How to be a Relationalist

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In Dasgupta (2013) I defended a relationalist view of mass. On this view mass is fundamentally relational, so that the state of a physical system vis-a-vis mass consists at bottom just in facts about mass-relationships, such as that one body is more massive than another. This is in contrast to the absolutist view that in addition to the mass-relations there are further facts about which "intrinsic" mass each body has.[1] In my paper I discussed a number of virtues of relationalism over absolutism. But David Baker (manuscript) argues that relationalism implies that classical physics is indeterministic and nonlocal in a certain way. Baker's stated aim is just to point out this consequence, but it is not hard to imagine someone complaining that the consequence is objectionable. So a relationalist should have something to say in response.

As Baker recognizes, there are complications with some of his examples—particularly his example of escape velocity—so a relationalist might quibble with those complications. But I think the complications are a distraction: I think Baker has effectively shown that relationalism leads to indeterminism and non-locality. Indeed, I now believe that a host of other relationalist views to which I am sympathetic also lead to indeterminism and nonlocality. Consider relationalism about *motion*, the view that all motion is motion relative to another body, as opposed to the absolutist view that there are extra facts about whether something is "really" moving independently of its motion relative to other bodies. It turns out that relationalism about motion also implies that classical physics is indeterministic and nonlocal physics—indeed, I will argue in sections 2-3 that this is the lesson of Newton's infamous "bucket argument". Another example is the case of handedness. Here the relationalist view is that the fundamental facts about handedness consist just in relations of congruence—that this hand is congruent with that one, incongruent with this other—in contrast to the absolutist view that there is a further property that distinguishes the *left*-hands from the *right*-hands. It turns out that relationalism about handedness also leads to indeterminism and non-locality.[2]

If all these relationalist views lead to indeterminism and nonlocality, the question is whether this a problem. This paper will argue that it is not. This will involve distinguishing two senses in which a theory can be indeterministic and nonlocal. These relationalist views do lead to indeterminism and nonlocality in *one* sense, but section 4 will argue that this is a *virtue* of relationalism, not a vice: indeterminism and nonlocality in this sense is exactly what we should want! There is a second sense of the terms, and in this second sense indeterminism and non-locality are indeed a vice. But in the bulk of the paper, sections 5-10, I will argue that these relationalist views *do not* lead to indeterminism or non-locality in this second sense. My conclusion will be that with respect to the question of determinism and locality, relationalist views get things exactly right.

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[1] In Dasgupta (2013) I called relationalism "comparativism". This is because in the case of other quantities like distance, even the absolutist agrees that the fundamental facts are relational; hence it seemed (and still seems to me) inappropriate to contrast absolutism with *relationalism*. Still, the multiplication of terms might be confusing in this paper, so here I revert to absolutism vs relationalism.

[2] For an introduction to the issue of absolutism vs relationalism about motion, see Sklar (1974), Maudlin (2012), and Dasgupta (2015). For an introduction of the issue about handedness, see Earman (1989), Pooley (2003), and Saunders (manuscript).

Determinism and locality are both intimately connected to metaphysical possibility, and to distinguish the two senses of determinism and locality we will need to distinguish two senses of metaphysical possibility (sections 8-9). This distinction between two notions of possibility might be of interest regardless of its bearing on the nature of determinism and locality.

In what follows I mostly focus on the case of handedness. This is because it is free of needless complications that arise in the other cases, and so easier to illustrate the main ideas. I will return to the case of mass only at the end (section 11). I will discuss the case of motion at times as we go along, but I leave a sustained application of my approach to that case for another time.

1. Relationalism vs absolutism about handedness

Given my focus on handedness, let me clarify the issue of relationalism and absolutism in that case. Consider a pair of gloves: one right-handed, one left-handed. They are known as "incongruent counterparts". They are counterparts because they share the same intrinsic geometry: each contains a thumb and a forefinger standing in the same angular relation, the same distance apart, and so on. But they are incongruent because there is no way of translating and rotating one glove through space in such a way that it exactly superimposes over the other. So defined, whether two gloves are congruent depends in part on the structure of space: they may be incongruent if space is Euclidean but congruent if space has the geometry of a Mobius strip. Let us assume for simplicity that space is Euclidean.

Consider some gloves divided into two equivalence classes under the relation of congruence. Call one class 'left-handed' and the other 'right-handed'. The question is whether there is a further physical property, above and beyond their relations of congruence, that distinguishes members of one class from members of the other. Absolutism is the view is that there is. This view comes in many varieties. The absolutist might say that there is a primitive, intrinsic property of *being left-handed* that all and only the left-handed gloves have. Or she might say that there is an oriented field pervading space, so that all and only the left-handed gloves are aligned with that field. Or she might say that gloves are situated in substantival space. On this third variety, the set of all glove-shaped regions of space can be divided into two equivalence classes under the relation of congruence. Call the regions in one class the L-regions. Then the idea is that all and only the left-handed gloves are located in L-regions.[3]

By contrast, relationalism is the view that there is no physical property that distinguishes hands in one class from those in the other. The hands in one class are congruent with each other, and incongruent with hands in the other class, and that is all there is to it. The clearest version of this view is the anti-substantivalist view that physical reality consists just in material bodies standing in spatio-temporal relations to one another. Suppose, as the anti-substantivalist must, that the geometry of the world—whether it is Euclidean or not—is fixed by (actual and/or possible) spatio-temporal relations between bodies. Then whether a pair of gloves is congruent

[3] To be clear, on this third version of absolutism I am (by stipulation) presuming the view on which there is trans-world identification of regions of space. So-called "sophisticated substantivalists" resist this claim, but their view (insofar as it is coherent, which I doubt; see Dasgupta (2015)) does not yield an absolutist view of handedness.

is fixed by the spatial relations between their parts. For the relationalist, these facts about congruence are all the facts of handedness there are.[4]

2. Machianism and Minimalism

The objection is that relationalism about handedness leads to an indeterministic and non-local physics. Let's start by seeing why this is so. In fact, Earman (1989) argued that the situation was worse: he argued that a relationalist has no physics of handedness *at all*. But in this section and the next I'll argue that Earman over-stated his conclusion: the right conclusion is what exactly Baker said about mass, namely that the relationalist's physics is indeterministic and non-local.

Earman's argument was based on the observation that certain things behave differently depending on whether they are left- or right-handed. This has been observed in neutral hyperons and the B-decay of cobalt atoms. But to avoid getting sidetracked with the physical details, let us work with a fictional example of Pooley's (2003, p. XX) that I have embellished. Imagine we discover that the components of matter are not little billiard balls or point-particles or strings, but *little hand-shaped things*. Call them handrons, and imagine that some are left- and others right-handed, and imagine that they move around and collide in accordance with deterministic laws of motion. Suppose further that they come in two colors: red and green. And suppose we observe that sometimes—but only sometimes—they change color when they collide. When we look closer, we discover that it is all and only the *left-handrons* that change color. These observations confirm the following "First Law" of handrons:

(F) Whenever a handron collides with another handron, it changes color iff it is *left*-handed.

Earman said that these observations would refute relationalism: since left- and right-handed handrons behave differently, there must be some real difference between them. As he put it, the relationalist 'does not have the analytic resources for expressing' a law like (F) (1989, p. 148).

Note that this is exactly analogous to Newton's famous bucket argument against relationalism about *motion*. Newton's argument was based on the observation that bodies of water behave differently depending on whether they are rotating or not; that water in a bucket sloshes up the side *if it is spinning* but stays flat if not. The argument is that the difference is not whether the water is spinning *relative to the bucket*, or *relative to the laboratory*, but whether it is spinning *absolutely*; that is, independently of its motion relative to other bodies. Thus, the objection is that observations of water in buckets confirm a theory that appeals to absolute acceleration, a quantity that the relationalist cannot recognize. To put it in Earman's terms, the relationalist 'lacks the analytical resources' to express the theory.[5]

But both objections are too quick. In each case, the relationalist can respond by offering an alternative physical theory of the phenomena, one that she *does* have the "analytic resources" to express.

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[4] See Brighouse (1999) and Pooley (2003) for discussion of how an anti-substantivalist is to understand relations of congruence. I will assume for the sake of argument that the relationalist has a notion of cross-temporal congruence. This entails, I think, that the relationalist must recognize *some* kind of cross-termporal spatial relation, contrary to what is sometimes known as "Leibnizian relationalism". But here I bracket exactly how this is best understood.

[5] For a fuller description of the bucket argument, see Sklar (1974, chapter 3), Maudlin (2012), and Dasgupta (2015).

In the case of motion, Mach took this approach when he proposed that water sloshes up the side of a bucket when it spins *relative to the fixed stars*. The general approach here was to choose some body (or bodies) and say that water sloshes up the bucket when it spins relative to *it* (or *them*). One could take the same approach in the case of handedness. Suppose that a particular handron was observed to change color upon collision. Call it 'Changy'. Then a relationalist could offer the following "Machian" alternative to (F) as her First Law of handrons:

(F-Machian) Whenever a handron collides, it changes color iff it is congruent with Changy.

Still, these Machian theories are unattractive. Some object to Mach's own theory of motion on the grounds that he never developed it with a precision to rival Newton's. Others object to these Machian theories on the grounds that fundamental physical laws should not make reference to particular entities like Changy or the fixed stars. But let me emphasize a third objection, which is that these Machian theories fly against scientific practice. If our basic law of motion were Mach's, one could never use it to model hypothetical physical systems in which the fixed stars do not exist. And yet scientific practice does this with basic laws all the time. Just imagine being asked in high-school physics class to solve a problem involving a harmonic oscillator: *on the face of it*, you are being asked to reason about a physical system that contains *just* an oscillator. More seriously, cosmologists routinely model counterfactual scenarios in which heavy elements, and hence the fixed stars, never form. Clearly, the same goes for any Machian approach that formulates the laws with reference to some special entity like Changy: the problem is that the theory does not apply to counterfactual systems in which the special entity does not exist, which flies against scientific practice.

Is this so bad? As a positivist, Mach may not have cared whether his theory could model far-out counterfactual scenarios. Still, it would be nice if relationalists can avoid the vice altogether, and I will argue that they can.

How? By proposing a theory that makes no reference to any particular bodies. In the case of handedness, this is straightforward. Perhaps the relationalist cannot say that the handrons that change color are all *left*-handed. But she *can* say that they are all congruent with one another, and incongruent with all those that do not change color. Thus, as Pooley (2003) and Saunders (2007) point out, she might simply offer *that* as her "minimalist" theory of handrons. More precisely:

(F-Minimalist) (i) If x and y are congruent handrons, then x changes color on collision iff y does too.
(ii) If x and y are incongruent handrons, then x changes color on collision iff y does not.

Unlike (F-Machian), (F-Minimalist) is not tied to any particular body and so applies to *any* counterfactual system containing handrons.

