Philosophy of Physics

# Structuralism as a Stance

RESEARCH

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## ABSTRACT

In this paper, I argue that ontic structural realism is best understood not as a thesis or doctrine concerning how the world fundamentally is, but rather as a "stance" in the sense of van Fraassen (2002). I do so via an argument analogous to that which van Fraassen offers for why materialism should be regarded as a stance; namely, that by thinking of it as such we have a better explanation of the behavior of the putative doctrine's adherents. In particular, I argue that thinking of structuralism as a stance best explains the toleration of disagreement within the structuralist community with respect to whether quantum fields ought to be classified as "objects" or "structures." I close by offering a preliminary characterization of what the structuralist stance could consist in, arguing that it should be thought of as a sort of methodological orientation or injunction; namely, the injunction to foreground, when doing metaphysics, that the language of physics is mathematics.



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# 1 INTRODUCTION

In the metaphysics of physics, there is, by now, a large literature on ontic structural realism (OSR). OSR is standardly understood to be "an ontological or metaphysical thesis that inflates the ontological priority of structure and relations" relative to individual objects (Ladyman 2020). It is also often presented as a thesis with impeccable naturalistic credentials. My purpose here, however, is to argue that OSR is best understood not as a thesis at all, but rather as a *stance* in the sense of van Fraassen (Van Fraassen 2002). In particular, I will argue that rather than a claim about how the world fundamentally is, it ought to be thought of as a sort of methodological orientation or heuristic; namely, *the injunction to foreground, when doing metaphysics, that the language of physics is mathematics*.

In support of this claim, I will first recount (Section 2) van Fraassen's arguments for regarding materialism as a stance, and then argue (Sections 3 and 4) that similar considerations support a stance interpretation of ontic structural realism. The basic argument will be that thinking of structuralism as a stance helps make sense of certain facts about the behavior of the structuralist community: in particular, of the *toleration of disagreement* within that community with regard to the question of what ought to be classified as "structure." Following that, I will turn (in Section 5) to how the stance should be characterized. I will argue that thinking of it as the injunction to take the mathematicalized nature of physics seriously in metaphysics helps to make sense of the facts regarding disagreement; comports with the central place of methodological critique in the work of prominent structuralists; and is supported by many of the same arguments that support structuralism construed as a thesis. Section 6 is a brief conclusion.

Since my exclusive concern in this paper is with structuralism construed as a position in the metaphysics of physics, not a defensive position within the realism debate in philosophy of science, in place of "ontic structural realism" below I will by and large write simply "structuralism." I begin by outlining van Fraassen's reasons for regarding materialism as a stance.

# 2 "MATERIALISM AS A STANCE"

As the title suggests, van Fraassen's monograph *The Empirical Stance* argues that empiricism should not be thought of as a "factual" position, but rather as a *stance*: That is, as an "attitude, commitment, approach, a cluster of such" (2002, 47–48). In particular, he argues that empiricism consists, at least in part, of a "rejection of explanation demands and dissatisfaction with and disvaluing of explanation by postulate… a rebellion against theory… ideals of epistemic rationality… and the virtue [its protagonists] see in an idea of rationality that does not bar disagreement" (2002, 47). This claim about empiricism and its implications for the nature of the debate over scientific realism has, by now, given rise to a large literature. But in that same work, van Frasssen argues that in addition to empiricism "some major putative exemplars of metaphysical theories" should be reconceptualized similarly (2002, 49). In particular, in a section entitled "Materialism as a Stance," van Fraassen argues that while *materialism* is standardly taken to be a thesis about what the world is like—in particular, one about how the world fundamentally is—he argues that it, too, is better regarded as "an attitude or cluster of attitudes" including "strong deference to the current content of science in matters of opinion about what there is" (2002, 59). Clearly this is revisionary. For, if van Fraassen is right, then "materialism may be a prime example of false consciousness in philosophy… materialists may take themselves to be maintaining a theory while they are in reality merely expressing attitudes" (2002, 50).

His argument for this contentious claim begins with a statement of how materialism is standardly conceived. This is as a "thesis," "claim," "doctrine," or "theory" concerning how the world is. This "putative metaphysical theory" he takes to be "summed up in the thesis: matter is all there is" (2002, 49). While noting that these current formulations are more likely to talk of "physicalism" or "naturalism" than "old-fashioned materialism" (ibid.), he treats them as interchangeable for his purposes; I will follow him here. The question is whether the proposition that "matter is all there is" qualifies as a "substantive thesis" or "factual claim." For van Fraassen, in order to do so the proposition must be "clearly true or false," must "rule something out," and as such be "genuinely debatable" (50–51). These seem uncontentious, and let us here simply assume that, for contingent claims at least, they all come as a package. van Fraassen then concedes that "[t]he thesis 'matter is all there is' certainly sounds like a substantive factual claim. Does it not rule out Descartes's mind-body dualism, Aquinas's souls, spirits, entelechies, cosmic purpose?" (50). However, he goes on to argue that appearances here are deceptive. For him, the *laissez faire* attitude with which materialists have approached the question of what it is that characterizes the material suggests that materialism is not best thought of as a factual claim after all. He writes:

> Suppose that the thesis is indeed the important part of materialism. Then something follows from this about what materialists will find it important to do. In that case they will certainly not rest until the distinction between matter and what is not matter has been made so clear that the thesis is a factual claim, which can clearly be either true or false. But if they do not, then by *modus tollens* we should conclude . . . what? (2002, 52)[1]

That materialists are not interested in this project of stating definitively what it is to be "material" is illustrated by the fact that the trajectory of materialism has been one of *post hoc* revision and toleration of entities excluded by previous attempts at characterization. For example, while the earliest exemplars of material things were instances of extended matter, such a restriction was subsequently viewed untenable after the advent of Newtonian forces or the postulation of point particles. And, nor were these then collectively taken to conclusively represent the extension of "material," given the introduction of classical fields, quantum particles, and so on into the pantheon of physical entities. To understand why this tolerance with respect to what qualifies leads us to view materialism as a stance, it is useful—although van Fraassen himself does not explicitly frame things in this way—to divide materialists into their "historical" and "contemporary" actors. As I use the terms, a "contemporary" materialist is one working in the post-Kuhn predicament, one who is aware that even their "most fundamental view of nature" may be "abandoned in the physical sciences" (2002, footnote 27, 58). A "historical" materialist is one "oblivious to such possibilities of change in science" (ibid.). Both render problematic the idea that materialism is a contentful thesis.

