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Spacetime Functionalism

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We naturally think that the way things are arranged in space and time is a fundamental feature of the world. In this paper, however, I explore an attractive account of space and time on which this is false. According to what I will call *spacetime functionalism*, the spatiotemporal structure of the world is not fundamental but instead grounded in the role spacetime regions play in the laws of nature.

This is a radical claim, for the vast majority of philosophers at least implicitly accept what I will call *spacetime primitivism*, the claim that there are fundamental facts about the spatial and temporal arrangement of the world.[1] There are various contemporary *scientific* hypotheses on which space and time are not fundamental; this paper instead explores the *philosophical* case for denying spacetime primitivism.[2]

This paper presents three arguments in favor of the spacetime functionalism. First, I will argue that we don't need fundamental facts about space and time to make sense of the world—spacetime primitivism is committed to *explanatorily redundant* facts. Second, spacetime primitivism requires us give up a highly plausible minimality constraint on the fundamental. And third, spacetime primtivism is *explanatorily impoverished*, as the spacetime functionalist has an elegant explanation for why spatial and temporal relations behave the way they do—for example, why they obey constraints like the triangle inequality, whereas the spacetime primitivist must stipulate objectionably brute necessary connections among the fundamental properties and relations.

Here's the plan for the paper. section 1 describes the issue at stake between spacetime functionalism and spacetime primitivism. section 2 addresses what I take to be the most serious objection to spacetime functionalism. Then section 3, section 4 and section 5 present the arguments in favor of spacetime

1 I use the label "spacetime primitivism" for the claim that the spatiotemporal structure of the world is *fundamental*, not that it is *unanalysable*. So it is compatible with spacetime functionalism that the *concepts* of space and time are primitive and unanalyzable.

2 The end of this section explains in some detail how spacetime functionalism relates to these scientific claims.

primitivism from explanatory redundancy, from metaphysical redundancy, and from the explanatory superiority.

1 Spacetime Primitivism and Spacetime Functionalism

It is a familiar fact that how strongly things interact depends on how far apart they are. For example, whereas a nuclear explosion on the moon would leave me relatively unscathed, a nuclear explosion in my coffee mug would really ruin my day. According to spacetime functionalism, facts like these are constitutive of distance in space and time; it is *in virtue* of the fact that an explosion in my coffee mug would harm me, but one on the moon wouldn't, that I'm closer to my coffee mug than to the moon. In slogan form: *distance is as distance does*. On this view, the spatiotemporal structure of the world is not fundamental but is instead grounded in its nomic structure. The spacetime primitivist, on the other hand, holds that there are fundamental facts about how things are arranged in space and time—whether those facts concern distance relations among objects or the structure of substantival spacetime.

On the version of spacetime functionalism I will develop here, spacetime regions are fundamental, but their geometrical structure is derivative. Instead, there are fundamental facts about how regions of spacetime are disposed to interact, and the geometry of the world emerges from this basis. That is, there are no fundamental spatiotemporal relations among regions; in their place there are fundamental facts about physically necessary conditionals linking individual regions, of the form: *it is physically necessary that if region* r_1 *has qualitative profile* p_1*, then region* r_2 *has qualitative profile* p_2. As I will explain below, this is enough to capture the spatiotemporal structure of the world in its entirety.

The question at stake between the spacetime primitivist and the spacetime functionalist is independent of another debate about the metaphysics of spacetime: that between *substantivalism* and *relationism*.

Substantivalists hold that regions of spacetime exist independently of material objects.[3] Relationists, on the other hand, hold that claims about regions

3 What does it mean to say spacetime exists "independently"? Mere *modal* independence is arguably not sufficient for substantivalism since in principle a substantivalist could deny that facts about spacetime are modally independent of material bodies. Rather, we should understand substantivalism as the claim that spacetime points and regions exist independently in the sense they do not exist *in virtue of* material objects and the relations between them. See Sklar (1974) and Dasgupta (2013).

of spacetime are grounded in the spatiotemporal relations among material objects.

This is a dispute about which entities instantiate the fundamental spatiotemporal properties and relations: material objects, or spacetime regions?[4]

The issue I tackle in this paper is independent of substantivalism-relationalism debate, since it concerns the spatiotemporal relations themselves, not their relata. Spacetime primitivism is the claim that some spatiotemporal properties or relations are fundamental. A spacetime primitivist may be relationist (for example, by holding that there are fundamental distance relations among material objects) or a substantivalist (by holding that spacetime regions instantiate fundamental relations like *being two meters from* or properties like *having a length of two meters*.)[5]

The spacetime functionalist denies that there are any fundamental spatiotemporal properties or relations. Instead, the spatial and temporal distance between things is grounded facts about how they interact.

For the purpose of the paper I will assume that substantivalism is true, so that (some) regions of spacetime (or its parts) are fundamental entities.[6] A substantivalist spacetime functionalist holds that while spacetime points and regions are fundamental entities they do not instantiate any fundamental spatiotemporal properties. Instead, the spatial and temporal distance between two points is determined by how they interact; that is, how the properties instantiated at one location affects which properties are instantiated at the other location.[7]

4 The substantivalist *could* answer: *both*! But it is very natural for the substantivalist who is not a supersubstantivalist (see below) to regard the spatiotemporal properties of and relations between material objects to be inherited from the spacetime regions they occupy. That is, it is a fundamental fact that, say, spacetime points p_1 and p_2 are two meters apart, and it is in virtue of this, together with the fact that electrons e_1 and e_2 are located at p_1 and p_2 that the electrons are two meters apart. Similarly, on this inheritance picture, an object o is square in virtue of being located at a region r_o that is square. If both material objects and spacetime regions instantiate fundamental spatiotemporal properties and relations, it it mysterious that the two kinds of fundamental spacetime features march together, so that no round objects are located at square regions.

5 My use of "property" and "relation" is intended to be compatible with nominalism—the nominalist spacetime primitivist holds that some spatiotemporal predicates are fundamental.

6 Substantivalists of any stripe face a choice about *which* spacetime regions are fundamental. If the entire spacetime manifold is fundamental, there is some pressure to regard the regions and points that are its proper parts as existing in virtue of it. If, instead, it is spacetime points that are fundamental, then it is natural to regard spacetime regions as existing in virtue of the points of which they are composed. But I will put this issue aside.

7 The substantivalist faces a choice concerning the relationship between regions of substantival spacetime and material objects like trees and mountains. A "dualist" substantivalist holds

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One might object that it makes no sense to claim that there are *spacetime* regions that have no fundamental spatiotemporal structure. But this is not so, given that substantivalism and primitivism are independent. The central commitment of substantivalism is that there is an object—the spacetime manifold—which plays a distinctive metaphysical role. A central part of this role is that material objects are either *located at* (or, for the supersubstantivalist, *identical to*) parts of the spacetime manifold. If primitivism is correct then the structure of the spacetime manifold is determined by the distribution of the fundamental spatiotemporal properties or relations. The view I am proposing is that the spacetime manifold is fundamental, but has its structure determined by the functional roles of its parts, where these functional roles are explained in terms of physically necessity.[8]

Because the spacetime functionalist explains the world's spatiotemporal structure in terms of physical necessity, the spacetime functionalist cannot be a Humean reductionist. The Humean reductionist about laws of nature holds that the laws are grounded in the spatiotemporal distribution of the

that material objects are distinct from the spacetime regions they occupy. There is a tree, and there is a tree-shaped region, and the first bears the *location* relation to the second. A monist substantivalist—a *supersubstantivalist*—holds that material objects just are spacetime regions. God creates a tree by imbuing a tree-shaped region with suitably verdant properties. I will remain neutral about whether or not supersubstantivalism is true.

8 As I understand it, spacetime functionalism is an explanatory claim. To say that the A-facts are grounded in, reduce to, or emerge from the B-facts is to say the A-facts obtain *in virtue of*, *because of* the B-facts. I take this non-causal flavor of explanation to be familiar from a range of issues in philosophy. Socrates' challenge to Euthyphro was to say whether the pious acts are pious in virtue of the love of the gods or *vice versa*. A promising way of understanding physicalism is as the claim that everything obtains in virtue of physical facts. (See, e.g. Loewer 1996.) I take this sense of explanation to be familiar to common sense judgments too, as when one says that Mary has a headache because her brain is in a certain state *b*. For more explicit defenses of this notion see Fine (2001), Schaffer (2009), Rosen (2010), or Sider (2011). But I invite those who are skeptical about the notion of ground to understand my thesis to concern the *minimal supervenience base* for the world: the spacetime primitivist, but not the spacetime functionalist, holds that the minimal supervenience base includes facts about the worlds spatiotemporal structure. Note that we can make a distinction between two kinds of "in virtue of" claim. One kind consists of cases in which A-facts obtain in virtue of B-facts, although it is possible for the B-facts to obtain in virtue of other facts instead, or for there to be nothing in virtue of which the A-facts obtain. Another consists of cases in which A-facts obtain in virtue of B-facts in any world in which they obtain. One might think, for instance, that even if consciousness facts obtain in virtue of physical facts, there could have been worlds in which consciousness facts obtain in virtue of ectoplasm facts. But it is less plausible to think that while knowledge facts actually obtain in virtue of facts about reliable processes (say), they might have failed to obtain in virtue of anything. I won't take a stand on whether the spacetime functionalism belongs with the former or the latter cases.

fundamental properties.[9] Since facts about the *distribution* of properties are determined by the structure of space and time, the Humean must be a spacetime primitivist. The spacetime functionalist reverses the direction of explanation: the world's spatiotemporal structure is grounded in nomic facts.