Sklar (1974) proposed an analogous minimalist theory in response to Newton's bucket argument. True, the relationalist cannot say that the flat bodies of water are all *absolutely* unaccelerated. But she can say that they are all unaccelerated relative to one another, and accelerated relative to those bodies of water that go concave. Thus, Sklar suggested that the relationalist can offer this "minimalist" law of motion; that is, a law that states '(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. XX).[6] On this view, the water in Newton's bucket goes concave because it is unaccelerated relative to other bodies that experience similar effects. This minimalist theory stands to Newton's theory just as (F-Minimalist) stands to (F). Unlike Mach's theory, it is not tied to any particular body and so can model counterfactual systems in which there are no fixed stars.[7]

3. Indeterminism and nonlocality

If there is an objection to these relationalist views, then, it is not that they have *no* physical theory of the phenomena at all (*contra* Earman and Newton). The objection must instead be that these minimalist physical theories are problematic in some way. But how? Pooley objected that (F-Minimalist) is indeterministic and nonlocal. This, I think, is what the objection really amounts to.[8]

It is easy to see that (F-minimalist) is indeterministic. Consider a world W containing just two left-handrons. Let the state of W at t0 be such that the laws of motion imply that the handrons will soon collide. Will they change color? (F) implies that they will, but (F-minimalist) does not. All (F-minimalist) says is that either both will change color, or neither will. So there are two possible futures consistent with (F-minimalist) and the initial state t0—the mark of indeterminism.

I just described W as containing two *left*-handrons, but does such a description make sense to a relationalist? Perhaps not; we will discuss this later. But for now it does not matter. For we may instead describe W as a world containing two *congruent* handrons, again arranged at t0 in such a way that the deterministic laws of motion imply that they will soon collide. For the relationalist, this is a complete description of the physical state of the world at t0. Yet (F-minimalist) is consistent with two possible futures, one in which they change color and another in which they do not; again, the mark of indeterminism. The absolutist avoids the problem because he distinguishes two possible initial states that fit the above description: one in which they are both right-handed, the other in which they are both left-handed. (F) then determines whether the hands in each system will change color.

I have been implicitly using the following standard definition of determinism:

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[6] Note that by 'relative motion' he means relative *acceleration*. Obviously this is just a rough gloss; the real theory would be mathematically more precise. But it is clear enough what kind of theory Sklar has in mind.

[7] For readers familiar with Sklar (1974), I should note that when introducing minimalism around pp. XX-XX he also introduced an *absolutist* theory that posits a primitive property of absolute acceleration. Unfortunately his discussion slurred the two theories together, and the subsequent literature picked up on his absolutist theory and ignored his minimalism. For what it's worth, I find his minimalist proposal by far the more intriguing.

[8] To be clear, Pooley focused on non-locality, but my guess is that he was thinking of the kind of indeterminism at issue here as a species of non-locality. For clarity, I distinguish them. The dialectic would be a little different if I were discussing the actual physics of handedness-dependent behavior, in which case the correlate of (F) would (arguably) be indeterministic anyway. But then the point would be that the correlate of (F-Minimalism) introduces another degree of indeterminism.

> A theory is *deterministic* iff any two metaphysically possible worlds in which it obtains, and which agree at one time, agree at all times.[9]

The point is that (F-minimalist) does not satisfy this definition regardless of whether we allow worlds to be described in terms of 'left' and 'right'. Note that the indeterminism here is somewhat unusual. It is not that (F-minimalist) is stochastic, assigning probabilities to possible futures. It just stays silent on the matter. Say that a theory is *complete* iff it is deterministic or assigns a unique probability to each possible future, given a complete description of a time-slice. Then the point here is that (F-minimalist) is neither deterministic nor complete.[10]

What about the claim that (F-minimalist) is nonlocal? The rough idea is this. Suppose that a handron *h* is about to collide. Will it change color? According to (F-minimalist), this depends on the results of other collision events containing handrons congruent to *h*. But it may be that the only such collision events occur many thousands of miles away. So, according to (F-minimalist), whether the handron changes color is not a function of its local environment but rather of its relation to potentially far off events—the mark of nonlocality.

It will be useful later on to be a bit clearer about the notion of locality in play here. As Baker explains when discussing the case of mass, the idea is that with local laws "approximately isolated systems can generally be treated as if they were entirely isolated" (manuscript, footnote 19). This is what allows us to model the gravitational behavior of the solar system to a high degree of accuracy while ignoring the gravitational effects of Alpha Centauri. The idea is that if we ignore everything outside the subsystem and pretend that it is its own possible world, this should have negligible effect on what the theory predicts about the subsystem. If S is a subsystem of a world W, this amounts to the following idea: that the result of *first* taking an intrinsic duplicate of the state of S at a time t *and then* evolving it forward according to the laws, is approximately the same as *first* evolving the entire state of W at t forward according to the laws *and then* taking an intrinsic duplicate of the state of S. Thus, locality amounts to a kind of commutativity between the operation of taking intrinsic duplicates of states and the operation of evolving forward according to the laws. Even Newtonian gravitation theory is local in this sense. Sure, if the sun doubled in mass there'd be an immediate gravitational effect on Earth, and that's non-locality of a kind. But since the effects of gravity decrease over space, we can still ignore Alpha Centauri when modeling the gravitational behavior of the solar system.

We can express this as follows. Given a theory T, call the worlds in which T is true and whose complete state at t duplicates the intrinsic state of S at t the *isolated S worlds*. These worlds represent how S can evolve from t, according to T, ignoring the rest of the world W. Then take the worlds that agree with W at t and in which T is true, and call the subsystem S in each world an *embedded S system*. They represent how S can evolve from t, according to T, taking into account the rest of the world. Then:

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[9] See Earman (1986) for definitions along these lines. His definitions quantify over *physically* possible worlds; I take these to be metaphysically possible worlds in which the actual laws obtain. To be clear, Earman and others have argued that this definition must be refined, but the issues they raise are not relevant for our purposes so I use this toy definition in what follows for simplicity.

[10] Compare the "Hole" argument for the claim that substantivalism renders General Relativity indeterministic; in that case too the indeterminism at issue is incompleteness, not stochasticity. See Brighouse (1994) for some of the issues involved there. Of course, (F-Minimalist) yields implications about all collision events when conjoined with information about a single collision event, for example that Changy changed color. But that conjunction is just (F-Machian).

> A theory T is *local* iff for any world W and any approximately isolated sub-system S of W, the isolated S worlds are approximate intrinsic duplicates of the embedded S systems.[11]

We can now show that (F-Minimalist) is not local in this sense.[12] Consider a world W that contains just four handrons: two left-handrons near one another, and light-years away two right-handrons nearby each other. Call these two sub-systems L and R respectively. Suppose at t0, the handrons in L collide and change color. And suppose that the deterministic laws of motion imply that at some later time t1, the handrons in R will collide. Will they change color? (F-Minimalist) implies that they will not. So there is only one embedded R system, one in which they do not change color. But if we now consider R as its own isolated world, we get a different result. For it is a world with just two right-handrons that collide at t1, and so (F-Minimalist) is consistent with two worlds, one in which both change color and one in which neither do. Each of these worlds is an isolated R world. So in this case the isolated worlds are not approximate intrinsic duplicates of the embedded systems; a failure of locality. As in the case of determinism, this argument can be made without describing W in terms of 'left' and 'right'. All we need stipulate is that the handrons in one sub-system are congruent with each other, and incongruent with both handrons in the other system, and the argument goes through just the same.

By contrast, the absolutist's physics is local in this respect. When we consider R as its own possible world, the law (F) implies that neither handron will change color, which is just what (F) implies when we consider the world W as a whole.

The upshot is that the relationalist's physics of handrons, (F-minimalist), is indeterministic and nonlocal in these respects, while the absolutist's physics is not.[13]

The same goes for Sklar's minimalist theory of motion. Given a world with just two buckets of water at rest relative to one another, Sklar's minimalist theory does not determine whether the water in either bucket will slosh up the side. All it says is that either both bodies of water will remain flat, or both will go concave, but it does not determine which (indeterminism). And whether a body of water goes concave depends on its motion relative to other, perhaps far-off, bodies of water (nonlocality).

This, I suggest, is the real moral of Newton's bucket argument against relationalism about motion, and Earman's argument against relationalism about handedness. Properly understood, the argument in each case is *not* that the relationalist can provide no physical theory of the

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[11] To be clear, I mean that the isolated S worlds and the embedded S systems can be put in a 1-1 correspondence under the relation of "approximate intrinsic duplicate". I should emphasize that I am not attempting to capture a general, all-purpose notion of locality, or to analyze the everyday or physical term "locality" (indeed the current definition does not adequately cover the stochastic case). I am instead introducing by stipulation a term that is useful for discussing the absolutism vs relationalism dispute.

[12] The argument here is based on Baker's (manuscript) argument, in the case of mass, that the relationalist's physics is indeterministic. But while he used a similar set-up to establish indeterminism while assuming locality, I take myself to already have established indeterminism and am using the set-up to establish non-locality.

[13] I am again sacrificing precision for the sake of brevity. It is not quite right to say that (F) is deterministic, since on its own it does not determine much at all. More accurately, the claim is that (F), together with laws of motion that are deterministic vis a viz motion, is a deterministic theory.

phenomena whatsoever. Rather, the argument is that the relationalist's physics, unlike the absolutist's, is indeterministic (in the sense of being incomplete) and nonlocal.

4. Turning the tables

But we only get an objection to relationalism if incompleteness and nonlocality are problematic. Are they? The consensus is that they are; that completeness and locality are weighty, perhaps nonnegotiable, desiderata.[14] Indeed, having noted that (F-Minimalist) is non-local, Pooley immediately concludes without further discussion that this is a major strike against relationalism. But I think this consensus gets things exactly back to front: the fact the relationalist's physics is incomplete and non-local is a *virtue*, not a vice!

To see this, we must ask what could justify a preference for complete and local theories. On the one hand, the justification could be *apriori*. For example, one might claim that the preference for complete and local laws is a primitive epistemic norm governing theory choice. Or one might might argue on broadly apriori grounds that the laws must be complete and local. For example, one might try arguing for an anti-Humean, "governing" conception of laws, and then argue that laws cannot "govern" in any literal sense if they are incomplete or non-local.

But on the other hand, the justification could be *empirical*. The idea would be that when we observed the world it *looked like* it was governed by complete and local laws. In the case of handedness the idea would be that when our (fictional) scientists observed handrons, they found that exactly 100% of the observed left-handrons changed color upon collision, and exactly 100% of the observed right-handrons did not. It was not that 80% of the observed left-handrons changed color, inviting a stochastic theory. No: fully 100% of them changed color. *On the basis of these observations* they proposed a deterministic law, namely (F). This is not an *apriori* expectation that the world is deterministic, but an *observation* that it looks to be that way. A theory like (F-minimalist), on which handrons are *not* governed by a deterministic law, therefore flies against a scientific finding that is well-confirmed by observation. *Mutatis mutandis* for locality: when we observed handrons, the idea would be, it did not *look* like their behavior depended on the outcomes of far-off collision events, but whether they were *left-handed*.

So, there are two versions of the objection to relationalism. One says that relationalism violates an *apriori* requirement that the laws of our world be complete and local; the other says that relationalism goes against the *observed fact* that our world is complete and local. I do not know which one Pooley had in mind, but the second seems to me far more pressing than the first. The history of physics—notably the history of geometry—shows that we should hesitate to put much weight on apriori principles to the effect that the world has this-or-that spatiotemporal or causal structure. Conflicting with such "principles" is not such a big deal. But conflicting with *observed scientific findings* is far more serious. If handrons are *seen* to behave deterministically, and relationalism implies that they do not, then relationalism is disconfirmed by observation.

The same goes in the case of motion. Why might it be a problem that Sklar's minimalist theory of motion is indeterministic? Not because we know apriori that the laws of motion are deterministic—we know no such thing. Rather, if it is a problem it is because when we observed water sloshing around in buckets, we saw that *precisely 100% of spinning bodies of water* went

[14] Skow (2007) is explicit about this desidera, and notes that it is shared by theorists of many different kinds, including relationalists such as Barbour (1999).

concave, confirming the hypothesis that bodies of water behave in accordance with deterministic and local laws like Newton's.