Focus first on contemporary materialists. For these materialists, the continual revisions to what is to count as "physical" need not be interpreted as emblematic of a degenerating research program, but rather as appropriate, given that we expect physics to continue to make profound advances. After all, given this expectation, being committed to a definition of the material appropriate to our particular scientific epoch would represent an "untenable historical parochialism" (2002, 52). But the open-endedness implied here, however well-motivated, gives rise to a well-known dilemma often known as "Hempel's dilemma": this is that "when their most important terms are tied to current scientific theories, they must

1 Note that van Fraassen seems to use "factual claim" and "substantive factual claim" as synonymous.

die with those theories; but if not, they seem to lack content altogether" (2002, 53). In other words, materialism is "apparently either trivial or false" (Brown and Ladyman 2009, 20).

By now, much has been written on Hempel's dilemma, and of course the claims here have been disputed. Ladyman and Brown, for example, deny that physicalism rules nothing out with regard to future developments in physics, and hold that this gives content to physicalism. While I myself am sympathetic to this view, it is not my purpose to defend that here.[2] Rather, what I want to draw attention to is that, while no doubt the most discussed, this forward-looking argument is not the only argument van Fraassen offers for why we should reconceive of materialism as a stance. This second argument is directed at "historical" actors, and is less concerned with questions of what materialism *rules out* with respect to future developments as with what it is has *ruled in* in the past. van Fraassen claims that were the position of the materialist a "simple belief," then "we would be faced with an insoluble mystery"; namely, of how it is that the materialist "know[s] how to retrench when his favorite scientific hypotheses fail." He asks: "How did the eighteenth century materialists know that gravity, or forces in general, were material? … How did the materialists know in the nineteenth century that the electromagnetic field was material, and how did later materialists persist in this conviction after the ether had been sent packing?" If this is a claim to knowledge, "the materialist must seemingly have some rather mysterious power: a knowledge that the newly introduced entities have the *je ne sais quoi* that makes for materiality" (van Fraassen 2002, 58–59).

Clearly they have no such power. What, then, is guiding materialists' collective decisions regarding where the lines should be redrawn? Van Fraassen proposes that "If the 'physicalist' or 'naturalist' part of this philosophical position is mainly the desire or commitment to have metaphysics guided by physics, then it is something that cannot be captured in any thesis or factual belief" (2002, 59). As such, were materialism to *be* such a desire or commitment instead of a factual belief, then the vexed question of how it is that materialists could come to know that the electromagnetic field (for example) is a material entity *cannot even arise*. Hence, van Fraassen proposes the following diagnosis of materialism:

> It is not identifiable with a theory about what there is but only with an attitude or cluster of attitudes. These attitudes include strong deference to the current content of science in matters of opinion about what there is. … Given this diagnosis, the apparent knowledge of what is and what is not material among newly hypothesized entities is mere appearance. *The ability to adjust the content of the thesis that all is matter again and again is explained instead by a knowing-how to retrench that derives from invariant attitudes* (59–60, italics added).

For van Fraassen, then, it is not simply that if materialism is a doctrine, then it is a contentless one, given the open-ended nature of scientific enquiry. It is also that if it is a doctrine, *then we have no idea* what could have been governing the historical community of materialists in their collective judgments. By contrast, thinking of materialism as a stance—as a sort of injunction to take as one's ontology whatever one's best physics postulates—gives a much better explanation of these epistemic dynamics. This latter argument may thus be construed as an *inference to the best explanation* for why we ought to think of materialism not as a doctrine, but as a stance.[3]

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2 See, however, Ritchie 2022, Section 2.1.2 for some criticisms of this "ruling out" strategy.

3 It seems to me that this use of abductive reasoning is compatible with van Fraassen's well-known hostility to that form of reasoning as a means of supporting realism. But my argument does not depend on that.

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There are therefore at least two arguments in play in van Fraassen for interpreting materialism as a stance—one of which is directed at contemporary actors and the other at their historical counterparts. And they, moreover, seem to be independent. For, even if Ladyman and Brown are right that materialists will universally hold that irreducible mentality does not qualify as a material entity, this itself does nothing to explain how it was that 19th century physicists knew that the classical electromagnetic field *does*. Of course, just as was the case with the forward-looking argument we can envisage challenges to this second argument for equating materialism with a stance. However, I take it as compelling that *if* it were the case that interpreting a supposed doctrine as a stance were to give a better explanation of the actions of the relevant community, then that would constitute a good reason to interpret it in that way.

In closing the chapter, van Fraassen hints that once we warm up to the idea that empiricism and materialism can be seen not as doctrines but as stances, we may begin see a similar dynamic at work in other contexts (61–62). What I want to do now is offer some confirmation of that by arguing that *structuralism* should likewise be seen as a stance.[4] Similarly to van Fraassen in the case of materialism, I propose that conceiving it as such gives the best explanation of some practices of the community of structuralists. I begin, however, with a recap of how structuralism is standardly conceived.

## 3 STRUCTURALISM AS A DOCTRINE

As already noted, ontic structural realism is normally considered to be a thesis or doctrine. In the words of Ladyman, it is "an ontological or metaphysical thesis that inflates the ontological priority of structure and relations" (Ladyman 2020). In the words of French, it is a position that "maintains that the fundamental ontology of the world is one of structures and that objects, as commonly conceived, are at best derivative, at worst eliminable" (French 2014, v). The two possibilities mentioned here regarding objects' status vis-à-vis that of structure are sometimes designated "priority-based" and "eliminative" structuralism. In the priority-based version, there are objects in physics but they are *grounded in* or *metaphysically determined by* structure, making them non-fundamental. According to eliminative structuralism, there are no objects in physics at all. These two positions may be more or less distinct: For example, if one endorses the position that only the fundamental "really" exists, then little will separate the contents of the arguments offered for either position insofar as they are grounded in physics (cf. Ladyman 2019). Nevertheless, in the interests of brevity, my focus here will largely be on priority-based structuralism; analogous arguments will apply in the eliminative case.