The spacetime functionalist must therefore be a non-Humean. To be a non-Humean is to hold that a complete description of fundamental reality must mention facts about laws, causation, dispositions, or some related nomic notion.[10] While spacetime functionalism is compatible with any of the mainstream non-Humean accounts of laws, I will assume a fairly minimalist non-Humean account according to which it is a fundamental feature of the world that certain propositions are *physically necessary*. I will express these propositions in terms of a primitive sentence operator, "*L*...", to be read as "*it is physically necessary that* ...".

It is worth noting that the Humean and the spacetime functionalist both take something to be fundamental that the other regards as derivative. One of the upshots of this paper is that many of the Humean arguments against primitivism about laws—for example, that non-Humean facts are unnecessary, epistemically unreachable, or that there is no explanation of how they do the work they were posited to do—militate equally against the Humean commitment to spacetime primitivism.

If spacetime primitivism is correct then the world's spatiotemporal structure is independent of its causal structure, so that it is in principle possible for things to be arranged differently in space and time although they interact just like they actually do.

For example, consider a scenario that is *just like* the world, but in which everything is much smaller. Suppose the Earth were the size of a beach ball. The moon would be the size of a softball, orbiting 40 feet away. The sun, four school-bus-lengths across, would be three miles away. A tiny version of you, about the size a virus, is reading an even tinier paper.

9 Classical statements of regularity accounts of laws are Mill (1843), Ramsey (1928), and Lewis (1973).

10 Non-Humean accounts of laws are varied. According to Armstrong (1983) facts about laws are analyzed in terms of a second-order relation of *nomic necessitation*. According to the dispositional essentialism defended by Bird (2007), a regularity is a law if it is entailed by the dispositional essences of the fundamental properties. And on the primitivism defended by Maudlin (2007), the fact that a regularity is lawful is simply a further unanalyzable fact about the world. Bigelow and Pargetter (1988) defend a variant of primitivism that I will be adopting for the sake of the paper: there are fundamental facts about nomological possibility.

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Or instead, imagine a scenario, again just like the actual world, but in which everything is much larger than it actually is. Suppose protons were the size of beach balls. Hydrogen atoms would be about 5 miles across. You are a colossal giant, spanning the actual distance from the Earth to the Sun.

In order for these to be worlds in which things causally interact just like they actually do, the laws must be different: if insects were the size of cars and governed by our laws they would collapse under their own weight. But we can imagine larger insects that are *not made of any more molecules than they actually are*, governed by laws that result in them engaging in precisely the same behavior as in the actual world.

In the smaller and larger worlds described above, distance *ratios* are unchanged: the size of the earth *relative to the sun* is the same. The spacetime primitivist could hold that the fundamental distance facts concern distance ratios, and conclude that these these are merely a rediscriptions of the actual world.[11]

But if facts about distance are independent of facts about causal interaction then we can consider more radical worlds in which things interact just as they actually do but in which distance ratios are not preserved. Consider, for example, a world in which things shrink (or grow) over time, but in which the laws also change to compensate, so that things behave just like they actually do.[12]

We can also consider worlds with different temporal structure. Suppose the world were "sped up" but otherwise unchanged, so that exactly the same events occur as in the actual world, but the time separating corresponding events is half as long as it actually is. Or consider a "slowing down" world, so that the same causal processes occur but at slower and slower rates.

11 Dasgupta (2013) argues that since halving every distance would not make any detectable difference to the world, facts about absolute distances are "empirically redundant" and this is a reason only to regard facts about distance ratios as physically real. I will argue in section 2 that this argument extends to distance ratios—i.e. comparative facts about distance—as well.

12 From the perspective of someone who holds that the only fundamental distance facts are those involving distance ratios, these worlds are distinct from the actual world in virtue of having a different pattern of *cross-time* distance ratios. We can consider a sparser metaphysics of distance that recognizes only distance ratios among things *at a single time*. (Ignore, now, the question of how to make sense of this in the context of the relativity of simultaneity.) On this view, the shrinking world is no different from the actual world, since the worlds agree on all the instantaneous distance ratio facts. But there are more radical worlds, such as the worlds described below, in which things interact just like they actually do but that do not disagree about the instantaneous distance ratios.

If spacetime structure is truly independent of the world's causal structure then we can describe scenarios with the same causal facts in which even the world's *topological* structure is different. Suppose that I am actually a few meters from you, trying to persuade you of the truth pf spacetime functionalism. Now consider a world in which things causally interact just as they actually do but in which I am many light-years away. The region a few meters away, in which I appear to be located, in fact contains a nuclear explosion. But, happily, the region that contains the explosion interacts with other regions as if it had the location of the region that contains me, many light-years away, so you are unharmed. And conversely, the region *I* am in has the functional role of a region that it only a few meters from you. So, photons leaving my skin reach your retina, and the air vibrations caused by vocal chords cause the air inside your ear to vibrate too. More generally, even though this world has a drastically different spatiotemporal arrangement, things causally interact just like they actually do.[13]

These worlds disagree about how far apart things are in space and time. But they do not disagree about what causes what; in each world, smoking causes cancer, Hitler's invasion of Poland causes WWII, and Muhammad Ali delivers a knockout blow to George Foreman.[14] Of course, since these worlds have different spatial and temporal arrangements there is a clear sense in which things *don't* causally interact in the way they actually do. After all, although in each world I can cause there to be a fresh mug of coffee on my desk, the worlds disagree over the size of the mug of coffee that would result. But there is an equally intuitive sense in which they agree about what causes what.

This is because these worlds have something important in common concerning the roles space and time play in the laws. For example, each world contains a region that contains something that looks and behaves like my coffee mug. I will say that each world contains a region that plays the same *functional role* as the region that contains my coffee mug. More generally, there is a mapping between these worlds that maps regions to regions with the same functional role. I'll say these worlds have the same *causal structure*.

13 It is worth noting that this lets us distinguish two different senses in which a window can be said to be broken. In one sense (the spatial sense) a window is broken if and only if its proper parts are no longer in spatial contact. But in the other sense (the causal sense) a window is broken if and only if its parts no longer compose a causally cohesive object, so that, e.g. pushing one part causes the whole window to move. These senses can come apart—imagine a version of the world described, but in which a region that contains a section of an unbroken window swaps functional roles with another region. In this world the window is spatially but not causally broken.

14 Although note the caveat in the following paragraph.

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(Remember, however, that it is not *causation* but facts about *physical necessity* that are fundamental on the version of spacetime functionalism I will develop here.)

Since the spacetime functionalist claims that geometrical structure of the world is grounded in how things interact, if spacetime functionalism is correct these scenarios do not, after all, correspond to different possibilities: since the worlds have the same causal structure they therefore have the same spatiotemporal structure.

Is this a count in favor of spacetime functionalism, because these scenarios involve making distinctions without differences? Or does this count against the theory since it fails to recognize distinct possibilities? I'm not sure; I find my intuitions to pull in both directions. So one response is to say with David Armstrong, *spoils to the victor!* and conclude that we should let our intuitions be guided by theory, not *vice versa*. But I am happy to grant that this is the source of some weak intuitive pressure against spacetime functionalism. Intuitions about the nature of fundamental reality must sometimes be revised in the face of countervailing evidence, as with the appearance that the sun revolves around the Earth, or that some events are objectively simultaneous. Similarly, I will argue that the evidence from intuitions against spacetime functionalism is outweighed by the arguments in favor of the view.

I'll now explicate the notion of causal structure I have in mind by explaining what it takes for two worlds to have the same causal structure. What is shared across the radically different worlds I have described? Intuitively, one thing worlds with the same causal structure agree on is there is an object that looks and behaves like Barack Obama. But we can't capture this with the claim that the worlds all contain a *duplicate* of Obama, since duplication is standardly defined so that two objects are duplicates only if their parts stand in the same spatial relations.[15]

Let us use a slightly different notion instead. Say that a property or relation is *qualitative* iff it is non-spatiotemporal. Two objects are *qualitative duplicates* when they share all qualitative intrinsic properties and relations.[16] Objects can

15 For example, see Lewis (1986a, 60). Lewis requires that if objects are duplicates then their parts must stand in the same perfectly natural relations; for Lewis, distances were (perhaps the only) perfectly natural relations.

16 That is, x and y are qualitative duplicates if and only if there is a one-one mapping between parts of x and parts of y such that every part of x is mapped to a part of y with the same intrinsic qualitative properties, and every n-tuple of parts of x is mapped to an n-tuple of parts of y that instantiates the same intrinsic qualitative relations. Note that everything is a part of itself. The

be qualitative duplicates even though they are not duplicates; something may be a qualitative duplicate of Obama even though it's millions of times larger. Qualitative duplicates have the same *qualitative profile*, where the qualitative profile of an object is determined by the intrinsic qualitative properties and relations instantiated by its parts.

Armed with the notion of qualitative duplication, we can express one thing that is shared between worlds with the same causal structure: if two worlds w_1 and w_2 have the same causal structure then there is a one-one mapping between regions in the worlds that maps every region to a qualitative duplicate region.

But the worlds agree on more than this; they also agree about how things interact. In each world, for example, a nuclear explosion in my coffee mug would harm my dog.

The functional role of a region is determined by how it interacts with other regions; this in turn is determined by the physically necessary conditionals linking the pattern of properties in that region to the properties of other regions. For example, suppose that at time t the world is just like it actually is except that a nuclear explosion has just detonated inside my coffee mug. Let r_t be the time-slice of the world at t, and r_t be an instantaneous region a few moments later.[17] Let ϕ be a complete intrinsic description of r_t, and let ψ be a complete intrinsic description of r_t. Then if the laws are deterministic, the following physically necessary conditional will hold:

(1) $L(\phi(r_t) \rightarrow \psi(r_t))$.