I claim, then, that *if* there is an objection to relationalism in either case, it is the charge that it goes against the observed fact that handrons, and buckets of water, behave in accordance with deterministic and local laws.

But what exactly is the observed fact? Here we must take care. To be sure, the absolutist's theory of handrons is deterministic and local; but did we observe handrons behaving in accordance with *that theory*? We did not. For let us be clear about the *content* of the absolutist's theory. He interprets 'left' as referring to that physical property L that he thinks distinguishes left- from right-handrons. So interpreted, (F) states that the handrons that change color are those with that physical property L. This theory is indeed deterministic and local, *but our observations did not confirm this theory*. We did not observe that the handrons that changed color were all aligned with some theoretical field. After all, everything would look (and smell, and taste) exactly the same in a world that differs only in that every handron is mirror-flipped from left to right and versa-versa; a world, that is, in which the handrons that change color are all *anti-aligned* with the field and the ones that *do not* change color are all aligned. What we observed gives us no reason to think that we live in one world over its flipped cousin. All we really observed are the relational facts common to both worlds, namely that the handrons that changed color were all congruent with one another. *This* confirms (F-minimalist), but does nothing to confirm the absolutist's interpretation of (F)![15]

Sklar noticed this point when motivating his minimalist theory of motion. He emphasized that we never directly observe whether a body of water is spinning in any *absolute* sense; rather, we just observe (i) whether it is sloshing around the sides of the bucket, and (ii) its state of motion relative to other bodies (Sklar 1974, p. 230). Everything would look (and smell, and taste) exactly the same in a world in which water stays flat when it is *spinning at some absolute rate*, and goes concave when it is spinning relative to that absolute rate. Thus, Sklar claimed, his minimalist theory of motion, not the absolutist's theory, is exactly what is confirmed by observation. I am just making the same point in the case of handedness.

It follows that the tables are turned: it is the *relationalist*, not the absolutist, who gets things right with regards to observations of determinism and locality! Sure, the relationalist's physical theory is indeterministic and non-local, but such a theory is *precisely* what observation confirms. If anything, it is the *absolutist* who has the problem here, postulating a deterministic and local theory that goes beyond what is confirmed by the evidence.

If this is surprising, it might be because we always observe *subsystems* of the universe, not the entire universe itself. If I observe a subsystem with a handron about to collide, and if I know that it is congruent with a handron outside the subsystem that changed color, then *my background knowledge* plus (F-Minimalism) implies that it will change color. Likewise, if I observe a subsystem containing a bucket of water, and if I know that it is at rest relative to a bucket of water outside the subsystem that remained flat, then *my background knowledge* plus

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[15] One might suggest that observation at least provides reason to believe that *there exists* a field, such that the handrons that change color are either all aligned or anti-aligned with it. The idea might be that this theory better explains the observations than (F-Minimalist), and so is justified on the basis of inference to the best explanation. But even if so, this theory is indeterministic and non-local in just the same way that (F-Minimalist) is. Thus, the fact remains that *the theory justified by observation*, whatever it is, is indeterministic and non-local.

Sklar's minimalist law implies that the water will remain flat. This gives the *appearance* of determinism: the behavior of any subsystem is indeed determined by the laws *and facts outside of it*. Nonetheless, our observations do not at all confirm that *the universe as a whole* is deterministic or local.

So far, then, it is the *relationalist*, not the absolutist, who has the upper hand.

5. The emergence of determinism

Still, there is a residual issue; albeit one tricky enough to concern us for the rest of the paper. True, we did not observe the deterministic and local behavior *described by the absolutist's theory*. But we did observe deterministic and local behavior *of a sort*. Real physicists investigating the B-decay of cobalt atoms do not limit themselves to talk of congruence; they routinely describe the atoms as being *left*- or *right*-handed and theorize about them in those terms (or cognates). So, if our fiction of handrons is to *minimally* resemble actual life, our fictional scientists would use 'left' and 'right' to describe handrons and theorize about them too. And the fact remains that if they described their observations of handrons in terms of 'left' and 'right', they would have found that 100% of the observed *left-handrons* changed color, confirming a theory *they would write down as* (F). And (F), I will argue, would then be *used in physical reasoning* in a deterministic and local fashion. In *some sense*, then, we still have empirical evidence that handrons behave deterministically; all we've learnt is that this is *not* evidence that they behave in accordance with *the absolutist's interpretation of* (F). The question is whether the relationalist can account for determinism and locality *in this sense*.

To be sure, a relationalist will regard this talk of 'left' and 'right' as non-fundamental, since fundamentally speaking the only truths about handedness are truths about congruence. But to account for the practice of physics the relationalist must make sense of this talk nonetheless. The question is how. What could 'left' and 'right' *mean* to a relationalist, such that this use of 'left' and 'right' in physical practice makes sense? And how is this deterministic usage of (F) consistent with the relationalist's view that *fundamentally speaking*—under the hood, as it were—handrons behave indeterministically as described by (F-Minimalist)? As we will see, it is not at all clear. If there is an objection to the effect that the relationalist cannot make sense of "the observed deterministic and local behavior of handrons", this is it. The rest of the paper will develop a response.

Let us clearly set out the practice that needs to be explained. It includes describing handrons in terms of 'left' and 'right', and expressing observations of their behavior by writing down statements like

(O) This *left*-handron changed color.
This *right*-handron did not.

And it includes taking these statements to confirm a theory that would be written down as

(F) Whenever a handron collides with another, it changes color iff it is *left*-handed.

Already the question arises as to what a relationalist could mean by this talk of 'left' and 'right'. But the practice I want to focus on also includes the fact that, having written down (F), our fictional physics would *reason with it as if it were deterministic and local*. I'll focus on

determinism, returning to locality later on. To see the point, consider first its use in predicting actual events. Imagine one of our fictional physicists teaching a student about (F), and suppose they happen across a left-handron. Sensing a teachable moment, the professor sets the following pop quiz:

Question 1: According to (F), will this left-handron change color?

The right answer, of course, is that it will; that given (F) it *must* change color; that (F) *determines* that it will change color; that (F) *rules out* any other possible outcome. The professor should give all these answers full marks. But this is to reason *deterministically* with (F).

To emphasize the point, suppose that when originally observing handrons, they had seen that most but not all of the left-handrons changed color. And suppose that a statistical analysis of the data confirmed the following:

(F*) (i) When a left-handron collides with another, there is an 80% chance that it changes color.
(ii) When a right-handron collides with another, it stays the same color.

Then if Question 1 asked what will happen to a left-handron according to (F*), the correct answer is that it will *probably* change color but *might* not; that (F*) leaves open *both possibilities* but says that one is *more likely* than the other. Thus, physicists will reason differently with (F*) than with (F): with (F) they reason *deterministically*, with (F*) they do not.

The same goes when reasoning about *hypothetical* events. To further test her students' comprehension of (F), our fictional professor might hand out another pop quiz:

Question 2: Consider a possible world in which there are just two *left*-handrons about to collide. According to (F), what will happen?

Again, the right answer is that both handrons will change color; that given (F) they *must* change color; that (F) does not leave open any other possibility; and so on. Again, the relationalist professor should give these answers full marks. But, again, this is to reason with (F) *deterministically*.

And note that the professor may go on to test her students by handing out a third pop quiz:

Question 3: Consider a possible world in which there are just two *right*-handrons about to collide. According to (F), what will happen?

This time, the students can easily calculate that neither will change color; that according to (F) this is the *only* possible outcome. Again, this is paradigmatic deterministic reasoning.

Questions 1-3 are known as "initial value problems": one is given the initial state of a hypothetical physical system and is asked to solve for what happens. In Questions 1-3, notice, the initial state is described in terms of 'left' and 'right'. My point is that initial value problems like these are standard in actual physics: the initial state of some cobalt atoms will be described in terms of 'left' and 'right' (or cognates) and one is asked to solve for what happens. If our fictional

physicists are to resemble actual physicists at all, they will trade in initial value problems like Questions 1-3.

This then is our data: the vocabulary of 'left' and 'right' enters into the practice of physics in recording observations like (O), stating theories like (F), and in reasoning about initial value problems in the deterministic manner described. The question is whether the relationalist can make sense of this practice, and it is not at all clear that she can.

There are two worries. The first is whether she can legitimately *characterize* initial value problems like Questions 2 and 3 in terms of 'left' and 'right'. This worry can be motivated by reflecting on a relationalist semantics of 'left' and 'right'. Suppose that the only meaning the relationalist could attach to 'left' is to treat '*x* is left-handed' as synonymous with '*x* is congruent with S', where S is some standard object like Changy, or a set of objects like hands on our heart-side or physical particles of some kind; and conversely for 'right'. On this semantics she can meaningfully describe *actual* handrons, such as that in Question 1, as left- or right-handed: they are being described as congruent or incongruent with S. But such a semantics is unable to account for the practice of characterizing the *counterfactual* handrons in Questions 2 and 3 in terms of left and right. For the standard object(s) S do not exist in the worlds described by Questions 2 and 3, and so on this semantics it cannot be true that those worlds contain *left*- or *right*-handrons.[16] More generally, the worry is that relationalism implies

> **Incommensurability:** There is a class C of metaphysically possible worlds such that, for any possible world W in C, and any handron *x* in W, there is no fact of the matter whether *x* is left- or right-handed in W.[17]

Different specific semantics of 'left' will differ on what the class C is, but the worry is that *any* relationalist semantics will entail that it is non-empty, and will include worlds like those described in Questions 2 and 3.

The worry might also be put without semantic ascent. For suppose one held that all facts about a possible world must be "fixed" or "settled" or "grounded" by the fundamental facts of that world. For the relationalist, the fundamental facts in Question 2 are just that there are two congruent handrons, and that they are about to collide. But how could that settle whether they are left- or right-handed? The worry would be that this sparse fundamental basis is not sufficient to fix it one way or the other; hence we have Incommensurability.

But put that worry aside for a moment. Suppose for the sake of argument that the relationalist can legitimately characterize the world in Question 2 as containing two *left* handrons. The second worry is whether she could then characterize the world in Question 3 differently, as containing two *right* hands. For the two worlds agree on all facts about

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[16] This is, in effect, our objection to the Machian proposal in section X. For if the relationalist defines 'left' as 'congruent with Changy', then in her mouth the theory (F) becomes synonymous with (F-Machian). And as we saw, this theory makes no predictions about worlds in which Changy does not exist.

[17] The idea that there is "no fact of the matter" as to whether a given handron is left- or right-handed in a world W can be understood in a number of ways. One way is to admit of truth-value gaps at W, and say that instances of "*x* is left-handed" and "*x* is right-handed" are neither true nor false at W. But those who dislike truth-value gaps can understand the idea differently and say all such instances are false at W. It will not matter for our purposes which version we pick (the main points can be reconstructed regardless) though I will sometimes talk as if there are truth-value gaps for simplicity.

congruence, and surely—the objection goes—relationalism implies that any two worlds agreeing on all facts about congruence cannot disagree on any further facts about handedness, such as whether something is left- and right-handed, precisely because on her view there are no further facts! Specifically, the worry is that relationalism implies

> **Relational Supervenience:** Metaphysically possible worlds agreeing on all relational matters of congruence agree on all matters of handedness.

Thus, *if* the world in Question 2 contains two *left*-handrons, Relational Supervenience implies that the world in Question 3 *also* contains two left-handrons; hence the relationalist cannot distinguish Questions 2 and 3. She cannot, that is, make sense of the practice of assigning the two questions and saying that they have *different* answers.