So stated, structuralism (of either form) seems clearly intended as a thesis or doctrine—it is a claim about how the world fundamentally is. What motivation, then, is there to conceive

4 A referee has objected that structuralism as a doctrine seems to be more controversial than the stance I introduce here, and that this casts some doubt on whether this stance adequately captures the gist of structuralism. Here I note three things in reply. First, I make no claim that the characterization of the structuralist stance that I offer here is exhaustive, and further criteria may be less widely endorsed than the injunction to mathematicalize metaphysics. Secondly, note that *applying* the injunction to physics theories leads one to metaphysical claims that are highly contrary to standard assumptions, and so while the injunction itself may seem uncontroversial that doesn't mean it has only uncontroversial implications. Thirdly, whether it even makes sense to regard a stance as controversial or uncontroversial, given that they do not consist of claims that can be disputed as opposed to attitudes, values, and aims, is itself far from clear. In sum, then, it is not clear to me that the referee's point represents an objection to my argument here; but I do also see that engaging in these sorts of comparisons between the structuralist stance and the doctrine is going to be essential to the development and evaluation of the stance view.

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of it as a stance? The first thing we can note in this connection is the similarity it bears to materialism. Insofar as both, read as doctrines, say that *everything (fundamental) is x*, both of them are explicitly forms of "monism."[5] Both of them are, in that sense, arguably quite traditional philosophical doctrines, claiming as they do that one metaphysical category is more fundamental than others. Given the broad similarity in terms of the basic forms of the proposition each makes and the close ties each maintains with science, it is not unreasonable to suspect that similar arguments that each doctrine constitutes "a stance misunderstood" might apply in each case. Indeed, it has already been argued by Jack Ritchie that structuralism is similarly vulnerable to a version of Hempel's dilemma (see Ritchie 2022, Section 2.2). It is easy to see why. Structuralism, like materialism, is a claim about what is fundamental, and one supposedly based in science. Thus, what counts as a "structure" for structuralism is something that is supposedly determined by physics: Holger Lyre, for example, writes that, for structuralists, it is "a physical, not a metaphysical question, what the fundamental structures in nature are" (Lyre 2012, 172). But basing such claims on current physics is liable to reify the wrong things. Therefore, Ritchie argues, "it looks as though the real fundamental structures will only become apparent in some unknown future physics. OSR, then, seems impaled on the second horn of Hempel's dilemma" (Ritchie 2022, 12).

While there is much to say here, this is not the route towards the stance interpretation that I am going to pursue. The reasons are twofold. First, I suspect it is likely that some structuralists—notably, Ladyman—would object to the idea that structuralism rules nothing out with respect to future physics, and so deny (as he did with materialism) that the doctrine is trivial simply because physics is unfinished.[6] Second, it is supposed to be the case that structuralism is supported by physics *in its current state*. Ladyman and Ross, for example, are explicit that, as they see it, "OSR is motivated directly" by "advanced physical theory as we now find it" (Ladyman and Ross op cit. xiii; see similarly French 2014, 322). One might wonder how this could be, given the difficulties inherent in any naturalistic project purporting to have insight into fundamental reality prior to the emergence of a truly fundamental theory of physics (see McKenzie 2020a for discussion). But my focus here is not the truth or cogency of structuralism so much as what the practices of structuralists suggest about its nature. Since it is undeniably the case that structuralists do, by and large, support their position by arguing that our best current theories support it, I will assume that it is the sort of thing that *could* be supported by "advanced physical theory as we now find it." And just as was the case with materialism, there are routes other than those through Hempel's dilemma that lead to the idea of structuralism as a stance.

To see why, recall that to qualify as a "substantive" thesis, a structuralism based on our best current physics must rule something out as a way that the world might be. In order to do so, it needs concepts of "structure" and "object" that that are precise enough to determinately exclude some states of the world as being compatible with the structuralist doctrine. However, both friends and foes of structuralism have long admitted that this will be a challenge. Prominent structuralists, for example, have conceded that "there exists no practical, straightforward method to extract the structural content from a given scientific theory" (Lyre 2009, 381) and that "'structure' is such a weasel-word" (Saunders 2003, 128; see also Roberts 2011, 50). Critics of structuralism have likewise noted that there is

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5 French (2014, 201), for example, explicitly embraces this moniker.

6 I cannot find any direct textual evidence to back up this claim, although Ladyman and Ross do state that "the tentative metaphysical hypothesis of [their] book" is "open to empirical falsification" (2007, 178). See Lorenzetti 2022 for a fuller discussion of what physical theories might plausibly refute structuralism.

a "continuum" between what is and is not structure (Psillos 1995, 31); as such, there is no "dichotomy of nature and structure" presumed by structuralist approaches in general. Other critics have claimed that the distinction between objects and structure is "painfully context-dependent" (Fraassen 2006, 303): for example, what would be classed as an "object" by the consumer may be more naturally regarded as a "structure" by the electrical engineer. Thus, one might think, the distinction between the two is a poor candidate for a fundamental joint in reality.

The fact that a "continuum" exists between structure and non-structure, and that interests salient in a given context might decide where the boundary lies, both point towards the idea that the concept of structure is a *vague* one.[7] Indeed, that the notion of structure is vague in kind has already been acknowledged by structuralists. Lyre, for example, concedes that "[t]he notion of structure is notoriously vague, and this is already one of the many problems of [structural realism]" (Lyre 2009, 381). French and Ladyman similarly admit that vagueness is embedded in both structuralism and "structure" (French and Ladyman 2011, 25). But it is important to appreciate the ways in which this is and is not a criticism. It has, in some sense, been an empirical discovery that certain scientifically central categories, such as species or gender, seem to be irreducibly vague. In that sense, vagueness may be simply a fact of scientific life, and one might reasonably think that this might extend to scientific metaphysics. In fact, van Fraassen himself has taught us that vagueness is a ubiquitous feature of language, both everyday and scientific. According to him, "[a] vague predicate is usable provided it has clear cases and clear counter-cases" (Van Fraassen 1980, 16). But, importantly for structuralists—at least, those basing their claims on our current physics—these we arguably do have for the term "structure": For the structuralist literature offers clear paradigms for *objects* and also clear paradigms for *structures*. For the former, we can count particles and spacetime points (cf. Ladyman and Ross 2007, 151). For the latter, we can count laws, symmetries, and relations (cf. French 2014, ix; Ladyman 2020, Section 4).