(If the laws are chancy, then there will be physically necessary conditional whose consequent specifies the *probability* that r_t is ψ.)

However, because a region's functional role should not encode facts about its spatiotemporal structure, it should be characterized in terms of *qualitative* physically necessary conditionals. Let ϕ_q and psi_q be specifications of the qualitative profile of r_t and r_t. If (1) is true then so is:

restriction to *intrinsic* properties is required so that objects can be qualitative duplicates even though they fail to share properties like *being exactly ten feet from President Obama*.

17 It is important to note that these are disjoint regions: spacetime is not made up of enduring points, but instantaneous points-at-a-time, *events*. Spacetime regions perdure: they exist at multiple times by having parts at those times. So the notion of location appealed to in a claim like "the ball started at l, bounced off the wall and returned to l" encodes information about the relation between two distinct regions that make up l: the spacetime region initially occupied by the ball, l_i, and the region occupied later l_f.

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(1_q) $L(\phi_q(r_t) \rightarrow \psi_q(r_t))$

I will say that qualitative conditionals like (1_q) describe *relations of lawful dependence* between regions. Since qualitative conditionals like (1_q) do not presuppose facts about the spatiotemporal arrangement of things in r_t and r_t, they offer a way to capture what functionally equivalent worlds have in common.[18]

Not all regions are alike; space and time are different. The laws of nature describe how the world evolves *over time*, not how it evolves from left to right. That is, a specification of what the world is like at a given *time*, together with the laws, provides a lot of information about what the world is like at other times.[19] But the laws together with a specification of what the world is like in a spatial region on its own tells us nothing about what the world is like outside that region.[20]

Because of the special role that time plays in the laws, I'll begin by saying what it takes for two regions that are time-slices to have the same functional role. Intuitively, two time-slices have the same functional role if and only if they exert similar influences on and are influenced similarly by other regions. That is, if two time-slices have the same functional role then they have same *forward-directed* and the same *backward-directed* functional role. The forward-directed functional role of a region concerns what is *entailed by* the laws together with a description of that region. The backward-directed functional

18 My case in favor of functionalism will be largely independent of details about what the laws of nature are like. Since spacetime functionalism can be formulated in the context of special and general relativity with only minor (and philosophically irrelevant) changes, when specificity matters I will for simplicity's sake assume the laws are those of Newtonian gravitational mechanics.

19 If the laws are deterministic, this determines the evolution of the world uniquely; if the laws are chancy, it provides complete information about the probabilities of the possible histories.

20 Some philosophers argue that this feature is what *makes* a dimension the time dimension. For example, see Skow (2007) and Loewer (2012). Note that it is not just that the laws govern evolution in time; the laws do so by governing the evolution of the *entire world* over time. That is, the laws alone typically say nothing at all about what follows if a certain subregion of the time-slice of the world at certain time is a certain way. For example, however unlikely or far-fetched it is, it is *consistent* with the laws that a nuclear-bomb-proof barrier is hurtling toward me in such a way as to shield me from any errant explosions. So the laws alone do not entail that if there is a nuclear explosion in my coffee mug then I will be harmed. Instead, the laws relate entire *time-slices*. In a relativistic context this is not quite true: specifying the nature of any time-like hypersurface inside the past light-cone of each point in r will, if the laws are deterministic, settle what r is like. Still, the general point holds that in general the laws say nothing about how regions smaller than time-slices constrain each other.

role of a region instead concerns what, together with the laws, entail that that region has various properties. (Here, "forward" and "backwards" mean *nomically* forward or backward, where this can be directly defined in terms of the laws; I am not assuming any connection to the direction of time).

Two time slices have the same forward directed functional role if they have qualitatively identical effects whenever they are qualitatively identical. Recall that two regions r_1 and r_2 are qualitatively identical if and only if there is a mapping M between points of r_1 and r_2 such that for any point p of r_1 and any property ϕ, $\phi(p)$ if and only if $\phi(M(p))$. Let us write the claim that two regions r_1, r_2 are qualitatively identical as $r_1 \approx r_2$.

Then we can say what it takes for two time-slices to have the same forward-looking functional role in the following way:

> FUNCTIONAL ROLE$_{timeslice(f)}$. Two time-slices r_1, r_2 have same forward-looking functional role if for any region r_3 and any qualitative profiles q_1 and q_2, if $L(q_1(r_1) \rightarrow q_2(r_3))$ then there is some region r_4 such that $L(r_1 \approx r_2 \rightarrow r_3 \approx r_4.)$[21]

Intuitively, this captures the fact that if detonating a nuclear bomb in my coffee mug would produce an explosion in my apartment, then for any timeslice with the same functional role, a detonation in my coffee mug would product a explosion in my apartment as well.

Backward-looking functional roles can be characterized in a similar way:

> FUNCTIONAL ROLE$_{timeslice(b)}$. Two time-slices r_1 and r_2 have same backward-looking functional role if for any region r_3 and any qualitative profiles q_1 and q_2, if $L(q_1(r_3) \rightarrow q_2(r_2))$ then there is some region r_4 such that $L(r_4 \approx r_3 \rightarrow r_1 \approx r_2.)$

When two regions are qualitatively identical, there may be more than one qualitative-property-preserving between their points, as in the case, for example, when both regions have two qualitatively identical subregions. Two regions play the same functional role only if there exists a mapping on which they have the same forward-looking and backward-looking functional role, and so it is important to keep track of which mapping is being appealed to; let

21 To incorporate chancy causation we need to require that if r_1 having q_1 lawfully entails that the chance that r_3 has p_2 is c, then r_2 being qualitatively identical physically entails that the chance that r_4 is qualitatively identical to r_3 is c.

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$r_1 \approx_M r_2$ mean that M is a qualitative-property-preserving mapping between r_1 and r_2.

Two regions have the same functional role if and only if there is a mapping M that satisfies the consequent of both Functional Role$_{ts(b)}$ and Functional Role$_{ts(f)}$.[22] Call such a mapping an *entailment-preserving* mapping; two regions have the same functional role if there is an entailment-preserving mapping between them.

One might worry that since the only physically necessary conditionals linking regions are those that concern time-slices, they don't give us the resources to capture the functional role of *spatial* regions. But the functional role of a spatial region can be characterized in terms of the functional role of the time-slice that contains it. For example, consider the spatial region that at time t contains my coffee mug, r_{mug}. Intuitively, the laws tell us *something* about the effects the qualitative profile of r_{mug} has on other regions, even if specifying the qualitative profile of r_{mug} alone entails nothing specific about other regions. We can cash this out by appeal to the *conditional* entailments associated with r_{mug}. In general:

> FUNCTIONAL ROLE($spatial$). Two spatial regions r_1 and r_2 have the same functional role if and only if there are time-slices ts_1 and ts_2 such that (a) r_1 is part of ts_1, r_2 is part of ts_2, and ts_1 and $ts2_1$ have the same functional role, and (b) any entailment-preserving mapping M between ts_1 and ts_2 maps r_1 to r_2.

We now have the resources to say what it takes for worlds to have the same causal structure:

> CAUSAL STRUCTURE. Two worlds w_1, w_2 have the same causal structure if and only if there is a one-one mapping M between regions of w_1 and regions of w_2 that maps every region to a region with the same functional role.

22 That is:

Functional Role$_{\text{timeslice}}$. Two regions r_1, r_2 have same forward-looking functional role if and only there is a mapping M between r_1 and r_2 such that (a) for any region r_3 and any qualitative profiles q_1 and q_2, if $L(q_1(r_1) \rightarrow q_2(r_3))$ then there is some region r_4 such that $L(r_1 \approx_M r_2 \rightarrow r_3 \approx r_4.)$ and (b) for any region r_3 and any qualitative profiles q_1 and q_2, if $L(q_1(r_3) \rightarrow q_2(r_2))$ then there is some region r_4 such that $L(r_4 \approx r_3 \rightarrow r_1 \approx_M r_2.)$.

This captures what is shared between the worlds we looked at above: in each scenario, for every region in the actual world we can find a region that plays the same functional role.[23]

The spacetime functionalist makes three distinctive claims. Two concern the nature of fundamental reality:

> Anti-Primitivism. There are no fundamental spatiotemporal properties or relations.

> Anti-Humeanism. There are fundamental facts about physical necessity.

The spacetime functionalist is not a *spatial nihilist*; rather, she holds an explanatory thesis about how facts about spacetime structure emerge from what is fundamental:

> Functionalism. The spatiotemporal arrangement of the world is grounded in its causal structure.

On this view, when God created the world He made the spacetime regions and determined the facts about physical necessity, and the structure of space and time emerged from this basis. Spacetime regions are fundamental, but their geometric structure is derivative.

I have not given a formula for calculating what spatiotemporal facts would emerge given arbitrary specifications of the world's causal structure. But a grounding claim can be substantive and interesting in the absence of such a formula: one can surely hold that phenomenal states are grounded in brain states without having to hand a formula that predicts which phenomenal states emerge under various brain states. Nevertheless, we can identify a substantive constraint governing the emergence of spacetime structure:

> Supervenient Spacetime. If there is a mapping M between regions in w_1 and w_2 that maps every region to a region that plays

23 So far, I have explained how to characterize the functional role of two kinds of regions: time slices and parts of time slices. Because of the distinctive roles space and time play in the laws, the full causal structure of space and time is captured by specifying the functional role of these regions. This is because in a classical setting the only distances that the laws "care about" are temporal distances and spatial distances among points on the same time slice; they are insensitive to spatial distances between points on different timeslices.

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> the same functional role, then M also maps regions to regions with the same spatiotemporal features.