These two worries amount to a kind *modal breakdown*. Thanks to Incommensurability, the relationalist cannot *characterize* initial value problems like Questions 2 and 3 in terms of 'left' and 'right'; and thanks to Relational Supervenience she cannot *distinguish* them.

By contrast, the absolutist faces no modal breakdown. He can interpret 'left' as denoting the special physical property L that all and only the left-handrons have. There is then no problem with characterizing worlds like Questions 2 and 3 in terms of 'left' and 'right': he is characterizing the distribution of L in those worlds. And there is no problem in distinguishing the worlds in Questions 2 and 3: they differ in their distribution of L. More generally, he interprets (F) as expressing the theory that a handron changes color iff it has L, and as we saw in section 3 this theory is deterministic. So the absolutist has no problem making sense of the deterministic reasoning described above. But the relationalist cannot interpret 'left' like this (and in any case she does not want to since on that interpretation, we now know, (F) expresses a theory that goes beyond what is confirmed by observation). So the question is whether she can interpret talk of 'left' and 'right' somehow else, in such a way as to make sense of the deterministic reasoning above.

If she cannot, she would have to bite the bullet and argue that the practice of physics should be revised. But this is an extremely unattractive bullet to bite—who would want to tell their colleagues in the physics department that their theories of cobalt atoms are entirely misguided?! The point here is most perspicuous in the case of mass. In that case, the relationalist view is that the fundamental facts about mass just concern mass-relationships, such as whether *x* is more massive than *y*. But the actual physics of mass is nonetheless practiced in units such as mass-in-kgs, an expression that the relationalist does not regard as fundamental. Observations are recorded in the language of mass-in-kgs, theories are expressed in that language, and initial value problems are routinely described in these terms too. Thus a high-school physics problem might describe an initial value problem in which there is a rocket on the surface of Earth, fired straight up at a certain velocity, and the student must calculate whether it escapes the Earth's gravitational field or falls back to the ground. In such problems, the mass of the rocket and the Earth are routinely described *in the language of mass-in-kgs*. If the rocket escapes, a second question may describe an initial value problem in which the rocket and the Earth are *double* the mass-in-kgs they were in the first problem, and the students will then calculate that in this case the rocket will fall back to the ground. These are precisely the initial value problems that Baker (manuscript) discussed when discussing relationalism about mass. Though he put it differently, his basic idea was that the relationalist appears unable to makes sense of these initial value

problems, yet no one bats an eye-lid when assigning them to high-school physics students. If the relationalist cannot make sense of them, so much the worse for her.[18]

This then is the central challenge for the relationalist, as I see it. The challenge is to interpret talk of 'left' and 'right' in such a way that (i) makes sense of the deterministic reasoning above, and yet (ii) does not collapse into the absolutist's interpretation, on which (F) expresses a theory for which there is no evidence.

6. Devices of coherence

In what follows I will show how the relationalist can meet this challenge. I will not argue that it is the best or only way, just that it works. I proceed in two stages. First, I will propose an account of how a relationalist might use the terms 'left' and 'right' to record observations like (O) and express a theory like (F). Then on the basis of that account, I will develop a theory of metaphysical possibility that avoids the modal breakdown, thereby making sense of the deterministic reasoning with (F) described above.

So, how might a relationalist use the language of 'left' and 'right'? The obvious way is to define 'left' as 'congruent with Changy', or some other standard. But we know that this leads straight to Incommensurability.

Thankfully, there is another way to use the terms. Let me illustrate with a fictional community. Imagine a community of relationalists who lack the terms 'left' and 'right'. They have only a 2-place relational predicate 'x is congruent with y' with which to talk about handedness. They wish to introduce 1-place predicates to help them store and communicate information about congruence more efficiently. To this end, they introduce two new marks, # and *. Their idea is to use these marks in such a way that if two hands are both marked #, or both marked *, this means that they are congruent; while if one is marked * and the other #, this means that they are incongruent. More precisely, they stipulate that the marks are monadic predicates that are governed by the following three rules of inference (R1)-(R3):

(R1)	(R2)	(R3)
x is #, *y* is #.	*x* is *, *y* is *.	*x* is #, *y* is *.
Therefore, *x* and *y* are congruent.	Therefore, *x* and *y* are congruent.	Therefore, *x* and *y* are incongruent.

But they stipulate nothing else. Note that these are exit-rules; there are no intro-rules that specify sufficient conditions for concluding (say) that *x* is #. Thus, they have not given explicit definitions of the predicates in terms of standard reference bodies.

Still, this is enough to ground a practice that encodes information about congruence. When they first encounter a handron *h1*, they can call it # or *, since either is consistent with the rules. Suppose they call it #. And suppose they then encounter a handron *h2* that is incongruent to *h1*.

[18] It might be thought that initial value problems like these can be interpreted as descriptions of possible *sub-systems* that exist alongside various reference points such as standard objects in Paris, laboratory equipment, and so forth, so that Incommensurability will never be a problem. But even if this is an option with *some* initial value problems, the solution clearly does not generalize. As I mentioned before, cosmologists think about initial value problems in which heavy elements, and hence our planet and all the reference points it contains, never exist.

If they call it #, then by (R1) they could infer a falsehood. So, insofar as they aim to utter things that imply truths, their hand is forced: they must call it *. In this way, when a speaker uses the marks her aim is to "cohere" with other accepted uses in the community, in the sense that their combined uses yield truths about congruence via (R1)-(R3). Once their use of the marks becomes entrenched—imagine them using these marks for a few decades—there will be a clear distinction between "correct" uses that cohere and "incorrect" uses that do not. In this way, they can use # and * to communicate information about congruence.

Cohering with one's community is no easy task, especially if the community is large and dispersed. To aid coherence, it can help to use a "standard glove" displayed in a public place. If each speaker ensures that she coheres with the claim that the standard glove is #, they will all cohere with one another. But—and this is important—they need not *define* the predicate "*x* is #" to be synonymous with '*x* is congruent to the standard glove'. The standard glove is functioning just as a practical aid to help them cohere with one another, not as a definition (nor as a reference-fixer). If they discover by surprise that all their interactions with the standard were subject to some massive but systematic illusion, so that the gloves they call # are in fact *incongruent* with the standard, they would report this discovery by saying that the standard is in fact *. So long as their other applications of # and * still cohere with one another, there is no need for further revision.

I think that that our use of 'left' and 'right' is, in all important respects, like their use of # and *. We use them as devices of coherence, so that our aim in uttering 'x is left-handed' is to cohere with other utterances in our linguistic community in the above sense. On this view, standard objects—like the hand on our heart-side, or certain kinds of molecules, or standard gloves in Paris—do not serve to define 'left' and 'right', but are practical aids to help us cohere with one another. But the claim that the coherence view is true *of us* is an empirical claim about language that I will not defend. Here I just make the uncontroversial claim that it is *possible* for a community of relationalists to use 'left' and 'right' as devices of coherence. What I will argue is that *if* the terms are used like this, this would account for their usage in physical practice described in section 5.

It is easy to see that it would account for the practice of describing observations like (O) and advancing theories like (F). For imagine that a community has been using 'left' and 'right' as devices of coherence for generations, so that there is a clear distinction between "correct" uses that cohere and "incorrect" uses that do not. They will then recognize left-hands from right-hands in much the same way that we do, say by making an "L" shape with the hand on her heart side, or whatever other method you like to use. For them, these methods are not an attempt to determine whether a given hand satisfies a definition of 'left', but an attempt to ensure that their use of the terms cohere. So, when observing handrons, they will fill their notebooks with inscriptions like

(O) This *left*-handron changed color.
This *right*-handron did not.

And they would take these to confirm a theory she would write down as (F). Since their use of 'left' is not tied to any particular standard object, their utterance of (F) is not equivalent to a Machian law.

This is not to settle all semantic questions about this usage. What proposition is expressed by (F), or by the sentences in (O)? What are their truth-conditions? I haven't said. For now, the claim is just that a relationalist who uses 'left' and 'right' as devices of coherence will describe her observations of handrons as above, and will take those observations to confirm a theory she will write down as (F).

That much is straightforward. The more difficult question is whether this coherentist account allows the relationalist to make sense of the deterministic reasoning with (F) described above, as manifested in Questions 2 and 3. Here she faced the "modal breakdown". Thanks to Incommensurability, the relationalist could not legitimately *characterize* the worlds in Questions 2 and 3 in terms of left and right; and thanks to Relational Supervenience she could not *distinguish* them.

We have already gone *some* way to dissolving the problem of Incommensurability. After all, one argument for Incommensurability rested on the assumption that the relationalist defines 'left' as congruent with some standard object like Changy; this semantics entailed that 'left' has no content when used to describe the worlds in Questions 2 and 3 in which Changy does not exist. But if 'left' and 'right' are devices of coherence, the assumption is false. Indeed when used as devices of coherence, it is unclear why it would be illegitimate to characterize the handrons in Question 2 as left-handed. After all, by characterizing them as 'left' she cannot derive anything false with (R1)-(R3); all she can derive is that they are congruent!

Likewise, we can already start to see how this *might* help dissolve the problem of Relational Supervenience, of showing how the relationalist can distinguish the worlds in Questions 2 and 3. For *if* she can legitimately characterize the handrons in Question 2 as *left*-handed, by the same reasoning it would equally be legitimate to characterize them as *right*-handed. Perhaps the "worlds" of Questions 2 and 3 should then be thought of as something like "worlds *under a description*", and can therefore be distinguished by their different descriptions?

But this is just speculation at this stage. The task now is to show that these speculations are in fact sound.

7. Modal correspondence

The key is to think about the notion of possibility involved in initial value problems. Philosophers tend use the term 'possible world'—and cognate terms like 'metaphysical possibility'—in such a way that the modal breakdown is, I think, inevitable. On this sense of 'possible world', I think there is no question that relationalism implies Relational Supervenience and Incommensurability. But it seems to me an open question whether this is the sense of 'possible world' relevant to a proper understanding of initial value problems. When a high-school physics teacher asks students to find a solution to a specific initial condition, it is far from clear that she is asking them to think about a "metaphysically possible world" in the philosopher's sense of the term! Indeed, physicists rarely use the term themselves, talking rather of "models" or "hypothetical physical systems" or "fictional situations".

Much the same goes for the notion of determinism. We defined determinism by quantifying over a set of indices, and we called the indices "possible worlds". But it seems to me an open question whether these indices must be understood as possible worlds in the philosopher's standard sense of the term. Again, note that an ordinary definition of determinism found in a

high-school physics text would likely not use the language of possible worlds, and would instead talk of models, or "closed systems", or something of that ilk. Indeed, it seems inevitable that these indices in the definition of determinism are the very same things that we describe in initial value problems. If so, any doubt as to whether the latter are possible worlds in the philosopher's sense transfers over to the former.

It is therefore a piece of *philosophical dogma* that identifies the things described in initial value problems, and the indices in our definition of determinism, with possible worlds in the philosopher's sense of the term. If this philosophical dogma cannot account for the deterministic usage of (F) described above, so much the worse for the dogma.

