about where we are in Galilean space-time.
(2) Therefore, we can know where we are in Galilean space-time.

Thus, even though there are infinitely many shifted worlds that look and smell exactly alike, Maudlin thinks we can know which one we inhabit. In which case the shift argument from detectability against Galilean substantivalism fails.

Is Maudlin right? I think not. I agree that (1) is true, but (2) does not follow. To be sure, (2) would be one explanation of (1): if we *can know* where we are in Galilean space-time, then that would explain why there are no *unanswerable* questions about where we are. But another explanation is that (1) is true because of our expressive limitations. On this view, (1) is true not because we can know where we are in Galilean space-time, but because we lack the capacity to refer to regions of space-time in a way that would allow us to formulate an unanswerable question. So, on this view, we cannot know where we are in Galilean space-time, just as the shift argument states.

I think there are reasons to prefer this second view. Remember, the argument that we are ignorant of location was *exactly the same* as the argument that we are ignorant of velocity. In both cases, there are infinitely many boosted or shifted worlds that look and smell and taste and feel exactly alike, and so are indiscernible in that sense. Why then should the situation be any different in the case of location than velocity? Why, just because I cannot formulate an unanswerable question about my location, should it follow that I am not ignorant at all? To the contrary, I would appear to have *two* cognitive failings: a failure to know, and a failure to be able to ask a certain kind of question. Maudlin's view has the bizarre consequence that this *double* failure amounts to a success!

To defend his view, Maudlin might appeal to a general principle to the effect that one is ignorant about some topic if and only if one can formulate a question about it that one does not know the answer to.[31] Call this the principle that *all ignorance is expressible*. This principle would rule out my explanation of premise 1. But I think that the principle is false.

To see this, suppose we live in a world W_1 of one-way eternal recurrence: there was a first epoch which lasted (say) 3 trillion years, followed by a qualitatively identical second epoch, followed by a third, and so on *ad infinitum*. Which one do we inhabit? Since they are all indiscernible, we cannot know. And in this case, the ignorance is expressible: we can formulate questions that we do not know the answer to, for example:

'Do I inhabit the 3rd epoch?'
'Do I inhabit the 4th epoch?'
…and so on.

But now consider a world W_2 exactly like W_1 except that there are infinitely many epochs extending to the past as well. W_2 is a world of *two-way* eternal recurrence in which there is no first epoch and no last. I claim that if we do not know which epoch we inhabit in W_1, we do not know which epoch we inhabit in W_2 either. After all, in *both* worlds the epochs are all indiscernible, so there is no telling the epoch's apart. But then the principle that all ignorance is expressible is false. For in W_2 the ignorance is *inexpressible*: we cannot formulate a question about the matter that is unanswerable. For in W_2 the 'questions' indented above are not meaningful, since 'the 3rd epoch' would not refer. If we lived in W_2, we could only refer to epochs by demonstrating them – '*this* epoch' – or by describing their relation to material bodies – 'the second epoch after the one that I inhabit'. But once we ask a question about which epoch we inhabit in these terms, it is easily answered. Thus if I ask

'Do I inhabit *this* epoch?'

the answer is obviously: Yes!

Or consider a variation on the case.[32] Consider a world W_3 just like W_2, except that the epoch 3000 cycles before ours differs from the rest in some minute respect. Perhaps one electron is a *little* to the left of its counterpart in other epochs. Intuitively, in W_3 we do not know which epoch we inhabit. And this ignorance would be expressible: if we lived in W_3, we would not know the answer to the question

'Do we inhabit the 1st epoch after the one that differs from the rest?'

But, as we just saw, the principle that all ignorance is expressible implies that, in W_2, we know which epoch we inhabit. It follows that the following counterfactual is true in W_3: were that electron a *little* bit over to the right, we would know which epoch we inhabit. Thus, the principle implies that our ignorance of which epoch we inhabit can be cured by minute changes to far-off epochs – an implausible result.

This suggests that the principle that all ignorance is expressible is false. Sometimes ignorance is inexpressible. In these cases, there is indeed a double failure – a failure to know *plus* a failure to be able to formulate an unanswerable question – and this double failure does not constitute a success. I claim that ignorance of our location in Galilean (and Newtonian) space-time is an example of this kind of case. In which case, *contra* Maudlin, the shift argument against Galilean substantivalism should be just as compelling as the boost argument against Newtonian substantivalism.[33]

10. Conclusion

For these reasons, I claim that if Newtonian substantivalism posits redundant and/or undetectable structure *about velocity*, then Galilean substantivalism posits redundant and/or undetectable structure *about location*. I reject the attempt to deny this conditional by proposing anti-haecceitism as an additional modal thesis. And I reject Maudlin's attempt to deny it by pointing out the expressive difference between velocity and location.

So, while Galilean substantivalism does better than Newtonian substantivalism by being rid of absolute velocity, we must recognize that it harbors other redundant and/or undetectable structure. Hence, contrary to the consensus I mentioned earlier, it is not a stable resting point.