Before moving on to argue for spacetime primitivism, I will first make clear that while the claim that spacetime is derivative or "emergent" is not new, spacetime functionalism differs in important ways from the theses that are typically discussed in the literature under this label.[24]

Some theories that hold that spacetime is emergent are much *weaker* than spacetime functionalism, since they hold that there *is* some kind of fundamental spatial or geometric structure, although the structure of familiar three-dimensional space and time are derivative.[25] I will treat these claims as versions of spacetime primitivism, since they posit fundamental spatial structure.

Other theories that hold spacetime is emergent are much *stronger* than spacetime functionalism, since they endorse novel physical theories governing the behavior of the fundamental ontology.[26] I will set these theories aside, since I want to focus on the *philosophical* rather than the physical arguments for denying spacetime primitivism.

One class of theories in particular that received a lot of attention with the advent of special relativity are *causal theories* of time or spacetime such as those developed by Reichenbach (1958), Grünbaum (1963), Winnie (1977) and Fraassen (1970).[27] What these theories have in common is that they aim to recapture the geometry of spacetime from facts about a primitive notion of *causal connectability* among points, where to say two events are causally connectable means something like: it is physically possible for a signal (i.e. a

24 David Chalmers (2019) also argues for a thesis he calls "spatial functionalism". One crucial difference between Chalmers' claim and the one defended here is that Chalmers' concerns the *concepts* of space and time, whereas spacetime functoinalism as characterized here is a purely metaphysical claim: there are no fundamental spatiotemporal properties or relations. This is arguably independent of the claim about concepts.

25 For example, Albert (2015) defends an interpretation of Bohmian quantum mechanics on which the fundamental space is an extremely high-dimensional *configuration space*, and facts about four-dimensional spacetime are grounded in facts about the laws that govern the motion of a point through configuration space. Similarly, some versions of string theory hold that the familiar macroscopic spatial and temporal dimensions emerge from what is going on in the multitude of dimensions posited by the theory. See, for example, Huggett and Wüthrich (2013).

26 Huggett and Wüthrich (2013) contains a survey of theories of quantum gravity that have the consequence that spacetime is emergent.

27 Although the idea is probably much older: Leibniz arguably gave a causal theory of time in "The Metaphysical Foundations of Mathematics".

massive particle or a light pulse) to be sent from one to the other. This program is confronted by various technical problems. Fraassen (1972) But crucially, the failure of causal theories of spacetime would not undermine spacetime functionalism because the reduction base of these theories is much sparser than that of spacetime functionalism. This is because there are many facts about physical necessity (for example, the fact that it is physically necessary that a world otherwise like this one but with a nuclear explosion in my coffee mug is one in which I die) that are not settled by the facts about causal connectability.

2 Is Spacetime Functionalism too Complicated?

A distinctive feature of the spacetime primitivist's account of fundamental reality is that the physically necessary conditionals linking regions are fundamental. This is opposed to a standard approach to laws and spacetime according to which these conditionals are derivative: on this standard view, God settled the arrangement of things in spacetime, and then settled the laws, and it is in virtue of these facts that it is physically necessary that if my coffee contains a nuclear explosion (and the world is otherwise unaltered) then I will die. The spacetime functionalist instead reverses the order of explanation by holding that physically necessary conditionals linking particular regions are fundamental.

This is an unfamiliar way of thinking about the fundamental nomic structure of the world. But are there good reasons to resist it?

One objection is that the spacetime functionalist's theory is *too complex*, for she must appeal to physical necessary conditionals linking incredibly many different individual regions.

The bare concern about complexity seems misplaced, however. After all, according to spacetime primitivists, it is a brute fact that some points but not others are close together; the spacetime functionalist merely replaces these individualistic facts with facts about direct dependence.

Perhaps a better way to make this objection is to appeal to the fact that complexity in the *laws* is much worse than complexity in contingent facts, and complain that the laws of the spacetime functionalist are incredibly complicated. In response, note that there is a clear sense in which there is much *less* structure in the fundamental facts about physical necessity according to the spacetime functionalist than there is for the spacetime primitivist! This is because the spacetime primitivist believes that the laws encode facts

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about spacetime structure: worlds with the same causal structure in general have different laws by the lights of the spacetime primitivist. The spacetime functionalist, on other hand, denies that the laws have enough structure to distinguish between these worlds.

A different way of developing this objection is to complain that the spacetime functionalist's fundamental nomic facts, which concern physically necessary conditionals linking individual regions, cannot be *stated* simply. The spacetime primitivist, on the other hand, can state her fundamental nomic facts (if she holds that there are any!) by appeal to a small number of general laws.

In response, the spacetime functionalist can grant that the laws of nature are precisely those laws found in physics journals. It's just that the laws, which are stated in terms of spatiotemporal structure, are not stated in fundamental terms. The familiar laws of nature that are stated in terms of spatiotemporal structure merely serve as simple and elegant ways of encoding the fundamental facts about physical necessity. In other words, the spacetime functionalist can hold that the standard laws are *scientifically* fundamental, while facts about physical possibility are *metaphysically* fundamental.

We should distinguish between *scientific* explanation and *metaphysical* explanation. For example, while the fact that a certain atom is ionized at t_2 might be scientifically explained by the fact that it absorbed some radiation at t_1. But the fact that it absorbed some radiation is not what *makes it true* that it is ionized. It is ionized in virtue of having a different number of protons and electrons.

Humeans about laws appeal to this distinction in response to the charge that their account of laws is circular. Humeans claim that the fact that some regularity R is a law obtains at least partially in virtue of the fact that R is a regularity. But laws are supposed to explain their instances. So that R is a law is explained by R (from Humeanism) and R is explained by the fact that R is a law (from the explanatoriness of laws). Armstrong (1983) claims that this makes the account circular. Humeans (like Loewer 2012) may respond by pointing out that the senses of explanation at issue are different. Laws are *metaphysically* explained by their instances, but instances are *scientifically* explained by the laws.[28]

28 Lange (2013) argues that while the two notions of explanation are distinct, scientific explanations are transmitted over metaphysical explanations, and that this means the Humean account of laws is circular after all. Hicks and Elswyk (2015) respond by arguing against bridge principles linking scientific and metaphysical explanation.

The spacetime functionalist can make a similar move; she can claim that the familiar laws that are framed in terms of spacetime are scientifically fundamental, while facts about physical necessity are nonetheless metaphysically fundamental.

There are independent, quite general reasons to think that the scientifically fundamental laws are not metaphysically fundamental—that is, not state in metaphysically fundamental terms.[29]

The fundamental physical laws are stated using *defined notions.* But defined notions are plausibly fundamental—they are less fundamental than the notions they are defined in terms of. For example, the fundamental scientific laws are differential equations; they say how the rate of change of one quantity relates to other quantities. But facts about rates of change, like acceleration, are not metaphysically fundamental. The acceleration of some body at time t is defined as the limit of the rate of change of velocity in successively smaller time periods containing t. Velocity is similarly defined in terms of position. But scientists feel no need to state laws about rates of change as very complicated claims about limits, and if they did the laws would become dramatically less simple.[30]

Another reason for thinking that the scientifically fundamental laws are not metaphysically fundamental is that scientific laws are *mathematical* claims. A very plausible explanation of this fact is that even though the world does not have fundamental mathematical structure itself—a two meter rod doesn't stand in the same relation to a three meter rod as the number 2 stands in to the number 3—we may usefully use mathematical structures to represent physical structures. But there are obvious reasons for physicists to describe the world mathematically even if the world has no fundamental mathematical structure: precisely because it is simpler and more elegant and easier to reason about the mathematical description.

The lesson, it seems, is that scientists deliberately state the laws in non-fundamental terms for the sake of the simplicity gained.

Of course this is perfectly compatible with there being a close connection between the scientifically fundamental and metaphysically fundamental laws, so that the fact that some property appears in the scientifically fundamental laws is defeasible evidence that it is metaphysically fundamental. But there are already independent compelling reasons to think that the metaphysically

29 Hicks and Schaffer (2017) argue for this claim in greater detail.

30 Moreover, if these claims about limits were themselves defined in the standard way, in epsilon-delta terms, the full statement of the laws would be even more complicated.

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fundamental laws are too complicated to be considered candidates for being scientific laws. So it is no objection to the spacetime functionalist that her view has this feature as well.

Perhaps what is really driving the objection is that the spacetime functionalist posits a vast number of *independent* fundamental nomic facts, whereas the spacetime primitivist can get by with positing only a small number of fundamental laws. This, we might think, is a serious cost for spacetime functionalism.

Simplicity is relevant to theory choice in a few different ways. Theories that attribute *less structure* (nomic or non-nomic) to the world are preferable. Since spacetime functionalism attributes less structure to the world than spacetime primitivism, this is not what drives this objection. A different principle concerning simplicity is that theories that can be *stated* simply and elegantly are better theories. Again, this principle does not count against spacetime functionalism because there *is* a perfectly simple way of stating the theory in terms of the scientifically fundamental laws. The principle that is required to drive the objection under discussion must be something like:

> NOMIC SPARSENESS (NS). All else equal, we should prefer a theory on which there are there are a small number of fundamental nomic facts.

If (NS) is a constraint on theory choice then this gives us some reason to resist spacetime functionalism. (Although I will also argue that all else is *not* equal.) However, it is unclear what the motivation for (NS) would be. The motivation does not come from an Occamist preference for theories that attribute less structure to the world. Nor does it come from a preference for theories that can be stated simply. Moreover, if (NS) were correct then it would count against much more than just spacetime primitivism. For example, according to dispositional essentialism, the fundamental nomic facts concern the essences of the fundamental properties. If there are uncountably many determinate mass properties, as many suppose, then the dispositional essentialist holds that there are a vast number of fundamental nomic facts. But however the merits of dispositional essentialism compare to other non-Humean accounts, it is odd to think—and no one has yet claimed—that *this* feature of the view makes the theory worse. This suggests that (NS) should not play a significant role in theory choice.