So, I claim that we should reject the dogma. The challenge is then to say what the things described in initial value problems, and the indices in our definition of determinism, are. To answer this, I will argue that we must distinguish between two varieties of metaphysical possibility. One is possibility in the philosopher's sense—the familiar sense in which relationalism implies Relational Supervenience and Incommensurability, and absolutism does not. I will call this "strict possibility". But I will argue that there is a closely related notion of possibility, which I call "loose possibility", on which relationalism does *not* imply Relational Supervenience or Incommensurability and the modal breakdown is avoided. More generally, the main result to be established is the following:

> **Modal Correspondence Thesis:** There is a one-one correspondence between the space of *strictly* possible worlds recognized by the absolutist, and the space of *loosely* possible worlds recognized by the relationalist, that preserves all relational facts of congruence *and* facts about left and right.

It follows that if the relationalist treats the things described in initial value problems as *loosely* possible worlds, then she can freely *characterize* the worlds in Questions 2 and 3 in terms of left and right, and *distinguish* them, just like the absolutist can. More generally, if the relationalist treats the indices in the definition of determinism as loosely possible worlds, then it turns out that (F), in her mouth, is deterministic! In this way she can make sense of the deterministic usage of (F) describe above.

The question is what this notion of loose possibility could be. It is not hard to find a formal object that makes the Modal Correspondence Thesis true: we can just say that a loosely possible world is a pair <W, *f*>, where W is a strictly possible world and *f* is a function assigning the word 'left' to one congruence class of handrons in W and the word 'right' to the other. This is just the idea of a "world under a description" mentioned earlier. Even if a relationalist cannot distinguish two *strictly possible* worlds that differ only in a uniform flip of left-to-right and vice-versa, she can easily distinguish <W, f_1> and <W, f_2>, where f_1 and f_2 differ only in flipping which congruence class is assigned the word 'left' and which 'right'. Functions are cheap, as they say. More generally, the space of pairs <W, *f*> recognized by the relationalist clearly corresponds one-one with the space of strictly possible worlds W recognized by the absolutist, thereby verifying the Modal Correspondence Thesis.

This solution is *formally* adequate, but it ignores the crucial *philosophical* question of how we are to understand the notion of loose possibility. If the world W is what philosophers typically mean by a "metaphysical possibility", what do the pairs <W, *f*> represent? Some kind of logical possibility? Or epistemic possibility? Or something else? This is where the real challenge lies.

Remember, the pre-theoretic idea behind determinism is that a system *must* evolve in a certain way, given the laws. And it is widely agreed that this is not the logical 'must': it is not that the present state of the system and the laws *logically imply* its future state. Nor is it an epistemic 'must': it is not that *an ideal agent could infer* how the system will evolve, given complete knowledge of its initial state and the laws—this notion of "Laplacian determinism" is not of interest to contemporary philosophers of physics. Rather, the consensus is that the sense of determinism of interest involves a *metaphysical* sense of "must". Our definition of determinism captures this by quantifying over a set of indices, the "possible worlds". But this will succeed only if each index is a distinct possible world *in some metaphysical sense of the term*. So it's not enough to just produce some formal object like <W, *f*>; it must also be shown that what it represents is a genuinely metaphysical kind of possibility.

The challenge, then, is to elucidate a notion of loose possibility that verifies the Modal Equivalence Thesis, *and show that it is a genuine species of metaphysical possibility*. But what exactly is *metaphysical* possibility? It is supposed to be distinctive by being constrained not by the logical constants (logical possibility), or by states of knowledge (epistemic possibility), but "by the world". Thus, when a physical system *must* evolve in a certain way, in the metaphysical sense of "must" relevant to determinism, the idea is that this is due not to our state of knowledge or the logical properties of a formal language, but due to *the physical system and the laws themselves*. This is suggestive, but hardly precise. To proceed, then, I will take the notion of strict possibility as our fixed point. This is the familiar notion of metaphysical possibility on which relationalism (but not absolutism) implies Relational Supervenience and Incommensurability. We can all agree that *it* is a species of metaphysical possibility. I will argue that strict possibility should be understood in terms of *fundamentality*, and that fundamentality should in turn be understood in terms of *explanation*. I will then distinguish a slightly different notion of explanation, and show that it yields the notion of loose possibility. Since strict and loose possibility will both be understood in terms of two related senses of explanation, that will suffice to show that each is as "metaphysical" as the other, whatever that means.[19]

8. Possibility and explanation

So, let us examine the notion of strict possibility, the ordinary notion of metaphysical possibility used familiarly by philosophers. As a first approximation, I claim that a strictly possible world is a *way of reorganizing fundamental matters*. For example, consider a relationalist view on which fundamentally speaking there are just handrons standing in various spatial relations with one another at any given time—ignore any non-spatiotemporal properties and relations for simplicity. A strictly possible world, then, is a way of arranging the spatial relations between handrons over time. This explains why this relationalist view implies Relational Supervenience, at least when the latter is understood as concerning strict possibility. For if a strictly possible world *just is* a way of spatially relating handrons, then any strictly possible worlds agreeing on all relational respects are the same.

[19] In Dasgupta (2013), when discussing the case of mass, I tried to distinguish strict from loose possibility using counterpart theory. The idea was to mimic Lewis' (1986) "cheap haecceitism", where he uses counterpart theory to distinguish between two modal indices: possible worlds and possibilities. I showed that this approach can be extended to the case of mass, and it could be applied to the case of handedness too. But counterpart theory (of any form) now strikes me as an inadequate way of getting to grips with metaphysical possibility, so here I explore a different approach.

This conception of a possible world is arguably implicit throughout philosophy. Consider the physicalist view that the world is fundamentally speaking purely physical. It is widely thought that this view has the consequence that worlds that are physically identical, and which contain no "alien" fundamentalia, agree on all facts about consciousness, normativity, and so on. This is indeed a consequence of physicalism, if a world is understood to be a way of recombining fundamental matters.

The idea that a strictly possible world is a way of reorganizing fundamental matters does not imply "combinatorialism", the view that *every* reorganization is a strictly possible world. Suppose that one way of reorganizing the spatial relations between bodies results in *x* being 2 feet from *y*, *y* being 2 feet from *z*, and yet *x* being 50 feet from *z*, in violation of triangle inequality. Some think that such a world is impossible. Thus, there may be principles like triangle inequality that restrict which ways of recombining fundamental matters are genuinely possible. We need not settle what the content of these principles are, if indeed there are any. Let us just call them "metaphysical principles" for future reference. When I claim that a world is a way of reorganizing fundamental matters, I mean a way of reorganizing them that is consistent with the metaphysical principles (whatever they are). By saying nothing about the content of the metaphysical principles, then, my claim does not settle many questions of what is in fact strictly possible. But the claim is not vacuous, since it implies that there cannot be *two distinct* strictly possible worlds that agree on all fundamental matters.

This way of thinking about possibility connects it to the notion of fundamentality. But what is fundamentality? As a first approximation, I propose to understand something as being fundamental iff it is *unexplained*, in a "metaphysical" or "constitutive" sense of the term.

To illustrate this notion of explanation, suppose that the fundamental matters just concern atoms spinning in a void. Still, there are chairs; it is just that chairs are things that exist when *and because* the atoms are arranged in a certain way. The fact that there is a chair *holds in virtue of* the arrangement of the atoms; that arrangement *explains why* or *makes it the case that* there is a chair. The mode of explanation here is not causal but "constitutive". We can be ecumenical in how we understand this notion. According to some contemporary "grounding" theorists, it is a primitive relation between facts.[20] But we need not assume this here: we can allow that, like the notion of causal explanation, it has an analysis in terms of dependency relations, or metaphysical laws, or unifying patterns, or what have you. We might even understand it semantically, in terms of something like Sider's "metaphysical semantics" (2011).[21] Indeed for our purposes we could also understand it in a deflationary manner that would be congenial even to a logical positivist. Even a positivist can accept that John's being a bachelor holds in virtue of his being an unmarried male; she just understands this as meaning that "John is a bachelor" follows logically from "John is an unmarried male" together with the analytic

[20] Schaffer (2016, forthcoming) develops a view on which grounding is primitive (though for him it relates entities of any kind, not just facts).

[21] Very roughly, what I have in mind here is the idea that P explains Q iff the metaphysical semantics has it that Q is true if P. But this bears considerable refinement, and of course if one wants to join me in defining fundamentality in terms of explanation, one had better not define metaphysical semantics in terms of fundamentality! But I will not elaborate on these issues here; the point is just that I intended to remain open to this kind of semantic approach to constitutive explanation.

definition of “bachelor”.[22] All I require is that we do not understand this notion of explanation in terms of possibility. Quite the opposite: we are going to understand the notion of possibility (partly) in terms of this notion of explanation.

The fundamental matters, as I use the term, are those matters that are unexplained in the constitutive sense: if they obtain there is nothing in virtue of which they obtain; they just obtain. Now, this strategy of analyzing fundamentality in terms of explanation is controversial; see Wilson (2016) in particular for objections. I will not try to offer a serious defense here for want of space, so my claim here will function as an unargued assumption. Alternatively, you can you can read me as stipulating the sense of “fundamentality” that I want to use, meaning that my substantive claim here is to understand strict possibility in terms of explanation. Still, let me briefly point out two nice properties of this conception of fundamentality.

One is that it explains why we should think that a possible world is a reorganization of fundamental matters. After all, why should there be this connection between fundamentality and possibility? What is special about *fundamental matters* (rather than other matters) such that every *possible world* a way of reorganizing *them*? If fundamentality were a primitive notion, the connection would be unclear. But if to be fundamental is to be unexplained, we have the beginnings of an answer. For it seems to me that there is a constitutive connection between explanation and possibility: roughly, that if something has no explanation it could have been otherwise. The idea is that if there is *no reason* why something obtains—if there is nothing *making* it obtain—then it *might not have* obtained. This is why (ignoring the metaphysical principles for a moment) if you rearrange those matters for which there is no explanation—the fundamental matters—you get a way things *could* have been; a possible world. Of course, as stated this constitutive connection between explanation and possibility is no more than an aphorism and needs considerable refinement. Still, like all good aphorisms, I think it contains a germ of truth; enough for us to get at least a glimpse of why there is this connection between possibility and fundamentality.[23]

Another virtue of understanding fundamentality in terms of explanation is that we arguably need the latter to understand strict possibility in any case. After all, suppose one wants to make the standard connection between worlds and modal operators, on which it is strictly possible that S just in case there is a strictly possible world in which S. This uses the notion of a world W being *a world in which S*. How is this to be understood? If it is a fundamental matter whether S, there is no problem: it will be built into the specification of W whether W is a world in which S. But more is the case at a world than just the fundamental matters. Suppose that the fundamental matters concern handrons spinning in a void, and suppose that W is a world in

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[22] This would be something akin to a D-N model of explanation, but with analytic truths taking the place of laws of nature. See Dasgupta (manuscript) for various “deflationary” ways of understanding this notion of constitutive explanation.

[23] One possible refinement is as follows. As stated, it implies that if it is necessary that S, then there is an explanation why S. And one may worry that this cannot be true in general, else we face an infinite regress of explanations. I agree that this is a worry, and in response I would suggest that the aphorism be restricted to matters that I have elsewhere called “substantive”; that is, matters that are “apt for being explained” in the constitutive sense. If so, then “autonomous” matters—matters that are not apt for being explained—fall outside the scope of the aphorism, and can then be necessary and true for no reason. Indeed, my view is that the metaphysical principles, if there are any such things, will be autonomous, and hence also outside the scope of the aphorism. But it would take us too far away from the main thread to develop the aphorism in detail here. In any event, it is not essential to the main thread: the main claim is that fundamental matters are unexplained matters; this aphorism is just one rationale for that claim.

which handrons are arranged chair-wise. Then, arguably, W is also a world in which there is a chair. But why? Why is it not a world in which there is a penguin? The question is what constrains what is the case at W, above and beyond the fundamental matters of W. One natural answer is that whatever is the case at W must *hold in virtue of* the fundamental matters at W. If there were a penguin at W, this would not hold in virtue of the chair-wise arrangement of atoms at W; that is why W is not a world at which there is a penguin. By contrast, the existence of a chair does hold in virtue of the arrangement of atoms at W; that is why W is a world in which there is a chair. If that is right, we need the notion of constitutive explanation anyway, in order to define what is the case at a given world W. Why not use it to understand fundamentality too?