In that sense, the complaint posed to structuralism *qua* doctrine cannot be that "structure" is an unusable predicate, for all that it may be vague, for we have clear instances of what does and does not count as structure. In this context, the worry, rather, concerns the treatment of cases that are not obviously one or the other. Since structuralism will be refuted if, and only if, it is not the case that everything essential to what we regard as "objects" is determined by what we regard as "structures," the more elastic the term "structure" is, the less falsifiable the thesis, and the more it risks losing the status of a substantive doctrine.

The status of structuralism thus hinges on the treatment of entities intermediate between the paradigms. Is it the case that the intermediate status of these entities could be exploited to turn a refutation into a confirmation, thereby undermining the "substantive" nature of the core thesis of structuralist metaphysics? It seems to me that it could. In particular, I will argue, the truth value of a structuralism based on current physics is sensitive to the way in which we choose to classify *quantum fields*—entities which some, but only some, structuralists classify as "structure." Importantly for my argument, this divergence in classification seems to go wholly uncommented upon, something that would be puzzling were structuralism, at its core, committed to identifying the fundamental. For this reason, I will argue that structuralists implicitly understand it not as a doctrine but as a stance. As with materialism, I will argue that this interpretation furnishes the best explanation of the behavior of the structuralist community with respect to individual divergences regarding the classification of fields.

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7 See Soames (2012) for an argument for why we should take vagueness to have both of these features.

# 4 THE STANDING OF THE STRUCTURALIST DOCTRINE

Since the focus in what follows will be on the status of quantum fields, I will first situate structuralism within the context of quantum field theory (QFT). QFT constitutes the framework of particle physics and underpins our most fundamental theory to date, the Standard Model of elementary particles incorporating the electroweak and strong nuclear interactions. As such, the paradigms of objects that we will be concerned with here are primarily *fundamental particles*—electrons, quarks, photons, and the like—and not so much spacetime points. As noted above, my focus here will be on priority-based structuralism, and so the question I will address will be that of whether the structures of QFT *metaphysically determine*, and so may be regarded as *more fundamental than*, these objects. More specifically still, I will address the question of whether the relevant structures here determine what *kinds* of elementary particles exist in nature; something clearly necessary if structure is to have a claim to determining what objects there are *simpliciter*, and hence to being more fundamental than them.[8]

Having identified the target objects and the work that must be performed by the structures, let us consider what ought to count as the relevant instances of the latter. Looking at the paradigms above—namely, laws, symmetries, and relations—it seems that it is symmetry that is the relevant structure here. Relations between objects—specifically, entanglement relations—have long been argued by structuralists to be those responsible for conferring the distinctness of objects all of the same kind (there being *very many* electrons, *very many* neutrinos, and so on). But the structure to which kind properties themselves are attributed is typically symmetry structure. The intimate relationship that exists between the symmetries and particles of contemporary physical theories is a recurring theme in the reflections of 20th century physicists and philosophers. At the heart of this relationship is the fact, established by Wigner, that elementary particles (or families of them) are conceived of in terms of the *irreducible representations* of the symmetry groups corresponding to the laws those particles accord with. The close conceptual relationship now known to exist between symmetry and particles, together with the cascade of empirical implications that flow from it, has many times inspired physicists to hazard the existence of a robust metaphysical or grounding relationship between the two. Examples of such statements now permeate the physics literature, but I will take as representative Steven Weinberg's claim that "[a]t the deepest level, all we find are symmetries and responses to symmetries. Matter itself dissolves, and the universe itself is revealed as one large reducible representation of the symmetry group of nature" (Weinberg 1987, 80).[9] The structuralist project is sympathetic to such expressions, and can be understood as the attempt to better articulate them and to make rigorous the arguments for them.

The arguments structuralists offer to this end are often driven by the conviction that the particle kinds are "derivable" from symmetries, and hence "determined" by them. For example, Holger Lyre correctly notes that "[w]e get mass and spin as Casimir operators of the Poincaré group and the various charges of the $U(1)\otimes SU(2)$ and $SU(3)$ interaction groups," from which he infers that "hence, mass, spin, and charge (in the most general sense) are… structurally derived intrinsic properties." This motivates his claim "that the world consists of a structure mainly given by the structure of the fundamental physical gauge

8 I have already discussed this question in (McKenzie 2020b), but for completeness I include the outline of the argument here.

9 Here I note that David Schroeren helpfully confirms that Weinberg intended statements such as these to be interpreted ontologically (Schroeren 2021, footnote 3).

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groups (including the Poincaré group as a gauge group itself). Particles are instantiations of the world structure possessing all structurally invariant properties" (Lyre 2012, 172). These statements from Lyre asserting the structuralist doctrine have been quoted approvingly by Ladyman and Ross, who also write "[h]ere is Lyre again: 'a group theoretic definition of an object takes the group structure as primarily given, group representations are then constructed from this structure and have a mere derivative status'" (Ladyman and Ross 2007, 147). More explicitly still, according to F.A. Muller:

> "[t]he associated Lie-Algebra generates the Casimir-invariants, among which we find mass and spin-magnitude… These properties of the physical system under consideration thus are determined by symmetry relations, which makes them acceptable for the structural realist. Hence [ontic structuralism] is the tailor-made version of scientific realism for QM" (2011, 232).

However, as I have argued in earlier work, despite the intimate relationships that undoubtedly exist between symmetries and particles, and the empirical successes that have flowed from conceiving of particles in terms of irreducible representations of symmetry groups, it is simply not the case that the symmetries of the theories we currently have determine the actual spectrum of particle kinds that we find in the world (McKenzie 2020b). And so, it is not the case that the latter are derivable from the former. This is because any such determination claim faces at least two problems.