The mere fact that the scientifically fundamental laws are not metaphysically fundamental is not particular to spacetime functionalism. Moreover, there are independent reasons to think the laws, when stated in metaphysically fundamental terms, will be vastly more complicated than their canonical statements. Since the nomic facts that the spacetime functionalist recognizes are *logically weaker* than those posited by the spacetime primitivist (because they distinguish between fewer possibilities), the complaint that spacetime functionalism is overly complicated is mistaken. And the mere fact that the spacetime functionalist must recognize many independent fundamental facts about physical necessity is no reason to object to the view. So I conclude that none of the objections to positing fundamental facts about physical necessity are very compelling.

3 The Argument from Metaphysical Redundancy

David Lewis said of the perfectly natural properties and relations that "there are only just enough of them to characterize things completely and without redundancy" (Lewis 1986a, 60).[31] There is something very intuitive about this thought. When God created the world, we might imagine, he didn't do unnecessary work. The fundamental facts should plausibly form a *minimal supervenience base*, so that everything supervenes on the fundamental facts but not on any proper subset of them. If the fundamental facts failed to form a minimal supervenience base, then some of them wouldn't be needed to characterize the world. I'll say facts like this are *metaphysically redundant*.

According to the spacetime primitivist, spatiotemporal properties and relations are fundamental. But as I will argue, facts about them do not form a mimimal supervenience base. So there must be metaphysical redundancy in the spatiotemoral primivist's account of the world. This is a count against spacetime primitivism.

I'll first explain why this is the case for the most naïve version of spacetime primitivism, and then explain why any more sophisticated version fails to deliver a minimal supervenience base as well.

31 Lewis makes a similar remark in his (1983, 12): "The world's universals should comprise a minimal basis for characterizing the world completely." Lewis clearly means something modal by "characterizing reality": a collection of facts characterize a world w completely if and only if they are true only at w.

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Consider a spacetime primitivist who regiments the structure of spacetime by positing a family of external relations, the distance relations.[32] That is, the relations *one meter apart*, *two meters apart*, *seventeen meters apart* and so on are all fundamental.

On this view, in order for God to determine how things are arranged in space at a given time He must decide separately, for every material object, which distance relations it stands in. Suppose He starts with my fridge; it is two feet from my coffee maker, 200 miles from Obama, 4000 miles from Putin, and so on.[33] Next, He determines all the distances the Eiffel Tower stands in: it is 95,000 miles from the South Pole, 239,000 miles from the moon, and so on. Third and fourth, He determines for each object its distance from the center of the sun and its distance from the summit of mount Everest. If this way of thinking about distance is correct, God has not even completed a tiny fraction of the work he needs to do to settle the distance facts once he has settled which distances these four objects stand in. But any additional work he does is unnecessary, for the distance relations these four objects stand in is enough to determine the distance between any arbitrary objects in the universe.

Say we want to know how far apart Obama and Putin are. According to the spacetime primitivist this is to ask which fundamental distance relation holds between them. But how far apart they are is already determined by the relations we have specified! For if we know how far Obama and Putin are from my fridge, the Eiffel Tower, mount Everest and the Sun, then by trilateration we know how far apart they are.[34] So this fact about the distance between Obama and Putin is metaphysically redundant. The spacetime primitivist

32 Note that in a relativistic setting it is neither spatial nor temporal distance relations that will be primitive but rather spatiotemporal interval relations. But nothing hinges on this and for familiarity I will use spatial distance relations as my example.

33 Composite objects plausibly inherit their locations, and therefore the distances they stand in, from their parts: my toaster is two meters from my coffee mug in virtue of the fact that the atoms making up my toaster are two meters from the atoms making up my coffee mug. And if substantivalism is true then it is plausible that the distances between material objects are inherited from the distances between the regions at which they are located: my toaster is two meters from my coffee cup in virtue of the fact that my toaster is located at r_1, my coffee cup is located at r_2, and r_1 is two meters from r_2. But I will ignore all of these complications to keep the discussion simple.

34 If we know a point lies on the surfaces of three spheres, then this is enough sufficient information to narrow the possible locations down to no more than two (unless the centers lie on a straight line). Knowing the point's distance to a fourth object will identify it, as long as the fourth object is not equidistant from either location.

could claim that only some facts about distances are fundamental. But any choice of some distance relations over others will be implausibly arbitrary.

Rather than taking distance relations as fundamental, the spacetime primitivist could instead encode facts about distance in other terms. But however she regiments the structure of spacetime her account will entail that there are metaphysically redundandant fundamental facts.

For example, she could posit two fundamental relations, *betweenness* and *congruence*.[35] *Congruence* holds between four points p_1, p_2, p_3, p_4 just in case the distance between p_1 and p_2 is the same as the distance between p_3 and p_4. But this account suffers from the same problem: if my coffee mug and my toaster bear *congruence* to your coffee mug and toaster and also to Fred's coffee mug and toaster, then this entails that your and Fred's mugs and toasters stand in *congruence* too. So this last fact is redundant.

The primitivist could instead take facts about *path lengths* to be basic. The distance between two points can then be defined as the length of the shortest path between them.[36] This avoids the redundancy that arose with distance relations, since the length of the shortest path between Obama and Putin is not settled by the lengths of the paths between my fridge, the Eiffel tower and the Sun and everything else. But taking path lengths to be fundamental results in redundancy of another form. Let a path be a fusion of points, and suppose we assign each path a positive real number that represents its length in meters.[37] Since we are assuming that space is dense, every path p is composed of two subpaths p_1 and p_2. The length of a path is determined by the length of all the subpaths that compose it. So if the length of p_1 and p_2 is determined, there is no need to then go on to determine the length of p. So any fundamental fact about the length of p would be metaphysically redundant. But there was nothing special about p; and therefore every path length fact is metaphysically redundant.

35 David Hilbert's (1899) axiomatized Euclidean geometry in these terms. Field (1980) uses this axiomatization in his nominalization of Newtonian mechanics.

36 Tim Maudlin argues that we should take facts about distance to be defined in terms of path lengths on the grounds that this allows us to explain constraints like the *triangle inequality*: for any three objects, a, , b and c, the distance between a and b is no greater than the distance between a and c added to the distance between b and c. This following section argues that Maudlin is mistaken.

37 Construing regions as mereological fusions rather than sets has the advantage of entailing that they are concrete (since anything with only concrete parts is concrete, but sets of concreta are arguably abstract.) The fact that spacetime regions have physically interesting properties that stand in causal relations is, I take it, a good reason to think they are not abstract objects.

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Finally, the primitivist could posit a fundamental geometric property of spacetime points that is aptly described by a mathematical object called a *metric tensor*. In effect, the metric tensor of a point p encodes information about distances within an infinitesimal neighborhood of p.[38] The length of a path p can then be obtained by integrating along p.[39]

But since the metric tensor at p provides information about the distance structure *nearby* p, redundancy re-arises. I'll illustrate this point with another example of a neighborhood-dependent property, velocity. The velocity of some object at time t is a matter of what the object does *nearby* t: the velocity of o at t is the limit of the average velocity of o in smaller and smaller intervals of time containing t. This means that specifying the instantaneous velocity of an object at every time involves redundancy. Suppose o traveles on some smooth trajectory between t_1 and t_2, and that the velocity of o at every time between t_1 and t_2 is given except for some instant t_i. Because velocity is defined in terms of nearby instants, the velocity of o at t_i is already settled by velocities at other times. So specifying the velocity at t_i would be redundant. But there was nothing special about t_i, and so the same is true of every fact about o's velocity.[40] The situation with metric tensor facts is precisely analogous. Suppose the metric tensor at every point in some space except for p is given. Then it is determined exactly what the metric tensor at p is. So specifying the metric tensor at p in addition would be redundant.[41]

This problem does not arise for the spacetime functionalist. This is because xxx

38 More precisely, the metric tensor at a point is an inner product on the tangent space of that point. Note that this raises the question of the status of topological facts, for the metric tensor can be defined only on differentiable manifold with a baked-in topology.

39 Actually the primitivist can't simply start with a set of points and add metric tensor facts, for she must also provide an account of the topology of the manifold.

40 The stipulation that o traveled smoothly is doing some work here since the claim about redundancy only follows given that o *has* a velocity at t_i.

41 Bricker (1993) argues on this basis that we should invoke novel fundamental properties that behave like metric tensors but are intrinsic to points, and therefore which aren't defined in terms of their neighborhoods. These properties are analogous to the intrinsic velocities invoked by Tooley (1988). These properties would seem encode a lot of information, since they have the structure that metric tensors have. But in fact Bricker's metric tensors only provide this information given that the laws happen to tie them to the neighborhoods of points that instantiate them. But then encoding this structure in the properties themselves is doing no work, which is all by the laws. While this view may escape the argument from metaphysical redundancy it makes the argument from explanatory redundancy more pressing.

If spacetime primitivism is correct then there is no non-arbitrary, non-redundant supervenience base for the world. This is a reason to prefer spacetime functionalism, for which these problems do not arise since the world's minimal supervenience base doesn't include facts about spatial or temporal distance.

4 The Argument from Explanatory Power

The spatiotemporal primitivist holds that spatiotemporal properties and relations are fundamental. This makes it puzzling that spatiotemporal relations march in lockstep. For example, the fact that *a* is two meters from *b* and *b* is two meters from *c* imposes constraints on possible distances between *a* and *c*. Some will be willing to go as far as David Hume and insist that the basic building blocks of the world are "entirely loose and separate" (1975, 61). Even for those who doubt the fundamental world is entirely "loose", however, it hard to deny that a theory is better if it is able to explain constraints among the fundamental properties and relations instead of having to leave them as brute stipulations.