To implement this last idea—that whatever is the case at W must hold in virtue of the fundamental matters at W—we need a nonfactive notion of constitutive explanation. This is a notion on which one state of affairs, which may or may not obtain, is explicable by others, which may or may not obtain. Let us regiment this with the following operator:

(#) T, U,… settle that S

where this does not imply that T, that U, or that S. Informally, this can be read "if T, U,…, that suffices to make it the case that S". I will assume that sentences of the form (#) do not vary in truth-value from world to world; they are just true or false, simpliciter.[24] And for convenience I will sometimes abbreviate this with quantification over states of affairs, or facts, or "matters", saying that some matters (or facts, or states) settle another matter (or fact, or state).

Putting this all together, we get the following picture of strict possibility. A strictly possible world is a way of reorganizing unexplained matters; that is, those matters that are not settled by anything. Suppose that these matters just concern atoms spinning in a void. Then a strictly possible world W is a way or reorganizing how the atoms are spinning in a void. And W is a world in which there is a talking donkey just in case the atoms in W are spinning in such a way that constitutes (that is, settles that there is) a talking donkey. It is then strictly possible that there is a talking donkey just in case there is a strictly possible world in which there is a talking donkey.

9. Strict and Loose Possibility

That, at least, is the picture. It rests on the idea that a strictly possible world is a way of reorganizing *unexplained matters*. But I will now argue that this notion of being an "unexplained matter" is ambiguous. Imagine a relationalist who uses 'left' and 'right' as devices of coherence. Then if we ask her whether matters of left and right have an explanation, there is a sense in which they do and a sense in which they do not. The former sense yields the space of strictly

[24] Does this mean that they are necessary? That may be misleading, since they are not true *at* worlds in the first place, and so not true at all worlds. I prefer to think of them as "aworldly" in something akin to Kit Fine's (2005) sense.

possible worlds discussed above; the latter sense yields the space of loosely possible worlds we are looking for.[25]

The key to distinguishing this latter sense of 'unexplained matters' is to recognize that talk of left and right in our relationalist's mouth is not fully *factual*. Lee and Yalcin (manuscript) have also argued that 'left' and 'right' are non-factual, but here I want to show how this follows from the coherentist usage of the terms described earlier.

Roughly speaking, by calling an utterance factual I mean that it aims at describing the world. When I utter

(1) Snow is white.

my utterance is factual in this sense: I am attempting to describe how the world is, namely that some entity (snow) has a certain property (being white). By contrast, when I scream

(2) Yay!

as my team scores, my utterance is nonfactual insofar as I am not trying to describe anything but express my pro-attitude to the event. Similarly, on a simple expressivist view of moral discourse, an utterance of

(3) *x* is good.

is nonfactual in the sense that it does not describe x but rather expresses a pro-attitude towards x. There is, of course, a sizable literature on what factuality *really* consists in, but I will not try to settle the matter here. For one thing, I am stipulating that this is what *I* mean by "factual" for present purposes, even if others use the term differently. For another thing, while my characterization here is somewhat rough, it is clear enough for present purposes: factual utterances aim to describe the world, non-factual utterances do not.[26]

An utterance that fulfills its aim can be evaluated as "correct", or "the right thing to say", given that aim. Therefore, since factual and non-factual utterances have different aims, they have different standards of evaluation. An utterance of (1) is correct when, and because, the world is as it is described; that is, when and because snow is white. More succinctly, (1) is correct when and because it is *true*. For factual utterances, then, truth is the primary mode of evaluation. By contrast, the aim of (3) is to express a pro-attitude towards *x*. Hence, it is fulfills its aim and can be evaluated as "correct" or "the right thing to say" when, and because, the utterer indeed has that pro-attitude.

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[25] In Dasgupta (2014) I tried to get at this distinction between two senses of being "unexplained" in terms of plural grounding. Suppose X has no explanation on its own, but some plurality of facts of which it is a member have an explanation when taken together. Then there is a sense in which it has an explanation—it is explained as part of a plurality—and a sense in which it does not—it has no explanation on its own. But I have come to think that the framework of plural grounding is unhelpful here. This is not to say that it is false, so much as unilluminating. I now think that the intuitive idea behind plural grounding outlined in section XX of (2014)—which is the basis of my account of my coherentist account of talk of 'left' and 'right'—is better theorized in terms of the non-factualism I'm about to discuss, rather than in terms of plural grounding.

[26] For further discussion on the factual vs non-factual distinction, see Gibbard (2003), Yalcin (2012)…

Returning to talk of ‘left’ and ‘right’, call my left-hand “Lefty” and consider an utterance of

(4) Lefty is left-handed.

Is this factual? It would be *if* ‘left’ were defined to be synonymous with ‘congruent with Changy’. For in that case one’s aim in uttering (4) would be to describe a way that the world is, namely that Lefty is congruent with Changy. And the utterance would be correct because it is true; that is, because Lefty is indeed congruent with Changy. Similarly, (4) is factual for an absolutist who interprets ‘left’ as referring to that physical property L that distinguishes the left from right hands. For in that case the aim of uttering (4) would be to describe Lefty has having that property L, and the utterance would be correct because Lefty indeed has L.

But if ‘left’ and ‘right’ are devices of coherence, things are different. For one’s aim in uttering (4) is then not to state a truth but to cohere with other utterances of one’s linguistic community—that is, to utter something which, along with utterances of one’s linguistic community, yields truths about congruence via the rules (R1)-(R3). So, the explanation of why the utterance is correct is not that it is true, but that it coheres. Remember, the rules (R1)-(R3) are just exit rules; they do not define a property of being left-handed, like L, possession of which by Lefty would explain why (4) is true. Rather, the correctness of the utterance is explained by its cohering with other utterances.

So, on the coherentist use of ‘left’ and ‘right’, such talk is nonfactual. Still, note that the nonfactualist need not deny that there are *truths* or *facts* of left and right. For she might introduce deflationary notions of truth and fact, and so earn the right to say that (4) is true, that it is a fact that Lefty is left-handed, and so on. But these truths and facts would be explanatorily “downstream” as it were; they do not enter into the explanation of why uttering (4) is correct. Moreover, note that her talk of left and right is significantly constrained by the world. After all, the aim of the talk is coherence, and utterances are defined to cohere iff they imply *truths about congruence* via the rules (R1)-(R3). Thus, unlike ‘Yay’, the standards of correctness do not depend solely on one’s subjective mental state; they depend to a significant extent on the worldly facts about congruence. So this is a nonfactualism only of a mild stripe, but a nonfactualism nonetheless.

It follows, I suggest, that there is no constitutitve explanation of why Lefty is left-handed; there is nothing about the underlying congruence facts *in virtue of which* it is left-handed. Again, this would not be so if we had defined ‘left’ to be synonymous with ‘congruent with Changy’, so that talk of left and right was factual. For in that case one might say that Lefty is left-handed *in virtue of* being congruent with Changy. But it seems to me that nonfactual discourse does not admit of constitutive explanations like this. This is clear with (2): it makes no grammatical sense to try to explain why Yay! But it is also true of (3), according to the simple expressivist view of moral discourse. On that view, there is a constitutive explanation of *why my utterance of (3) is correct*: it is correct in virtue of the fact that I have that pro-attitude towards x. But it is *not* part of this expressivist view that x is good in virtue of my pro-attitude towards x. To think so would be to confuse expressivism with subjectivism, the view on which ‘x is good’ in my mouth means *that I have a pro-attitude towards x*. The same, I claim, goes with (4). There is a constitutive explanation of why my utterance of (4) is correct: it is correct because it coheres with my neighbor’s utterances. But this is *not* an explanation of why Lefty is left-handed. To think so would be to mistake (4) with the factual assertion *that Lefty is congruent with hands her neighbors call ‘left’*. And that mischaracterizes the phenomena: when ‘left’ is used as a device of

coherence, the aim of uttering (4) is not to describe Lefty as having a certain property, but to cohere with other utterances.[27]

What we see here is a distinction between a (non-trivial) explanation of *what makes an utterance of "S" correct*, and an explanation of *what makes it the case that S*. With factual utterances these are the same, precisely because correctness in those cases amounts to truth. But with non-factual utterances they are different: that which makes it the case that an utterance of (4) is correct—namely, that it coheres with other utterances—does *not* make it the case that Lefty is left-handed. They are different precisely because in these cases of non-factual utterances, correctness does *not* amount to truth.

The upshot is that if the relationalist uses 'left' and 'right' as devices of coherence, there is a sense in which matters of left and right have an explanation and a sense in which they do not. On the one hand, the correctness of all talk of left and right is constitutively explained in terms of congruence: (4) is correct in virtue of the fact that Lefty is congruent with hands that my neighbors call 'left'. In *this* sense, matters of left and right *do* have a constitutive explanation in relational terms. On the other hand, there is nothing in virtue of which Lefty is left-handed; there is no constitutive explanation of why that is the case. In *that* sense, even for the relationalist it is a brute, unexplained matter whether Lefty is left-handed! If it sounds odd to hear a relationalist saying this, remember that being left-handed is, in her mouth, a non-factual matter. Thus it remains the case that, on her view, all the *factual* matters for which there is no constitutive explanation are relational; that is what makes her view count as *relationalist*.

Indeed, whenever some matter has an explanation in the first sense but not the second, it is a non-factual matter. So we can characterize the two kinds of unexplained matters like this: it is *loosely fundamental* whether S iff nothing settles whether S; and *strictly fundamental* whether S iff (i) nothing settles whether S and (ii) it is factual whether S. Put in these terms, the question of absolutism vs relationalism concerns the *strictly* fundamental matters of handedness: the absolutist thinks they consist in the distribution of the physical property L that (on his view) distinguishes the left from right hands, the relationalist thinks they consist in relational matters of congruence. The relationalist I envisage then adds that matters of left and right are *loosely* fundamental, but that does not contradict her relationalism.

We therefore have two senses in which something can be fundamental (unexplained). Insofar as a possible world is a way of reorganizing fundamental (unexplained) matters, we have two corresponding notions of a possible world. The *strictly possible worlds* discussed above, we now see, are ways of reorganizing *strictly fundamental* matters. For the relationalist, the strictly fundamental matters (concerning handedness) just concern relational matters of congruence; hence a strictly possible world just is a way of reorganizing relational matters of congruence (and other strictly fundamental matters concerning mass, color, or what have you); hence strictly possible worlds agreeing on relational matters agree on all matters of left and right. This then is the sense of "world" on which relationalism implies Relational Supervenience. But for the absolutist, the strictly fundamental matters include matters of left and right (or, more precisely, the distribution of the distinguishing physical property L), and so a strictly possible world on his view is a way of reorganizing matters of left and right (as well as other strictly

[27] To be clear, it is not impossible to speak a language on which 'left' is defined as 'is congruent to what members of my community call "left"'. Speakers of that language would correctly say that Lefty is lefty handed in virtue of being congruent with things that their neighbors call 'left'. My claim is that speakers who use 'left' and 'right' as devices of coherence do not speak this language.

fundamental matters). That is why the absolutist is not committed to Relational Supervenience: he can distinguish strictly possible worlds that differ only in a uniform flip of left to right and vice-versa. This is all as expected, for strict possibility is the familiar notion of metaphysical possibility familiar to philosophers.