> **Problem 1.** The symmetries of our theories do not determine how many particles there are in nature. For example: The SU(3) gauge symmetry of QCD does not determine how many flavors of quarks there are, only that there cannot be more than 16.
>
> **Problem 2.** The symmetries of our theories do not determine the magnitude of many of the properties definitive of the fundamental particle kinds. For example: while Poincaré symmetry dictates that particles with some real value of mass $m > 0$ will have integer or half-integer spin, and constrains massless particles to integer spins, it does not dictate the particular mass had by any fundamental fermion.[10]

These facts are well known to physicists.[11] They have important practical consequences, in that they mean that instead of being deducible from symmetries of the Standard Model the masses of particles must be simply "put in by hand"; that is, matched to experiment. The fact that these many parameters are free—indeed look "absolutely random and hectic" (Feynmann 1988)—is partly responsible for the widespread intuition among physicists that the Standard Model is not the final theory they in are search of. But however familiar they may be, they completely undermine the basis for taking structuralism to be the correct metaphysics of physics, insofar as that metaphysics is supposed to be supported by physics "as we now find it."

For these reasons, it seems that the doctrine of structuralism is not supported by current physics. This is significant, because—as we saw in Section 3 above—structuralism is supposed to be so supported. However, the argument given here establishes that objects fail to supervene on structures only if there are no other candidates for structures that

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10 Arguably, it is necessary, on conceptual grounds, for the fundamental fermions to have spin-1/2, simply because this is the fundamental representation of SU(2).

11 The following quote from Steven Weinberg encapsulates both points: "[T]he Standard Model is clearly not the end of the story. We do not know why it obeys certain symmetries and not others, and why it contains six types of quark, not more or fewer types. Beyond this, appearing in the Standard Model there are about 18 numerical parameters (like ratio of quark masses) that must be adjusted by hand." (Weinberg 2001, 60).

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could be invoked in this context besides symmetries. But this is obviously not the case. In fact, this status has been claimed by some—though not all—structuralists for quantum fields themselves. In the following subsection, I will show that this is the case and consider what warrant could be offered for classifying them this way. Following that, I will show that including fields alongside symmetries has the potential to transform the negative conclusions drawn from Problems 1 and 2, above. Given the evident importance of the issue, I will then argue that the silence in the literature on the issue of how fields ought to be classified is better explained by assuming that structuralism is a stance.

## 4.1 THE PLACE OF FIELDS IN STRUCTURALISM

It has already been pointed out that objects and structures are often held to form a "continuum." Quantum fields arguably occupy a position intermediate between the two extremes. They are akin to the paradigms of objects (particles) insofar as they are routinely attributed some of the same properties, such as spin and mass.[12] Like particles, they have an associated dynamics—the field equations. These fields can be shown to carry energy, momentum, and angular momentum, so that "they are even able to simulate some of the properties of moving bodies" (Bohm 2004, 30). In these senses, they are like other paradigmatic objects in physics. But they are unlike particles insofar as they are often held to *produce and destroy* particles (Weinberg 1995, 31), and thus are presumably distinct from these paradigms in some sense at least. They are moreover like paradigm structures such as symmetries and laws in that they are global entities that one can barely imagine described without heavy use of mathematics, although also unlike those paradigmatic structures in that it seems they *satisfy* laws which *possess* symmetries.

Given these analogies and disanalogies to paradigms at either extreme, where are we to file them? As objects, as structures, or as neither? It seems that there is no consensus here. Rather, what we see is different structuralists classifying them in different ways. For example,

- French (2014, 304) presents structuralism as offering an "alternative ontology" to both particle and field interpretations of QFT.
- Kantorovich (2003, 673) argues for "the ontological priority of symmetries over a wide range of matter fields," later taking this argument to constitute a confirmation of ontic structural realism (Kantorovich 2009).
- Lyre (2004) presents field strengths as "object-like posits" distinct from "structural content."

All of these authors seem, in these quotes, to be taking fields to be something other than structure (even if they are not always explicitly classified alongside objects). However, there are other structuralists who take fields to be instances of structure. Consider, for example, the following quotes from Muller and from Ladyman and Ross.

- "Enter ontic structural realism: there are no particles at the fundamental level of physical reality, there are only structures and object-like features of structures. What seems the fundamental substance of physical reality are quantum fields. Quantum fields are structures. They have, perhaps, object-like features: the *field quanta*" (Muller 2014, 429).

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12 Certainly, physicists often talk this way: Steven Weinberg, for example, refers to the Klein-Gordon equation as that which "the components of a field of definite mass $m$ satisfy" (Weinberg 1995, 200). There are, however, difficulties with taking this talk literally, at least for certain properties: see footnote 16 below.

- "OSR agrees with Cassirer that the field is nothing but structure. We can't describe its nature without recourse to the mathematical structure of field theory." (Ladyman and Ross 2007, 140).

We see, then, that different structuralists classify quantum fields differently: Some classify them as structures, and others do not. Nor am I aware of any acknowledgement of this divergence anywhere in the literature. However, it seems *prima facie* plausible that how they are categorized is going to prove important to the status of structuralism construed as a doctrine—specifically, as a "monistic" doctrine concerning what is fundamental, supported by our best current physics. Doreen Fraser, for example, has described it as the "consensus view" that, according to QFT, particles are not fundamental, and noted that the "natural candidate" for that status is quantum fields themselves (Fraser 2021, 323). By counting fields as structures, structuralism will immediately be as well supported as that consensus.

My claim that the status of structuralism is highly sensitive to the classification of fields as either structures or objects therefore depends on the question of whether it really is the case that particles—paradigms of objects—can be established as non-fundamental within QFT. Reviewing the literature shows that it is difficult to answer this question with an unqualified "yes." However, that literature nevertheless confirms that structuralists should, at this point in time, really care about the question of whether fields are structures; at least, on the assumption that structuralism is a doctrine.