Necessary connections call out for explanation. For example, many philosophers infer from the fact that normative properties supervene on natural properties that normative properties are grounded in natural properties, precisely because this supervenience ought to be explained. If natural and normative properties were both fundamental, the thought goes, it would be mysterious why they were so nicely choreographed. We might imagine that God creates the world, one fundamental property at a time. Once he has settled the distribution of the natural properties, he goes on to specify the distribution of normative properties, but *necessarily* does so in precisely such a way that one class of properties supervenes on the other. But why? Why should God's creative powers have to follow this pattern?

One can hold that necessary connections should be explained whenever possible without being committed to the radical Humean doctrine that there are no necessary connections at the fundamental level. Consider David Lewis' complaint about David Armstrong's account of laws of nature. On Armstrong's account it is a law that anything with F has G if and only if F bears the second-order relation *nomic necessitation* (or *N*) to G. Lewis objects that no explanation has been given for why the fact that N(F,G) should entail that anything with F also has G:

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> Whatever N may be, I cannot see how it could be absolutely impossible to have N(F,G) and Fa without Ga […] The mystery is somewhat hidden by Armstrong's terminology […] who would be surprised to hear that if F "necessitates" G and a has F, then a must have G? But I say that N deserves the name of "necessitation" only if, somehow, it really can enter into the requisite necessary connections. It can't enter into them just by bearing a name, any more than one can have mighty biceps just by being called "Armstrong". (1983, 366)

Lewis seems to think that there is something especially problematic about Armstrong's theory. I don't think that's right. Armstrong posits a special second-order relation to make sense of laws. But it is a virtue, not a vice, of Armstrong's account that he does not merely posit and stop there. He says something about how his chosen machinery is supposed to behave. The phenomenon Lewis is objecting to is utterly mundane: any theory must have some entities or primitives that aren't explained in other terms, and any interesting theory will say something about how these primitive features behave.

Lewis is a spacetime primitivist. He recognizes a family of perfectly natural external relations, the distances. But for them to play the role of distances they must obey certain constraints, like the triangle inequality: it had better be the case that for any three points *a*, *b* and *c*, the distance between *a* and *b* added to the distance between *b* and *c* is not more than the distance between *a* and *c*. And it had also better be the case that a given pair of points only ever stand in one of these fundamental external relations: two points cannot stand in multiple distance relations. How does Lewis explain these constraints? He doesn't. That *a* is 1*m* from *b*, *b* is 1*m* from *c*, and *a* is 1*m* from *c* are all distinct, basic states of affairs. We might imagine Armstrong offering a parody of Lewis' complaint:

> Whatever these distance relations may be, I cannot see how it could be absolutely impossible to have *one-meter(a,b)*, *one-meter(b,c)* and *twenty-meters(a,c)*. I say that these relations deserve the name "distances" only if, somehow, they can really obey the necessary constraints. They cannot obey them just by bearing a name, any more than [etc.]

Still, Lewis does have a legitimate complaint against Armstrong. It is that Armstrong posits necessary connections where he doesn't need to. Armstrong must simply stipulate that *nomic necessitation* behaves in the way he claims it does. The Humean reductionist about laws need not make any such stipulation.

We can profitably think of Lewis's complaint as an appeal to a certain kind of parsimony.

Theories that make fewer assumptions are, all else equal, better theories. This principle takes on a few different guises in metaphysics. It's familiar to distinguish between the *ontology* of a theory (which things it says exist) and its *ideology* (those expressions of the theory which are unexplained, the primitives of the theory.) We can distinguish between varieties of simplicity correspondingly. Ontologically simpler theories posit fewer (types or tokens of) entities. Ideologically simpler theories use fewer primitive expressions.

But there is a further notion of simplicity that does not take either of these forms. Say that *axiomatically* simpler theories are those that contain fewer stipulations about how the primitives of the theory behave.

Suppose the spacetime primitivist accounts for the structure of space and time by positing a family of perfectly natural external relations, the distance relations. These relations must be stipulated to behave in certain ways if they are apt to play the role of *distance* relations. First, they exclude one another. It had better not be possible for two things to stand in hundreds of different distance relations. And second, they must obey broader constraints in their distribution, like the triangle inequality: it had better be true that for any three objects, o_1,o_2,o_3, the distance between o_1 and o_3 is at most the sum of the distances between o_1 and o_2 and o_2 and o_3.[42] This a cost that the spacetime functionalist avoids.

As we saw in the previous chapter a more sophisticated spacetime primitivist need not regard distance relations as fundamental. But however the spacetime primitivist accounts for the structure of space the same problems will reemerge for similar reasons.

For example, suppose that path lengths are fundamental and facts about the distance between two points obtain in virtue of facts about the length of the shortest path between them. Maudlin (2007) claims that the benefit of taking path length to be prior is that constraints like the triangle inequality emerge by definition instead of having to be stipulated. But as we saw in the

42 As Maudlin (2007) points out, there are many more constraints once we consider the distribution of distances for more than three objects.

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previous section there are still plenty of constraints on path lengths that must be postulated. For example, we must stipulate that the length of a path is always equal to the sum of the lengths of the subpaths composing it.[43]

These unexplained stipulations are theoretical costs. We should avoid positing necessary constraints whenever we can; all else equal they make a theory worse. Spacetime primitivists must simply postulate that their favored primitives obey certain constraints such as the triangle inequality. The spacetime functionalist, on the other hand, has no need to, since these constraints naturally emerge from the nomic facts to which spacetime reduces.

The spacetime functionalist theorist takes facts about nomic necessity to be fundamental. We saw that Armstrong must stipulate that *nomic-necessitation* behaves in a certain way. But there is nothing unique about Armstrong's account in this respect; *any* non-Humean must make an analogous claim.[44] So the spacetime functionalist should stipulate that $L(p)$ entails p.

But once this constraint is in place the spacetime functionalist has a ready explanation for the constraints that the primitivist must take for granted. Take the fact that no two points can stand in more than one distance relation. This would require that one point is associated with two different and incompatible sets of physically necessary conditionals. For example, suppose that p_1 and p_2 are both one meter and two meters apart. Then it is physically necessary that if there is a lonely object with mass m at p_1 then the gravitational field at p_2 will be g_1, and also physically necessary that it be g_2. But this would require the same point to have two gravitational field values, and this is impossible. More generally, physical magnitudes within a determinable family, like 1kg mass and 2kg mass, exclude one another. Given this fact and the fact that nomic necessity is alethic, it follows that it is impossible for two points to stand in more than one distance relation.

Of course, the spacetime functionalist is left with the unexplained incompatibility of physical magnitudes. But so too is the spacetime primitivist. The

43 Suppose instead that distances are encoded with the relations *congruence* and *betweenness*. It must be stipulated that *congruence* is transitive and *betweenness* is transitive. Finally, consider the view that facts about the metric tensor are basic. It must be stipulated that if the metric tensor at some point p represents a locally positively curved space then p is not surrounded by a locally negatively curved space, for example.

44 For example, the dispositionalist will leave principles like the following unexplained:
Dispositional Principle. If something is disposed to x given y, and y occurs, then (absent finks and masks) it y's.

spacetime functionalist has no need, unlike the primitivist, to *additionally* stipulate that constraints like the triangle inequality hold.[45]

Spacetime primitivists must posit brute necessary connections between the basic building blocks of the world, whereas these connections emerge naturally given spacetime functionalism of spacetime. This is another reason to prefer spacetime functionalism.

5 The Argument from Parsimony

The argument from parsimony is simple. Spacetime functionalism attributes less structure to the world than spacetime primitivism. All else equal, we should prefer theories that attribute less structure to the world. So, all else equal, we should prefer spacetime functionalism over spacetime primitivism.

Of course, all else is only equal if spacetime functionalism is able to explain our evidence just as well as spacetime primitivism. This section will present two arguments in favor of this claim. The first argument will pursue an analogy between absolute velocities and spacetime primitivism which gives us reasons to think primitive facts about space and time are *undetectable* and therefore *empirically redundant*. The second argument makes the perhaps surprising claim that our apparent evidence does not include facts about the world's spatiotemporal structure. Since we should believe the best explanation of our apparent evidence, we should adopt spacetime functionalism.

My first case against spacetime primitivism is analogous to the case against endorsing facts about absolute velocity in the context of Newtonian gravitational mechanics (NGM).

You are moving at different speeds relative to different things. You are stationary with respect to your armchair, moving at about 66,500 mph around the sun, and at about 515,000 mph around the center of the Milky Way. But how fast are you *really* going? Do you also have an *absolute* velocity in addition to all these relative velocities?

The consensus among philosophers of science is that we should think not. As Newton himself was aware, what the laws of NGM say about how things in a system interact is completely independent of how fast the system is moving. But this means that even if you have an absolute velocity, it is impossible to detect it. The fact that absolute velocities are undetectable shows that we don't

45 In other work I argue for an account of physical magnitudes that allows us to explain the incompatibility of magnitudes.

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need them to make sense of the world: they are *empirically redundant*. Since we should prefer theories that attribute less structure to the world, we should prefer an account of the world that does not recognize absolute velocities.[46]

Why aren't absolute velocities detectable? On a natural way of thinking about detectability, for a physical quantity q to be detectable requires that there is a *measuring procedure* for q: a process whose outputs (a) are reliably correlated with the value of q and (b) are accessible to us, so that the procedure allows us to form reliable beliefs about the value of q.[47] For example, a measurement procedure might correlate the value of q with the position of a dial in some measuring device, or what is displayed on a computer screen, or the arrangement of ink particles on a piece of paper, so that by observing the dial, computer screen or paper, we can form reliable beliefs about q.