By contrast, say that a *loosely possible world* is a way of reorganizing the loosely fundamental matters. On the relationalist view under discussion, the loosely fundamental matters include relational matters of congruence *and* matters of left and right, so a loosely possible world is a way of reorganizing those relations *and, in addition, reorganizing what is left- and right-handed*. Even for a relationalist, then, matters of left and right can be freely stipulated of a loosely possible world; there is no need to require that they be fixed or settled by the relational facts at that world, so there is no danger of Incommensurability when it comes to loosely possible worlds. For the same reason, there can be loosely possible worlds that agree on all relational facts and yet disagree on what is left and right. Thus when it comes to *loosely* possible worlds, relationalism does *not* imply Relational Supervenience either!

It is clear, then, that the relationalist can recognize a distinct loosely possible world for each strictly possible world recognized by the absolutist. But is the converse also true? One might think not. After all, the absolutist (as we are imagining him) thinks that the *only* strictly fundamental matters of handedness are matters of left and right, and matters of congruence are settled by them. By contrast, the relationalist thinks that matters of left and right *and* matters of congruence are loosely fundamental. Does that mean there are weird loosely possible worlds that the absolutist makes no sense of, for example one in which there are two incongruent left handrons? In principle, yes. But more likely, the relationalist will think that the conditionals encoded in the exit rules (R1)-(R3)—for example, that if two handrons are both left-handed then they are congruent—are metaphysical principles. This is not *ad hoc*: on her view those exit rules are constitutive of meaning, and hence the encoded conditional is plausibly a conceptual or analytic truth. If that is right, then it follows that the relationalist does not in the end recognize these weird worlds that the absolutist cannot make sense of. Hence we have

> **Modal Correspondence Thesis:** There is a one-one correspondence between the space of *strictly* possible worlds recognized by the absolutist, and the space of *loosely* possible worlds recognized by the relationalist, that preserves all relational facts and facts about what is left and right.

And this is precisely what we were after!

10. How to Be a Relationalist

We can now see how the relationalist can meet the challenge from section 5. The challenge was to interpret talk of 'left' and 'right' in such a way that (i) makes sense of the deterministic reasoning with (F), yet (ii) does not collapse into the absolutist's interpretation on which (F) expresses a theory for which there is no evidence.

The solution is to interpret 'left' and 'right' as devices of coherence. Used this way, we saw that the relationalist can legitimately record observations in those terms, and take those observations to confirm a law she will write down as

(F) Whenever a handron collides with another, it changes color iff it is *left*-handed.

The question was whether she can make sense of the deterministic reasoning, and it should now be apparent that she can. That reasoning consisted of solving initial value problems like Questions 2 and 3; and that involved *describing* the counterfactual situations in those questions in terms of left and right, and *distinguishing* them. But this is straightforward *if* those situations are thought of as loosely possible worlds. After all, we know that the absolutist can characterize Question 2 as concerning a *strictly possible* world containing two handrons with that physical property L that she thinks distinguish the left-handrons, and Question 3 as concerning a *distinct* strictly possible world containing two handrons without L. Therefore, by the Modal Correspondence Thesis, the relationalist can do exactly the same with *loosely possible* worlds.

More generally, the relationalist can say that (F) is deterministic and local, though we should now be a little more precise about what this means. In section 3 we defined determinism and locality thus:

> A theory is *deterministic* iff any two possible worlds in which it obtains, and which agree at one time, agree at all times.
>
> A theory T is *local* iff for any world W and any approximately isolated sub-system S of W, the isolated S worlds are approximate intrinsic duplicates of the embedded S systems.

These definitions quantify over possible worlds, so having distinguished strict from loose possibility we should distinguish two varieties of each notion. Thus we can call a theory *strictly deterministic* iff it satisfies the above definition when understood as quantifying over *strictly* possible worlds, and *loosely deterministic* when understood as quantifying over *loosely* possible worlds; likewise for *strict* and *loose* locality. By the Modal Correspondence Thesis, it follows that (F) is strictly deterministic and local on the absolutist's interpretation iff it is loosely deterministic and local on the relationalist's interpretation.

In this way, I claim, the relationalist can meet the challenge of making sense of the deterministic usage of (F) without collapsing into the absolutist's interpretation on which (F) expresses a theory for which there is no evidence.

Now, as I emphasized in section 7 this solution is adequate only if loose possibility is a genuine species of metaphysical possibility. Otherwise, the relationalist has not shown that (F) is deterministic *in the right sense*. The argument in sections 8 and 9 is that it is indeed a genuine kind of metaphysical possibility. The key lies in the connection between metaphysical possibility and constitutive explanation (section 8): that if something is constitutively unexplained —if there is nothing *making* it be that way—it could have been otherwise in a metaphysical sense of the term. What I showed in section 9 is that there are two related notions of being constitutively unexplained: being strictly fundamental, and being loosely fundamental. Each notion then gives rise to a corresponding notion of possibility: strict and loose possibility, respectively. Thus loose possibility is as much a genuine notion of metaphysical possibility as strict possibility is, and for the same reason.

This approach will be rejected by those seduced by the idea that there is a clear, univocal notion of "metaphysical possibility" that we grasp independently of its connection to fundamentality and explanation. On this view, metaphysical possibility may (as it happens) correspond to ways of reorganizing strictly fundamental matters, but no notion of metaphysical

possibility corresponds to ways of reorganizing loosely fundamental matters. This view is antithetical to the approach I take here, on which there is no content to talk of metaphysical possibility apart from its connection to explanation. But there is obviously no space to settle this deep issue of modal metaphysics in this paper; I can only be explicit about what my approach is.

Still, even granting that loose possibility is an appropriately metaphysical modality, one may still object that it is not the right *kind* of metaphysical modality for the relationalist to use when thinking about initial value problems and defining notions like determinism and locality. The worry would be that there is no reason why the relationalist should use *it*, rather than strict possibility, other than the *ad hoc* reason that things work out nicely for her if she does. But in response, I think this objection gets things exactly back to front. After all, the difference between strictly and loosely possible worlds is that the former represent how the *factual* matters could have differed, while the latter represent how *all* matters could have differed. When it comes to matters of left and right, the absolutist thinks that all matters are factual; hence he will draw no distinction between the strictly possible worlds and the loosely possible worlds. But for the relationalist there is an important difference: the strictly possible worlds represent only how things could have differed with regards to matters of congruence, while the loosely possible worlds represent how things could have differed with regards to congruence *and* matters of left and right. Thus, modal questions about how things could have differed vis a vis matters of left and right are intelligible, for the relationalist, only as questions about loose possibility. Indeed it would be entirely perverse to require the relationalist to model her counterfactual reasoning about left and right with strictly possible worlds! Quite the reverse: loosely possible worlds are precisely what makes sense for her to use when thinking counterfactually about left and right, independent of the fact that things work out nicely for her if she does.

Even granting this, one might *still* worry whether loose determinism counts as *determinism* in any serious sense of the term. The worry here is that in the definition of determinism, it is important that worlds agree at a time if they agree in all respects *intrinsic* to that time. Otherwise, one could say that agreement at a time requires agreement on what happens before and after that time, in which case determinism becomes trivial. And the worry would be that matters of left and right are not intrinsic to a time, on the relationalist's view, since they serve to summarize relational matters of congruence that may hold between times. In response, I do not want to quibble over whether right and left count as intrinsic for the relationalist (I suppose we could distinguish loose and strict senses of intrinsic…) Rather, the important point is that even if we allow agreement at a time to include agreement in matters of left and right, this does not render determinism trivial in the slightest. Indeed many theories, such as (F*) in section 5, will turn out to be loosely indeterministic. So, regardless of whether left and right should count as intrinsic, there is no worry that the notion of loose determinism becomes trivial.

Of course, for the relationalist all this talk of 'left' and 'right' is just a way of talking; it does not get at how things are at the (strictly) fundamental level. When doing physics in *strictly fundamental* terms, she will just talk in terms of congruence. Thus the strictly fundamental First Law of handrons will be:

(F-minimalist) (i) If x and y are congruent handrons, then x changes color on collision iff y does too.
(ii) If x and y are incongruent handrons, then x changes color on collision iff y does not.

I argued in section 3 that this is indeterministic and non-local, and in fact the argument there shows that that is true in both the strict and loose sense. But as we saw in section 4, this is a *virtue* of relationalism, since, fundamentally speaking, indeterministic and non-local behavior is all the observed phenomena indicate.

So here is the relationalist picture. At the strictly fundamental level, the world is an indeterministic and nonlocal system governed by (F-minimalist). But we rarely represent matters of handedness in strictly fundamental terms; we almost always use 'left' and 'right' as devices of coherence to characterize the world in non-strictly fundamental terms. And characterized like *that*, handrons behave in the (loosely) deterministic and local way stated in (F). More generally, the relationalist will—justifiably—reason about left and right in the same deterministic and local manner that the absolutist will; the only difference will be their interpretation of the reasoning.

And the same goes for other modal reasoning about left and right concerning counterfactuals, causation, explanation, and so on: the relationalist will exactly mimmic the absolutist's reasoning, differing only in her interpretation of what it means. Thus, suppose an absolutist asserts a counterfactual such as 'Had two left-handrons collided, they would have changed color". And suppose he interprets this as having a possible-worlds truth-condition a la Lewis-Stalnaker. Then the relationalist can agree that the counterfactual is true, and even agree with the same possible-worlds truth condition, adding just that she interprets this condition as involving loosely, not strictly, possible worlds. Or suppose that the absolutist offers a causal explanation of why a given handron changes color: it changed color because it is left-handed. Then the relationalist can offer the same causal explanation; the only difference will be that the absolutist will regard the explanans—that the handron has the physical property L—as strictly fundamental, whereas the relationalist regards it as non-strictly fundamental; indeed as non-factual. And if the absolutist offers an analysis of the causal explanation in modal terms, the relationalist is free to copy it so long as she interprets it as concerning *loose*, not strict, possibility.

This last example of causal explanation might sound odd: if the handron's being left-handed is not fully factual, then how can it do causal work? The worry would be that only factual matters can be "real" causal pushes and pulls. But I think the worry is misplaced. Remember, the relationalist is not attempting to show that there is a *strictly fundamental* property of being left-handed that does any *strictly fundamental* causal pushing and pulling at the bottom level. She is rather earning the right to speak like an absolutist, with no pretense that this is getting at how things are most fundamentally in the strict sense. Thus, she is happy to say that a handron changes color because it is left-handed, so long as it is noted that this is not getting at the strictly fundamental pushes-and-pulls.

11. The case of mass

That is how to be a relationalist about handedness. I think that one should be a relationalist about *mass* in precisely the same way too. Let me finish by spelling this out and returning to David Baker's work that I mentioned at the beginning.

As in the case of handedness, the issue here concerns the *strictly* fundamental facts about mass. The absolutist thinks that they concern which intrinsic mass each body has on its own, independent of their relations to other bodies. Those facts then settle facts about their mass-

relationships: if *x* is more massive than *y*, this is because of the intrinsic mass they each have. The relationalist, by contrast, thinks that the mass-relationships between bodies are themselves strictly fundamental. Relationalists may disagree on which relationships are fundamental—ratios, orderings, or something else—but for our purposes nothing hangs on that issue and I will assume they are mass-ratios for simplicity.