## 4.2 CLASSIFICATION MATTERS

Consider first the perspective expressed by Muller, according to which there are only fields and (perhaps) other structures at the fundamental level; objects such as particles are, at best, simply aspects or features of the underlying field. The rationale behind this is now a standard textbook presentation and is as follows (for simplicity I follow normal practice and focus only on the case of massive scalar bosons, but the morals will generalize to any free field of the Standard Model). A free, classical, massive scalar bosonic field $\phi(x)$ evolves according to the Klein-Gordon equation

$$(\partial^{\mu}\partial_{\mu} + m^2)\phi(x) = 0. \quad (1)$$

The field that solves this equation is quantized by promoting it to an operator and subjecting it to the canonical commutation relations. The result is a quantum field operator $\hat{\phi}(x)$, which acts on the Hilbert space of representing the states of the field. When expressed in the "Fock-space representation," this takes the form

$$\hat{\phi}(x) = \int \frac{d^3p}{(2\pi)^3} \frac{1}{\sqrt{2p_0}} (\hat{a}_{\mathbf{p}} \exp^{-ip.x} + \hat{a}^{\dagger}_{\mathbf{p}} \exp^{ip.x}) \quad (2)$$

where the $\hat{a}^{\dagger}_{\mathbf{p}}$ and $\hat{a}_{\mathbf{p}}$ represent "creation" and "annihilation" operators, respectively: operators which, when acting on field states, raise and lower the field momentum by $\mathbf{p}$ (e.g., Peskin and Schroeder 1995, 24). As such, given (2), a natural interpretation of the free field is as a system of excitations and de-excitations at points of spacetime. Such excitations are known as *field quanta*. Since the creation operator produces momentum eigenstates, quanta are not localized. Nevertheless, several considerations are taken to justify identifying quanta with particles. Chief among them is the fact that the states created by acting with $\hat{a}^{\dagger}_{\mathbf{p}}$ on the ground state are systems with spin *0* and whose energy $p_0$ is given by $\sqrt{(\mathbf{p}^2 - m^2)}$. Special relativity informs us that this is the energy that corresponds, given that the state has momentum $\mathbf{p}$, to a physical system of mass $m$. These entities are moreover *countable* via the number operators $N(\mathbf{p}) = a^\dagger_{\mathbf{p}} a_{\mathbf{p}}$, and *aggregable* in the sense that a state with *n* quanta and one with *n'* quanta may be combined to form a state with *n+n'*. For these reasons, it is often held that quanta have the properties appropriate to particles despite their manifest failure of localizability (see, e.g., Peskin and Schroeder 1995, 22; Teller 1995, 30).

Beginning, then, with expressions (1) and (2), which seemingly make reference to fields alone, it seems we are able to derive the existence of entities that deserve to be called "particles." This suggests that some kind of priority claim may be warranted here. One might phrase the situation here in terms of "determination": The field determines the existence of particles, which are for that reason non-fundamental. However, the identification of particles with certain excited states of the fields—the claim that particles *just are* a particular state of the field—invites the stronger language of "reduction." Indeed, Gregg Jaeger has claimed that a reductive view on the particle-field relationship is the canonical one amongst physicists. According to him, "the most common view of the ontology of RQFT recently has been that it includes only fields… particle-quanta, if accepted at all into the ontology of RQFTs, are considered entirely reducible to fields" (Jaeger 2021, 2).[13] And, not only is this view apparently common in physics, it also has some illustrious representatives. The view of Steven Weinberg, for example, was that "[t]he fundamental equations of the Standard Model deal not with particles and fields, but with fields of force alone; particles *are just* bundles of field energy" (Weinberg 2001, 109 (italics added); quoted in Jaeger op cit, 2.). On the assumption that *reduces to* entails *being less fundamental than*, the language of reduction here supports the idea that particles are secondary to fields.[14]

These facts are clearly relevant to the question at hand. The reason is that if this popular view within physics is right, then it seems that structuralism is vindicated, *if* one takes fields to be structures. Since the particles of the Standard Model are all regarded as quanta of the corresponding fields, it follows on the quanta interpretation that for every fundamental field of the Standard Model there corresponds a type of particle.[15] Therefore if we know how many fundamental fields there are we automatically also know the number of fundamental particles types, and Problem 1 above for structuralism is immediately assuaged. Further, if particles of a given kind are simply "bundles of the [corresponding] field's energy and momentum" and in that sense are "entirely reducible" to the relevant fields, then it arguably *does not matter* that we have to put the masses of the particles in by hand,—meaning that Problem 2 is dealt with as well. For, on the reductive picture in which particles just are states of the field, what one is measuring when one measures the "particle mass" *m* is a property that can, in some sense, be attributed to the underlying field, and as such is the sort of thing that could be primitive. To be sure, there are some subtleties involved here if this purported reduction is to succeed. For example, given that the claim is that particle-like entities are derivable from equations (1) and (2), if one interprets the mass term in (1) as simply *meaning* the particle mass, then any attempted reduction of particles to fields and their dynamics would be precluded. Such an interpretation is, however,

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13 Note that Jaeger himself does not accept this, on the grounds that even if true it would apply only to free fields (see below).

14 While it is, of course, very common to draw this inference, the inference is not straightforward: most saliently, the language of reduction implies identity claims while that of priority connotes asymmetric notions. Here I will simply take as given that the language of reduction supports claims about priority. See, e.g., (Lorenzetti 2023) for a recent attempt at reconciliation of the two terms, or (Rosen 2010, Sec. 10).

15 "The fundamental ingredients of nature that appear in the underlying equations are fields: the familiar electromagnetic field, and some twenty or so other fields. The so-called elementary particles, like photons and quarks and electrons, are "quanta" of the fields–bundles of the fields' energy and momentum." (Weinberg 2001, 59).

common (see, e.g., Ryder 1996, 82). However, one can also find the term interpreted without any reference to particles: for example, in terms of expressing "the energetic cost of having the field around at all" (Peskin and Schroeder 1995, 17; see also Lancaster and Blundell 2014, 99).[16] Assuming that something like that interpretation can be defended (as anyone who puts forward the reduction claim here must), it is open to anyone who regards fields as fundamental to hold that it is simply a brute and inexplicable fact what the value of $m$ is. As such, they may view it as no threat to structuralism that the "particle masses" must be put in by hand, and Problem 2 above is thereby dealt with.