If a quantity q is detectable by any means then we can argue that in particular there must be a measurement procedure that correlates the value of q with the *positions* of material bodies; for example, the positions of ink particles on a piece of paper. After all, if there is any measurement procedure for q that allows me to form reliable beliefs about q, then I could decide to write down the content of my beliefs on a piece of paper, and so the procedure that includes my recording the result on paper will itself be a reliable measurement procedure.[48]

But given NGM it is *impossible* for there to be a measurement procedure like this for absolute velocity! Suppose there were such a procedure and that it is carried out by Sally the scientist. Sally writes down the result on a piece of paper: *My absolute velocity is 5 mph.* Now imagine a world that is just like ours, except that everything is moving 1000 miles an hour faster in a certain direction. The two worlds agree on the relative motions and positions of every object, and Sally therefore writes down *My absolute velocity is 5 mph.* in this world too. But Sally's absolute velocity is different in the two worlds, and so

46 For discussion of this case see Earman (1989), Brading and Castellani (2003), Roberts (2008), North (2009), Baker (2010), and Belot (2011). Some philosophers (for example Dasgupta 2013; and Maudlin 2007) present the case against absolute velocities as revolving around the vice of positing undetectable structure rather than the vice of positing redundant structure.

47 This way of thinking about detectability comes from Albert (2015) and Roberts (2008).

48 This is at least this case for what is detectable *for us*. Perhaps there could be beings that have the ability to sense their absolute velocity directly, even though they would be in the bizarre position of being unable to communicate their sensations in the form of letters or in spoken conversation or in sign language. (Roberts 2008 discusses the possibility of such beings, and the implications this has for the claim that absolute velocities are undetectable.) But I take it that we are not like these beings.

the measurement procedure must have produced a false result in at least one of them. So the procedure can't have been reliable after all.

This suggests the following necessary condition for some quantity to be detectable:

> P1. A quantity q is detectable in w only if there is a measurement procedure for q in w.

Since there is no measurement procedure for absolute velocities in NGM, absolute velocities are undetectable.

However, for some quantity q to be detectable it is not sufficient for there to be a measurement procedure for q. Consider the hypothesis—(Stationary)—that there are facts about absolute velocities but the laws specify that the center of mass of the universe is stationary. There *is* an measurement procedure for absolute velocities given (Stationary): to find the absolute velocity of some body, simply find its motion relative to the center of mass of the universe.

But there is an important sense in which absolute velocities would still be undetectable given (Stationary). For the measurement procedure described above is only a reliable measurement procedure for absolute velocities if the laws are those of (Stationary). So our having evidence concerning the absolute velocities of things depends on our having evidence that the laws are those of (Stationary). But we don't have any such evidence, since the world according to (Stationary) is indiscernible from a world in which there are no absolute velocities and the laws are simply those of NGM.[49]

Consider the theory—(Goblin)—that consists of NGM together with the stipulation that it is physically necessary that there is an invisible, massless goblin collocated with each massive object. It's extremely natural to think that we should give (Goblin) lower credence because it posits things, goblins, that aren't needed to explain the data. But according to (P1), if (Goblin) were true then goblins would be detectable: simply locate the massive objects and infer the existence of goblins there. So if (P1) were correct then we could not argue against Goblin on the grounds that the theory contains redundant structure, since goblin-free theories fail to account for all the detectable facts. But this isn't right.

49 Dasgupta (2013) appeals to similar reasoning to argue that absolute mass facts, as opposed to merely mass ratios, are undetectable.

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The general point is that in order for something to be detectable, not only must there be laws that allow us to implement a measuring procedure, we must also know *what the laws are* that govern our measuring procedure. This suggests that we adopt a more general principle concerning detectability:

> P2. If there is a measurement procedure for some quantity q if the laws are L, but not if the laws are L, and we have no evidence that the laws are L rather than L, then q is undetectable.

This principle correctly predicts that even if (Stationary) is true, absolute velocities are undetectable, and that goblins are undetectable even if (Goblin) is true.

The fact that absolute velocities are empirically undetectable shows that we don't need facts about absolute velocities to make sense of the world; the extra spacetime structure required to make sense of them is superfluous structure.

The spacetime primitivist holds that there are primitive facts about the spatiotemporal arrangement of the world. I will now argue that facts like these are just like absolute velocities. Worlds that differ only in how things are arranged in spacetime are indiscernible, and so we don't need primitive spacetime facts to make sense of the world. Spacetime primitivism is committed to redundant structure, for the additional fundamental facts it requires perform no explanatory work.

The argument from redundancy against spacetime primitivism is analogous to the case against positing facts about absolute velocities:

(S1) Spacetime functionalism attributes less structure to the world than spacetime primitivism.
(S2) *Ceteris paribus*, if two theories are both empirically adequate we should prefer the theory that attributes the least structure to the world.
(S3) Spacetime primitivism and spacetime functionalism are both empirically adequate.
(S4) So, *ceteris paribus*, we should prefer spacetime functionalism to primitivism.

This argument is valid, and so it remains only to defend the premises.

As for (S1), we could appeal to a modal test for when one theory attributes more structure than another. The claim that endorsing absolute velocities requires extra structure is typically motivated in this way: if there are absolute velocities then there are possibilities that differ only in that everything is

moving at a different constant velocity. Similarly, if spacetime primitivism is correct then the actual world and the shrinking world are distinct possibilities. But this is not so according to the spacetime functionalist. Since spacetime functionalism ignores distinctions recognized by spacetime primitivism, spacetime primitivism contains extra structure.

But this modal test is at best a useful heuristic. For consider someone who believes that there are absolute velocities but denies the relevant claims about possibility. For example, as Dasgupta (2013) points out, she might believe that Spinoza was right and there is only one possibility, the actual one. Or she may just endorse (Stationary). A spacetime primitivist could deny that the shrinking world and the actual world are distinct possibilities on similar grounds. But surely these quirky modal beliefs are simply irrelevant to how much structure a theory attributes to the world. A better test is simply to look at the fundamental facts the theories posit. After all, attributing excess structure is a matter of what the world is actually like, not what it could have been like. The spacetime primitivist recognizes all the fundamental facts the functionalist does, and more besides: primitive facts about the spacetemporal arrangement of things. So spacetime primitivism attributes more structure to the world than spacetime functionalism.[50]

I take the principle expressed in (S2) to be ubiquitous in both scientific and common sense reasoning, and enshrined in inference to the best explanation. (S2) is not the claim that simpler hypotheses are always better; just that, faced with two hypotheses that are otherwise equally worthy of belief, we should prefer the one that attributes less structure to the world.

On to (S3). The case for thinking that spacetime functionalism is empirically adequate is analogous to the case of absolute velocity. Since absolute velocities are undetectable, an account of the world that doesn't recognize absolute velocities is alike in all detectable respects with an account that does, and so both theories are empirically adequate as long as one is.

I will argue that primitive spacetime facts are undetectable, and since spacetime functionalism agrees with spacetime primtivism on all the detectable facts, spacetime functionalism is empirically adequate if spacetime primitivism is.

Why think primitive spacetime facts are undetectable? Well, consider whether there is a measurement procedure for distance facts, for example.

50 Spacetime functionalism is the claim that facts about spacetime are not fundamental, not that they are false. So the principle appealed to is: attribute as little structure to *fundamental* reality as possible.

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There must be a procedure that, given two points p_1, p_2, results in a recording of "p_1 is x meters from p_2" only if p_1 is in fact x meters from p_2. Suppose that placing the end of some measuring tape next to one point, holding the tape taut so that it lies on the second point, and recording the number on the tape adjacent to the second point is such a measurement procedure.

Suppose we try to measure my height by this method. Now consider the halved or shrinking worlds described in the previous section, in which my height is different from what it actually is. Since these worlds have the same causal structure as the actual world, they agree about the output of the measurement procedure. So in order for the tape measure to give me evidence about my height I need to have evidence that the laws are those of the actual world and not those of the halved world or the shrinking world. But we don't have any such evidence. These worlds have the same causal structure, and so they are perfectly indiscernible. The same things happen, and for the same reasons. After all, suppose you actually form the belief that there is beer in the fridge on the basis of your perceptual evidence. Then in any world with the same causal structure as the actual world, a purely qualitative duplicate of you forms the same belief on the basis of seeing a purely qualitative duplicate of the beer (and drinks it for the same reason!)

So for every world recognized by the spacetime primitivist there is a an empirically equivalent world recognized by the spacetime functionalist. Thus spacetime primitivism is empirically adequate only if both theories are. This completes the defence of premise (S_3) in the argument. Even though spacetime functionalism attributes less structure to the world than spacetime primitivism it is still able to account for the data. The extra structure of spacetime primitivism is redundant structure.

So much for the argument from undetectability. I will now present a related but different argument for the claim that spacetime primitivism is committed to redundant structure. It is clear enough that the spacetime functionalist attributes less structure to the world than the spacetime primitivist. But the crucial question is whether she can get away with less. Can we explain our evidence with the sparser resources of spacetime functionalism?

Not, of course, if our evidence includes facts about how things are arranged in space and time. For according to the spacetime functionalist worlds with the same causal structure are the same world, but (at least, according to the spacetime primitivist) they disagree radically about how things are arranged in space and time. Since spacetime functionalism is only worthy of belief if it is capable of explaining our evidence, the spacetime functionalist must argue

that our evidence does *not* include facts about how things are arranged in space and time.

I'll now argue for for this claim. Well, not quite—I will argue that *in the sense of evidence that is relevant in metaphysics,* our evidence does not include facts about the spatiotemporal arrangement of the world.