The natural question, then, is whether there is another view that is rid of that structure. In section 8, I gestured at one approach, on which the fundamental facts about space-time are purely qualitative. But such views have not yet been properly developed. Thus, even in the sanitized environment of classical physics, we do not yet know what the best metaphysics of space-time is.[34]

Short Biography

Shamik Dasgupta is an assistant professor at Princeton University. He received his PhD in philosophy from New York University in 2009. His research to date has focused on using physical symmetries as a guide to metaphysics.

Notes

* Correspondence: Philosophy, Princeton University. Email: Shamik@shamik.net

1 This subtlety in formulating the issue is widely recognized. For example, Field (1984) says that 'a relationalist might want to 'logically construct' regions [of space] out of aggregates of matter, and given such a 'logical construction' the relationalist will assert that regions do exist' (p. 33).

2 Which is not to say that she offers no explanation at all. Both views face the question of whether the most fundamental spatial relations are numerical – e.g. *is 762 meters from* – or whether these are explained in terms of purely qualitative relations – e.g. *x is between y and z* and *x and y are congruent with z and w*. See Field (1984) for a discussion of this issue.

3 See Sklar (1974), Brighouse (1999) and Belot (2011) for more on how a relationalist can make sense of this talk of the geometry of space.

4 Some theorists prefer to define 'scientific realism' differently; see, for example, Boyd (1975) for an alternative definition. But we can bracket this issue here: I am interested in the view expressed in van Fraassen's quote, whatever we call it.

5 What is sometimes called the 'Field Argument', due to Field (1984), might be vulnerable to this kind of objection. Field argued that field theories are committed to substantivalism, since a field is an assignment of values *to points of space and time*. But this is too quick. The *mathematical models* of a field theory consist in an assignment of values to a domain, but it is a further question what about these models are genuinely representational.

6 1This form of argument is known as Inference to the Best Explanation (IBE). See Lipton (2000) for an overview of this mode of reasoning, and see van Fraassen (1989, Part II) for a discussion of the relation between IBE and (what he calls) scientific realism.

7 This figure, along with all the figures in this paper, was produced by Thomas Barrett. I am extremely grateful for his time and expertise.

8 Admittedly, this is only a sketch of an explanation. A deeper explanation would say that the water goes concave because a *force* acts on it: a parcel of water near the bucket's wall is moving in a certain direction, and in the absence of forces would continue moving in that direction, but is forced to change direction by the walls of the bucket. (A full account of the forces involved here is rather complex, and involves the electromagnetic forces that bind the bucket's matter and repel other bits of matter from piercing it.) Thus, the walls impart a force to the water and 'squeeze' it up. But given the equation f = ma, force correlates with acceleration. So, however deep one digs, the explanation is (or implies) that accelerating water experiences the effect and non-accelerating water does not.

9 At least, this view is often attributed to him, but whether the attribution is accurate is a question I will not attempt to settle here. See Descartes (1983).

[10] Full disclosure: I have not actually run this experiment. If you doubt my prediction, you are welcome to apply for funding to carry it out yourself.

[11] I called this *Newton's* bucket argument, but I am no scholar and it may not reflect precisely what Newton had in mind. My primary aim here is not historical accuracy, but to present what I take to be a compelling argument. For related presentations of the argument, see Sklar (1974, chapter 3), Arntzenius (2012, chapter 5), and Maudlin (2012, chapter 2). For an alternative presentation, see Rynasiewicz (1995a, 1995b). Note that as I present it, the challenge is for the relationalist to explain why the water goes concave. As Skow (2007) shows, a distinct and harder challenge is for the relationalist to capture the full empirical content of Newton's theory of motion in substantival space. Barbour (1999) and Pooley and Brown (2002) defend relationalist theories that, they claim, explain inertial effects, but they do not claim to capture the full empirical content of Newton's theory.

[12] See Sklar (1974), Earman (1989), and Maudlin (2012) for representative examples of this pessimism.

[13] Indeed, Newton anticipated the Machian project with his own thought experiment of this kind. He imagined two globes at rest relative to one another, joined by a cord in an otherwise empty universe. If they are rotating round their center, he argued, there would be an observable tension in the cord, whereas if they were at rest, there would be no tension. But for the relationalist, these two situations are the same. Hence, argued Newton, the relationalist cannot explain the difference between these two situations.

[14] Another line of argument against Sklar's view is that it leads to a physics that is non-local and indeterministic. But I believe that this argument ultimately rests on contestable philosophical commitments too, so the point just made in the text stands. I hope to discuss this argument in more depth on another occasion.

[15] Sklar did not explicitly distinguish this second relationalist view from his first relationalist view expressed in his long quotation above. Indeed, his discussion tended to slur the two views together. I do not know which view he prefers; all that matters here is that the views are distinguished. Of course, on the first relationalist view, one could introduce a predicate, 'zero acceleration', that applies to systems with no inertial effects. But on that first view, this predicate will not play any explanatory role. On the second relationalist view, by contrast, the primitive properties of acceleration are said to explain inertial effects, just like acceleration through substantival space does according to substantivalism.

[16] See Huggett (1999) for excerpts from the correspondence.

[17] Sklar (1974, p. 179) discusses a related response to Leibniz.