Putting everything together, then, on "the most common view of RQFT recently" within the physics community—a reductive view which has also been expressed by some structuralists—it should *really matter* to the structuralist how it is that we classify fields. For if we do not classify fields as structures in addition to symmetries, then it seems structuralism based on our current best physics is straightforwardly *false*: Symmetries alone do not suffice to determine the determinate masses we associate with fields and particles, and so fail to determine the ontology that it presents as non-fundamental. But if, in addition to symmetries, we classify fields as structures, then it seems that structuralism has a claim to be *true*: Fields determine how many particles there are, and while some of the properties of those particles are undetermined, they may nevertheless be properly regarded as brute and inexplicable since they are just features of the underlying fields. Whether or not we choose to classify fields as structures therefore seems to be of the utmost significance for structuralism considered as a doctrine.

It is, therefore, rather surprising that there has been no acknowledgement of the different ways that structuralists classify fields. Indeed, one might take the relaxed attitude of structuralists toward this question to suggest that the truth-value of structuralism is not what they regard as important about it. If so, then one is well on the way toward the view that structuralism is best thought of not as a doctrine, but rather as a stance. To paraphrase van Fraassen, above:

> Suppose that the thesis is indeed the important part of [structuralism]. Then, something follows from this about what [structuralists] will find it important to do. In that case they will certainly not rest until the distinction between [structure] and what is not [structure] has been made so clear that the thesis is a factual claim, which can clearly be either true or false. But if they do not, then by *modus tollens* we should conclude . . . what?

## 4.3 COMPLICATIONS

Those familiar with the philosophical discussion of the relations between particles and field, however, will be aware that in reality things are not so simple. For while the above may describe a widely-held view in physics, the idea that particles are recoverable from field theory continues to be extensively debated in philosophy of physics. In addition to the worries about localization that were bracketed above, a central reason for philosopher's skepticism is that the quanta interpretation does not seem to be available for interacting fields. The reason is that the creation and annihilation operators employed in the definition of quanta cannot be given a covariant definition in the presence of interactions

16 Here I note that although both physicists and philosophers do routinely talk of "a field of mass $m$" (e.g., Weinberg 1995, 396), it is probably not correct to say that the field itself literally has mass. (It is unclear what its rest frame would be, for example, given that it is generically in a superposition of momentum states.) But, of course, if this interpretation of $m$ could in fact be defended, this would only help the reductionist's case.

(Fraser 2008, 850). Interactions are however an ever-present feature: while they can be negligible, in some contexts, "for all practical purposes" (FAPP), they are always strictly speaking present. This Doreen Fraser describes as a "fatal flaw" (ibid.) of ascribing a particle interpretation to QFT.

What is the significance for structuralism of this view from the philosophy of physics? While there are different responses one could attempt here, I will focus on the fact that some philosophers have argued that there *are* notions of particle distinct from the field quanta concept that are still available in the context of interacting QFT. In particular, Jonathan Bain (2000) and David Wallace (2001) have each argued that scattering theory offers an alternative serviceable notion of particle, construed in terms of "effectively-localizable" (Wallace 2001, 10) or "FAPP-localizable" (Bain 2000, 395) states. Here I will discuss only Wallace's presentation. In this paper, Wallace argues that particles *qua* effectively localizable entities can be seen as an "emergent concept" within quantum field theory: something that quantum field theory itself establishes as existing, albeit only in certain regimes. These are the regimes of negligible interaction—crucially, the same regimes in which our evidence for particles is harvested in the first place. Moreover, Wallace argues for the emergence of particles on the grounds that there exist *states of the field* that have approximately the properties we associate with particles. Thus if these claims that particles are emergent entities are correct, it may well be that conclusions relevantly similar to those obtained in the context of the physicists' "received view" will obtain here, and thus the same implications for structuralism.

There is surely something attractive about this idea of particles as phenomena that emerge from field theory in the same sort of limits that our evidence for them is derived. However, it remains that the FAPP-localizable QFT states that Wallace derives in this context are derived in the context of a free field theory. The driving assumption of Wallace's paper is that a theory in which the interaction is tiny but nevertheless finite is "very well approximated" by the free theory (Wallace op cit, 8): The fact that states which possess approximately the properties of particles can be derived in this theory is thus taken to suggest that something very like them is derivable without the free-field idealization. But it has, to my knowledge, yet to be established that anything other than strictly no interaction is required to derive even an approximation to effectively-localizable entities.[17] To be sure, the underlying physical continuity assumption that finds expression here—the assumption that if $X$ may be inferred from physical description $\phi$, then an approximation to $X$ may be inferred from an approximation to $\phi$—is without question a natural one to make: Indeed, certain principles along these lines have been claimed to be *a priori* necessary for the very viability of physics.[18] But for all that such continuity may strike us as natural to assume, it nevertheless appears that many canonical metaphysical concepts are not stable under small perturbations of the underlying physics (see McKenzie 2020a and McKenzie unpublished for examples and discussion). Indeed, one might well have assumed that such continuity would hold of the quanta concept of particles and nevertheless been drastically incorrect. As such, until it has been demonstrated that this instability does not likewise infect this emergent notion of particle based on scattering theory, and hence that an approximation to FAPP-localizability is, after all, derivable within an interacting theory,

17 Wallace does explicitly state that he uses a free theory over an interacting one only for reasons of "mathematical tractability," not on account of any conceptual barriers (Wallace op cit 8). This may very well be true, but in this dialectical context what is needed is a demonstration.

18 See, for example, the illuminating discussion of Duhem's "principle of stability" and others like it in (Fletcher 2020).

on the issue of whether QFT furnishes an acceptable particle concept in realistic contexts I will take the jury to be out.[19]

Given the complexities of the relation between fields and particles, my conclusion is best stated as a conditional one. If one holds that particles can be identified with quanta and hence with states of the field—a view apparently embraced by some structuralists—then it evidently *really matters* to structuralism qua doctrine how it is that we classify fields: Arguably, structuralism is true if fields are structures and false if they are not.[20] If, on the other hand, one denies that particles can be identified with field quanta, then it isn't yet clear what the relationship between particles and fields is, since it is still an open question whether interacting fields can furnish an acceptable alternative notion. But even in that case, it remains that structuralism *has a chance* of being vindicated by current physics if we classify fields as structures in a way that it simply does not if we restrict that classification to symmetries. Thus, it remains both on the face of it and under scrutiny that it seems *highly relevant* to structuralism *qua* doctrine, argued for in the context of our best physics, whether fields are structures or not. And all this should be entirely unsurprising, for the simple reason that our best physics is *quantum field theory*. Clearly structuralism has a better shot at being true if what physicists typically take to be the fundamental posits of our most successful theories themselves qualify as "structure." As such, I believe it remains that, were structuralists really and principally concerned with the truth-value of the doctrine, one would expect the differences in classification between prominent structuralists to be acknowledged and grappled with. This we do not see. I therefore believe that my conclusion of the last section stands.