There is a close connection between the concepts of *evidence* and *rationality*: to believe rationally is to accord credence in proportion to the evidence. So theories of evidence make predictions about rational belief.

Because of this many externalist theories of evidence apparently *undergenerate* predections of rational belief. Consider someone whose internal mental life is indistinguishable from your own but who, sadly, is a massively deceived brain in a vat. Many externalists insist that you have evidence your unhappily situated twin lacks (otherwise on what grounds do we believe we ourselves are not in the bad case?) For example, Williamson (2000) holds that our evidence just consists in what we know. If I know that I have hands, then my having hands is part of my evidence; my twin will clearly lack this evidence). But if part of what makes *my* belief that I have hands rational is something that my deceived twin lacks, it would seem that my twin's belief that he has hands is not rational (or at least, if it is, then the rationality of my own belief is oddly overdetermined.) But there is something very compelling about that the thought that if one of us is rational, we both are—after all, our mental lives are indiscernible, and we reason in identical ways.[51]

We should believe the propositions supported by our evidence. If externalism about evidence is right, then there is a sense that my twin *should not* believe he has hands. Perhaps there is a sense of "should", associated with a conception of evidence, on which this is right. But it seems extremely hard to deny that there is also a sense in which, if I ought to believe I have hands, then my twin ought to believe he has hands too. And associated with this notion of rationality there is a conception of evidence on which we have the same evidence. Denote this concept evidence$_{Int}$. (For a useful foil, call the Williamson notion of evidence$_{Ext}$.)[52]

While I'm happy to grant the existence of multiple conceptions of evidence, it also seems clear that only one of these conceptions can usefully inform

51 This puzzle for externalism about evidence resembles the New Evil Demon Problem presented for externalism about justification first discussed in Cohen (1984). For a discussion of the extension to evidence see Silins (2005).

52 I'll remain as neutral as I can about what, exactly, is part of our evidence$_{Int}$. According to Conee and Feldman's (2004) account of evidence, my twin and I have the same evidence.

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deliberation. Imagine my deceived twin deliberating about whether or not to believe he has hands. It does him little good to be told: *believe whatever is support by the things you know!*, for what he is deliberating about is exactly whether he knows the things that would be count in favor of believing he has hands.

The concept of evidence$_E$*xt* seems to *undergenerate* rational belief in the case of my deceived twin. But it also appears to *overgenerate* rational belief.

Recall (Goblin), the theory that the laws are those of NGM together with the stipulation that there is an invisible, massless goblin collocated with every massless object. Suppose that (Goblin) is true. Now consider Greta, who believes (Goblin.) Surely we think that Greta is being irrational—she should reflect on her beliefs and realize that there is a simpler theory that explains her evidence just as well as (Goblin)—namely, NGM.

But if we should believe whatever explains our evidence$_E$*xt*, Greta *should* believe there are goblins. This is because she does know where the goblins are—she is very good at locating massive objects, and very good a correctly inferring the existence of a goblin there. The whereabouts of goblins are therefore part of her evidence, and so she should reject the Goblin-free theory on the ground that it can't explain her evidence.

Similarly, consider Sid, who believes (Stationary) and is in a world where (Stationary) is true. Assuming he possesses the relevant astronomical information and makes the appropriate inferences, Sid *does* know about absolute velocities. If he is rational in rejecting theories that fail to account for her evidence, he is rational in maintaining his belief in Newtonian absolute space. But intuitively this isn't right; there is at least a sense of "ought" in which Sid ought not to believe in absolute velocities.[53]

Again, we can note that considerations about what our evidence$_E$*xt* consists of will not, in general, be very helpful in deliberation. Imagine Greta and Sid deliberating about whether or not to believe in the inflated or the simpler theories they are considering. It is no help to admonish them to believe what-

53 Suppose instead that our evidence consists of what we know *non-inferentially*, where a belief is non-inferential if we don't believe it on the basis of inference. (See Bird 2004.) Against the skeptic we can claim that we know non-inferentially that we have hands. But, we might think, we have plenty of non-inferential knowledge about the spatiotemporal arrangement of the world. Surely I can know where things are just by looking at them! But if (Stationary) were true, we arguably could also have non-inferential knowledge about absolute velocities. (As long as our true beliefs about the absolute velocities were caused by and sensitive to the absolute velocities, say.) So again, this principle has the incorrect result that the believer in absolute velocities would be justified in rejecting theories that failed to account for absolute velocity facts.

ever explains their evidence$_{E}$*xt*, for the theories themselves have different consequences for their evidence$_{E}$*xt* consists of.

This suggests the following moral. If you are unsure about what to believe, the best piece of useful advice that can inform your deliberation is: *believe the best explanation of your evidence$_{I}$nt*. This is precisely the situation with the debate between the spacetime primitivist and the spacetime functionalist. Which theory is correct will dictate which propositions are included in our evidence$_{E}$*xt*. But just as it was inappropriate for Greta to reject goblin-free theories of the world on the grounds that they fail to explain her evidence, it would be equally inappropriate for you, gentle reader, to reject spacetime functionalism on the grounds that it fails to account for all the facts about how things are arranged in space and time. What matters is that spacetime functionalism explains the appearances, and does so while attributing less structure to the world than spacetime primitivism. This is a count in favor of the theory.

Note that the dispute at issue between spacetime functionalism and the spacetime primitivist is about *what we ought to believe*, not about what we know, given the beliefs we have. Just as Greta knows where the goblins are, but still shouldn't believe in them, I grant that if spacetime primitivism *were* true then we would know how things are arranged in space and time. But this does not yet answer the question of whether or not to believe that spacetime primitivism *is* true.

A quite different response to the argument from redundancy is that while, all else equal, we should prefer theories that attribute less structure to the world, all else is not equal between spacetime primitivism and spacetime functionalism. By allowing the extra structure required by spacetime primitivism we obtain a theory that is much more explanatory, or otherwise superior, and so the extra structure earns its keep. Spacetime functionalism may attribute less structure to the world, but it is so unwieldy, or disjunctive, or ugly that it is overall unworthy of belief. However, the previous sections, which presented the arguments from explanatory power and metaphysical redundancy, argued that spacetime functionalism is not just theoretically on a par with spacetime primitivism, it is to be preferred precisely because it is explanatorily superior.

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6 Conclusion

I hope to have shown in this paper that spacetime functionalism deserves serious consideration as an alternative to spacetime primitivism. This has important implications elsewhere in metaphysics.

I'll close by mentioning one such issue. The debate over Humeanism is one of the most polarizing in metaphysics. Recall that the Humean reductionist about laws cannot be a spacetime functionalist. This means we are faced with the question of how the merits of non-Humean spacetime functionalism compares with the merits of Humean spacetime primitivism.

Each of these packages of views takes something as primitive that the other regards as reducible. Moreover, many of the traditional arguments against non-Humeanism are based on considerations that count similarly against spacetime primitivism as well.

For example, one argument against non-Humeanism involves the charge that we lack epistemic access to the non-Humean's extra machinery, since there are worlds with the same regularities as the actual world but in which this machinery is absent.[54] To the extent that one shouldn't argue for metaphysical conclusions from epistemic premises, we can reframe this concern as one that is really about redundant structure: we can make sense of the world without the non-Humean's extra machinery, claims the Humean, and so we have no reason to posit this extra structure.[55] I have argued that these kinds of considerations also form the basis of an argument against spacetime primitivism.

A distinct kind of concern about non-Humeanism is that it is *mysterious*. One way of presenting this worry is that while the Humean has a story to tell about why laws play the epistemic role they in fact do—for example, why they back explanations, counterfactuals, and induction—the non-Humean must simply stipulate that laws are fit to play these roles.[56] A related argument is that the non-Humean account is unduly mysterious because it is committed to unexplained necessary connections. This charge is based on the claim that it must be simply postulated that the non-Humean's laws entail the regular-

54 This argument is made in Earman and Roberts (2005).
55 Schaffer (2009) presents this argument in favor of Humeanism.
56 See Loewer (1996).

ities they are invoked to explain.[57] I have argued that precisely analogous considerations count equally against spacetime primitivism.

This suggests that the question of whether or not Humeanism is correct is left undecided by the arguments typically marshaled in favor of Humeanism. Proper way to assess the relative merits of Humeanism and non-Humeanism, it seems, must involve a comparison of the overall *packages* of views in metaphysics with which they may be combined. That, however, is a project for another day.

Note Added, by Eddy Keming Chen and Dean Zimmerman

Marco Dees wrote the first version of this paper in 2015, as part of his dissertation submitted for his Ph.D. in philosophy at Rutgers University, New Brunswick. This version of the paper was finished before his untimely death in 2018. We believe that it contains insights that will be of interest to the philosophical community, and we were pleased when Marco's family asked us to explore whether it would be possible for it to be published in an academic journal. Marco defends the idea that the spatiotemporal structure of the world is not fundamental, but is instead grounded in the role spacetime regions play in laws of nature. We are glad that the paper has been, after peer review, accepted by *dialectica*. Given the current state of the literature, it would have been better to call Marco's view "spacetime causal functionalism", in order to make clear the contrast between his theory and versions of spacetime functionalism as defended, for example, by Eleanor Knox in the context of general relativity and by Nick Huggett, Vincent Lam, and Christian Wüthrich in the context of quantum gravity. It is likely that, given the opportunity for revision, Marco would have taken the opportunity to compare his causal functionalism with these other forms of spacetime functionalism. In the end, we decided to leave the paper as Marco had written it, hoping that others will be inspired to work out the comparisons.*

Marco Korstiaan Dees

57 This is the basis of Lewis' famous argument against Armstrong in his (1983). As I explain in section 3, this feature is not specific to a version of non-Humeanism that takes laws to be basic: the same of true, for example, of primitive dispositions.

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