In the case of handedness the central issue was the interpretation of 'left' and 'right'. This time, the issue concerns the interpretation of units such as 'kilogram'. The natural absolutist interpretation has it that '1 kg' directly refers to a particular intrinsic mass, for example that possessed by the standard kilogram in Paris. A term of the form 'r kgs' will then refer to another intrinsic mass, specifically that which is r times as massive as the one denoted by '1 kg'. So interpreted, talk of mass-in-kilograms describes the world in strictly fundamental terms.[28]

Clearly, the relationalist cannot adopt this interpretation. What then is she to make of talk of kilograms? One option is to define '1 kilogram' to be synonymous with 'equal in mass to the standard kilogram in Paris'. But another option, which I recommend, is to understand 'kilogram' as a device of coherence, just like 'left' and 'right'. To see how, imagine a community of relationalists who lack the language of mass-in-kilograms; they just have the relational predicate '*x* is *r* times more massive than *y*'. Still, they can introduce predicates of the form '*x* is *r* kilograms' by agreeing to use them in such a way that the ratio between the numbers applied to two bodies is the same as their mass-ratio. More precisely, suppose they stipulate that the predicate is governed by the following exit-rule:

(K)
x is r kilograms
y is s kilograms
Therefore, x is r/s times as massive as y

But suppose they stipulate nothing else: there are no intro-rules that specify sufficient conditions for concluding (say) that a given body is 2 kgs. Thus, they have not given an explicit definition of the predicate "x is 2 kgs" in terms of standard reference bodies like the standard kilogram in Paris.

Nonetheless, just as with 'left' and 'right', this is sufficient to ground a meaningful practice of using the predicates. When they first apply to it a body, they have free reign: they can say that it is 1 kilogram, or 2 kilograms, or whatever. Suppose they say that it is 2 kilograms. After that, their use is constrained. If they come across another body twice as massive as the first, they must call it 4 kilograms else they could infer a falsehood via (K). In this way, their aim in applying these predicates of mass-in-kilograms is to *cohere* with their neighbors, in the sense that their combined uses imply truths about mass-ratio via the rule (K). Over time the predicate will become entrenched: there will be a clear distinction between correct uses that cohere and incorrect uses that do not.

I believe that this is, in all important respects, how our talk of mass-in-kilograms functions. Standard objects like the one in Paris are not used to *define* our expression "1 kilogram", nor fix

[28] At least, it is strictly fundamental at the level of *reference* or *truth-conditions*; the *concepts* used to pick out the intrinsic masses include mathematical concepts which she need not regard as strictly fundamental. So, by saying that kilogram talk gets how things are at the strictly fundamental level, this does not entail a "pythagorean" view on which numbers are strictly fundamental.

its reference. The standard kilogram plays no semantic role at all. Instead, it is a practical aide that helps billions of language users worldwide to cohere: if we all ensure that we cohere with the statement that the standard object is 1 kg, we will succeed in cohering with each other. Still, this claim about how *we* use 'kilograms' is an empirical hypothesis that I will not defend here.[29] All I need is the uncontroversial claim that it is *possible* for a community of relationalists to use 'kilograms' like this, as a device of coherence.

If a relationalist uses 'kilograms' as a device of coherence, then—just as with 'left' and 'right'—we get a distinction between loose and strict possibility. For her talk of kilograms will be non-factual, and hence *loosely* fundamental but not *strictly* fundamental, for precisely the same reasons as with handedness. Thus, on her view the strictly fundamental matters about mass just concern mass relationships; and so a strictly possible world will be a reorganization of mass-relationships (along with a reorganization of other strictly fundamental matters unrelated to mass); and so no two *strictly* possible worlds can differ about mass without differing in some mass-relational respect. This is the analogue of Relational Supervenience in the case of mass. Still, on this relationalist view the *loosely* fundamental matters include matters of mass-in-kilograms; hence a loosely possible world will include a free specification of the mass-in-kilograms of all bodies; hence there can be loosely possible worlds that agree on all mass-relationships and disagree only in a uniform doubling of mass-in-kilograms. Indeed, the space of *loosely* possible worlds will correspond one-one with the space of *strictly* possible worlds recognized by the absolutist, for the same reasons as before. Thus we have:

> **Modal Correspondence Thesis for Mass:** There is a one-one correspondence between the space of *strictly* possible worlds recognized by the absolutist, and the space of *loosely* possible worlds recognized by the relationalist, that preserves all relational matters and matters of mass-in-kilograms.

We can now see how each view will interpret a physics of mass-in-kilograms. To keep things simple, focus just on a classical mechanics consisting of f=ma and various force laws, where f=ma is to be understood as a short-hand for the following relation between quantities in terms of units of measurement:

(N) The total force-in-Newtons acting on a body = its mass-in-kilograms x its acceleration-in-meters-per-second-squared.

What does this theory (N) amount to, on each view?

For the absolutist, remember, talk of kilograms describes the world in strictly fundamental terms; hence (N) is a strictly fundamental theory—at least with regards to mass—that states how the intrinsic masses denoted by terms of the form 'r kilograms' relate to the other quantities of force and acceleration. When paired with the normal classical force laws, this is a strictly deterministic package: given the total force-in-Newtons acting on a body at a time, (N) determines the body's rate of acceleration in meters-per-second-squared.[30]

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[29] I do think that the thought experiments I presented in Dasgupta (2013, section X) and (2014, section X) speak in favor of this coherentist interpretation. But I will not pursue this thought here.

[30] To be clear, classical mechanics is arguably not deterministic; for arguments to this effect see Norton (XXXX) and XXXX. But I am bracketing these kinds of failures of determinism since they are not germain to our discussion.

The relationalist who uses 'kilograms' as a device of coherence also accepts (N); the difference is just how she interprets it. For her, (N) is not a strictly fundamental theory. It is rather a theory couched in non-factual vocabulary; vocabulary that functions as a device of coherence. Still, it is a *loosely fundamental* theory, and by the Modal Correspondence Thesis it follows that (N) is loosely deterministic for the relationalist iff it is strictly deterministic for the absolutist.

When the relationalist wishes to do physics in strictly fundamental terms, she must restrict herself to talk of mass-relationships. What then would her physics of mass look like? One option would be to propose a Machian law such as

(N-Machian) The total force-in-Newtons acting on a body = its mass-ratio with the standard kilogram in Paris times its acceleration-in-meters-per-second.

But this inherits the same problems as other Machian laws: it does not apply to worlds in which the standard kilogram in Paris does not exist. Better is a minimalist theory that stands to (N) just as (F-minimalist) stands to (F). Such a theory is somewhat complex to write down in full generality, but the idea is that it would imply statements like

(N-Minimalist) If one body is r times as massive as another and they are both subject to the same force, the first will accelerate at $1/r$ the rate as the second.[31]

Now, (N-Minimalist) is indeterministic in both the strict and loose sense, just like (F-Minimalist) was. After all, it implies nothing about how a world with one body will evolve over time. But as in the case of handedness this is a virtue, for the indeterministic behavior described by (N-minimalism) is all we really observe. We did not observe the deterministic behavior described by the absolutist's interpretation of (N). We did not, that is, observe that *this particular intrinsic mass M* affects acceleration in the way described in (N), since everything would look (and smell, and taste) exactly the same in a mass-doubled world—a world in which the mass *that's half M* affects acceleration in that way, and the behavior of all the other intrinsic masses is similarly transformed.

So, the relationalist's strictly fundamental physics of mass in indeterministic, and that is a point in her favor. Still, one rarely does physics in strictly fundamental terms; more often we theorize in terms of units like 'kilograms' and propose theories like (N). By the Modal Correspondence Thesis for Mass, (N) is loosely deterministic for the relationalist iff it's strictly deterministic for the absolutist. More generally, the relationalist can exactly mimic all the absolutist's modal reasoning about mass according to (N), including casual, explanatory, and counterfactual reasoning. The only difference is that the former interprets this reasoning as concerning loose possibility; the latter, strict possibility.

To see this in action, consider the kind of initial value problems discussed by Baker (manuscript). He considers a Newtonian world W1 containing just one planet and a rocket at rest on its surface. We are given the mass-in-kilograms of both objects, and we are told that the rocket is fired upwards at a certain velocity (relative to the planet). According to (N), will it escape the planet's gravitational field? Given how Baker sets up the case, the answer is that it escapes. Baker also considers a second world W2 just like W1 except that the planet and rocket are both twice the mass-in-kgs as they are in W1, and he shows that in this case the rocket will

[31] See Field (1980) for a proper articulation of what a set of minimalist laws like this might look like.

not escape.[32] Note that these are two initial value problems in which (N) is used *deterministically* to yield a *unique* solution as to what the rocket will do. They are analogues of Questions 2 and 3 concerning handedness. In Questions 2 and 3, the initial states differed only in a uniform mirror-image reversal, and this determined a difference in whether the handrons changed color. In Baker's worlds, the initial states differ only in a uniform doubling of mass, and this determines a difference in whether the rocket escapes.[33]

Now, Baker used these initial value problems to show that relationalism implies indeterminism. After all, we have two worlds W1 and W2 that agree in their initial state in all mass-relational respects, and (by construction) in all respects other than mass; and so for the relationalist their initial states agree in *all* respects. And yet they diverge thereafter; hence indeterminism. Insofar as Baker meant to raise an objection to relationalism, this was the objection he raised.

But I think that Baker mis-locates the objection. He is right that relationalism yields an indeterminism of sorts: its strictly fundamental physics is (N-Minimalism), which we know to be indeterministic. But we now know that this is a virtue. Rather, the question is whether the relationalist can even make sense of Baker's initial value problems. The worry would be that relationalism implies an analogue of Relational Supervenience, namely that worlds agreeing in all mass-relational matters agree on all matters of mass; and also an analogue of Incommensurability, namely that sparsely populated worlds containing (say) just two massive bodies cannot be meaningfully characterized in terms of kilograms. And so, the worry is, we get the same kind of modal breakdown as we did with handedness, on which the relationalist cannot make sense of the kind of deterministic reasoning with (N) that Baker rightly says is entirely commonplace.

Note that the absolutist has no problem here. He has no problem *distinguishing* W1 and W2 with respect to their mass, for on his view they differ in the intrinsic masses of the planet and rocket. And he has no problem *describing* the planet and rocket's masses in each world in terms of mass-in-kilograms, since on his view this is just to describe which intrinsic masses they have. If the absolutist is the only one who can make sense of commonplace physical practice, this is (I think) a serious problem for relationalism.

But the solution should now be clear. The relationalist will interpret Baker's initial value problems as describing two *loosely* possible worlds. By the Modal Correspondence Thesis for Mass, the relationalist can distinguish these worlds, and also describe them in terms of mass-in-kilograms, just like the absolutist can.

The relationalist's picture, then, is the same as with handedness. At the strictly fundamental level, massive bodies move around in accordance with minimalist laws that are indeterministic. But that is precisely what we observe (properly construed) so that is a virtue of relationalism. The relationalist then introduces talk of 'kilograms' as a device of coherence, and put in those terms her theory of massive bodies exactly mimics the absolutist's theory in being deterministic; the only difference is how they interpret it.

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[32] In fact, Baker does not just describe these initial value problems; he also argues that we must distinguish and recognize both. I have no objection to that argument; I am just bracketing it for brevity.

[33] To be clear, I designed Questions 2 and 3 up precisely so that they would be analogous to Baker's examples.

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