[18] Some – for example, Earman (1989) – think that they must preserve topological features such as smoothness and differentiability. Others – for example, Ismael and van Fraassen (2003); Dasgupta (forthcoming) – think they must preserve the appearances. See Brading and Castellani (2007) for an in-depth introduction to symmetry in the context of classical physics.

[19] In the context of General Relativity (GR), one often sees a third approach: That the symmetries of GR mean that substantivalism entails *indeterminism*. This is the much-discussed 'Hole Argument'. But I agree with Hoefer (1996) that the focus on determinism is a red-herring and that the real issues involve redundancy and/or undetectability. Indeed, when Earman and Norton (1987) originally presented the Hole Argument, they focused on the issue of undetectabillity as well as indeterminism; it was the subsequent literature that took up the issue of indeterminism at the expense of detectability.

[20] To be clear, there is also a third use of symmetry, whereby one starts with a principle to the effect that the laws must have certain symmetries, and one uses this principle as a guide to discovering what the laws are. Einstein's classic 1905 paper on special relativity – translated as 'On the Electrodynamics of Moving Bodies' – is the paradigm of this sort of reasoning. But here, I am focusing the mode of inference whereby one already knows what the laws are, and one then uses that knowledge (via the symmetry reasoning described above) to settle ontological questions such as substantivalism. The two approaches just mentioned in the text are the two ways of developing this latter mode of inference.

[21] I should stress that it is no trivial matter to describe, in precise terms, a pair of theories like T1 and T2 that are empirically equivalent. But it should not be controversial that such cases can be described – indeed, we will see a clear example of a case like this in section 7. The point in the text is just that, in such cases, velocity through Newtonian space will be undetectable even though boosts are not symmetries of the laws.

[22] One could instead start off with a temporal distance between each *point* in the 4D structure, and then use that to induce a temporal distance between each 3D space. It does not matter for our purposes which way we proceed.

[23] Though, see Teller (1991) for a dissenting opinion. There, he argues that Galilean substantivalism is no better than Sklar's view, discussed in section 2, on which (1) and (2) are left unexplained.

[24] See, for example, Arntzenius (2012), Maudlin (2012), and Pooley (manuscript).

[25] These 'tilt worlds' are not shift worlds: They cannot be generated by shifting all matter uniformly over 3 feet to the right. One can think of tilted worlds as generated by a *time-dependent* shift, whereas shifted worlds are generated by a shift with no time-dependence.

[26] Is the conclusion here that *acceleration* is undetectable? That depends on how one defines acceleration. If one defines it to be motion along a curved trajectory, then the conclusion is that acceleration is undetectable. If, instead, one defines it as

motion under the influence of force, then the conclusion is not that acceleration is undetectable, but that motion along a curved (vs straight) trajectory is undetectable.

[27] This explanation can be filled out in a number of ways. One might say that there is not enough structure to 'meaningfully describe' the difference between boost worlds in the first place. Or one might say that a boost operation does not generate a distinct possible world, but rather a different description of the same world. But there is no need to work out further these details here.

[28] Here, it might help to emphasize again that substantival space-time is a *physical entity*, not a mathematical structure. It may be that, when doing mathematics, we should recognize no difference between isomorphic mathematical structures. And it may be that, when using mathematical structures to represent physical systems, we should adopt the convention of using isomorphic structures to represent the same system. But none of this implies that anti-haecceitism is true, i.e. that there is no difference between isomorphic possible worlds. For anti-haecceitism is not a thesis of mathematics, nor a thesis about how mathematical structures represent physical systems, but a thesis concerning physical matter and its possible arrangements in physical space.

[29] Might the sophisticated substantivalist's mentioned earlier have had this qualitativist view in mind all along? This is an exegetical issue that I will not explore fully here, and it is easy to slide into verbal disputes about what counts as 'qualitativism'. Here I just point out that their work contains much talk of counterpart theory and related modal theses that imply anti-haecceitism, in an effort to explain why (Shift) is false, and no attempt to develop a new view about the structure of space-time that would guarantee on its own that (Shift) is false. My point is that it is this new kind of view we should be after.

[30] Horwich (1978) made a related point, but drew a different conclusion from it. Teller (1991) also makes a similar point.

[31] We should read the 'can' liberally here, to allow the agent resources to expand her language, and so on.

[32] This variation was suggested to me by Ned Hall.

[33] In cases of inexpressible ignorance, what does the ignorance consist in? It is not obvious. For in ordinary cases of ignorance – e.g. when I do not know who will be the next president – there is a question to which I do not know the answer, and a popular view is that the ignorance *consists* in not knowing the answer (see Schaffer (2007) for a review of that popular answer). But in cases of inexpressible ignorance, the ignorance cannot (by definition) consist in a failure to know the answer to a question – at least, not one we can formulate. So what does it consist in? A full defense of the position I advocate in the text owes us an answer this question. See Dasgupta (forthcoming) for one approach.

[34] I am extremely grateful to Thomas Barrett for preparing the figures that appear in this paper. Thanks also to Thomas Barrett, Daniel Berntson, Robbie Hirsch, Michaela McSweeney, John Morrison, and an anonymous referee for their extremely helpful comments on earlier drafts of this paper.

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