I will close the argument given in this section by briefly considering two possible rejoinders. For, as van Fraassen would be the first to remind us, may there not be other candidate hypotheses that explain the phenomena just as well? Could one not hold, for example, that the relevant parties to this debate are simply unaware of the discrepancy in how they classify quantum fields, and that were they made aware they would work to settle the discrepancy in how fields are classified? I regard this as unlikely. All the references cited above are cited in Ladyman's *Stanford Encyclopedia* article on Structural Realism—arguably the authoritative statement of the state of the field—and as such it seems likely that *someone* would have noticed the discrepancy, were the extension of "structure" regarded as important. Another potential explanation is that structuralists are well aware of the discrepancy in classification, but think that the question of whether fields qualify as structures or not is simply unanswerable, and so pointless to even dispute. After all, one might say, cases of classification are often adjudicated in terms of practical concerns (see again Soames 2012), but such concerns are not obviously germane to metaphysics; as such, there is simply nothing to draw on to resolve the question. While I am not at all sure that structuralists would agree with that, if the question of what counts as "structure" really were fundamentally irresolvable, then surely this would only provide an additional motivation to cease to view structuralism as a doctrine, and contemplate it instead as a stance.

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19 I note that Doreen Fraser has claimed that the arguments for particle emergence based on scattering theory make indispensible use of the "fictional system" defined only in the limit case of strictly zero interaction (Fraser 2021), which, if true, would block the availability of claims that particles exist even as non-fundamental entities. (She makes this criticism explicitly of Bain, but the reasons seem to transfer to Wallace.) But, as I understand things, at least, the idea that strictly zero interaction is necessary for approximate FAPP-localizability has not been established any more than has the contrary. For example, Fraser's stated reason for holding that the fictional free-field system "must be posited" (331) concerns the unavailability of the quanta interpretation in the presence of interactions. But Wallace's paper does not even mention the quanta concept and the aim of Bain's is to provide an alternative to it.

20 Pending, of course, the identification of other overlooked candidates for structures in QFT. I do not see any obvious candidates.

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# 5 STRUCTURALISM AS A STANCE

Above, I offered some reasons to hold that structuralism should be thought of as a stance. In this final section I will gesture at how I think that stance ought to be characterized. Just as van Fraassen makes no claim that his characterizations of either empiricism or materialism *qua* stances are exhaustive, I make no claim to articulating in full what structuralism as a stance could be. But I will argue for taking a particular conception as an essential and core aspect of it, and hope that this work can serve as a starting point for a fuller characterization.

To help us hone in on what the structuralist stance consists in, I suggest that we continue to pursue the analogies with materialism that I have made reference to throughout. Thus recall van Fraassen's claim, noted above, that "if the 'physicalist' or 'naturalist' part of this philosophical position is mainly the desire or commitment to have metaphysics guided by physics, then it is something that cannot be captured in any thesis or factual belief." Van Fraassen is thus equating materialism with a certain methodological commitment: the commitment to have one's metaphysics guided by physics. That metaphysics ought to be conducted in this way is, of course, the rallying cry of naturalistic metaphysicians. As such, I propose that to accept the materialistic stance on van Fraassen's view is to accept what I will call the *injunction of naturalistic metaphysics*: the claim that one ought to conduct metaphysics in a physics-informed way.

It is abundantly clear that structuralists embrace the injunction of naturalistic metaphysics. For one thing, a chief argument for their brand of metaphysics is supposed to be that it follows naturally from physics and, independently of, appeals to intuition and common sense (Ladyman and Ross 2007, 30 and *passim*). But more importantly, structuralists frequently take pains to enjoin metaphysicians to conduct their theorizing in a more science-guided way. Indeed, while a prime purpose of Ladyman and Ross's *Every Thing Must Go* is to defend structuralism, its first chapter excoriating contemporary metaphysics for failing to be so guided is surely the most notorious segment of the book. The work of French and McKenzie on the "Toolbox" approach to metaphysics has similarly been prominent in discussions of what it means to do naturalistic metaphysics (French and McKenzie 2012, French and McKenzie 2016).

Contemporary structuralism, therefore, has a strong methodological component insofar as it entreats us to take physics as our guide to metaphysics. Thus, if structuralism is to be conceived of as a stance, one might be tempted to simply equate it with the naturalistic injunction. But there are certainly other philosophers who defend naturalistic approaches and make no claim to being structuralists, and indeed who may even vociferously reject that moniker. As such, while embracing the naturalistic injunction seems to be part and parcel of structuralism, it cannot represent that which is distinctive of structuralism. I, therefore, propose that the structuralist stance consists of a certain strengthening of the naturalistic injunction. Namely, I propose that structuralism be conceived as the injunction *to foreground, when doing metaphysics, that the language of physics is mathematics*. It is the injunction to engage with real physics theories in the language in which they are written, not with toy predicate reconstructions in which so much of what is distinctively mathematical about those theories has been washed out.

Different arguments for why this injunction should be understood as a core of the structuralist stance could be given. It seems that something like this exhortation is already present in the existing literature on structuralist metaphysics: Simon Saunders, for example, suggests that failing to appreciate the fact that "the primary vehicle for understanding reality is mathematics" will tend to lead to metaphysical distortions (Saunders 2003, 130). However, the most compelling reason for conceiving of the structuralist stance as one centered on the language of physics injunction is more positive in nature. It is based on the fact that many arguments aimed in support of the structuralist doctrine can instead be viewed as confirmations of the importance of that injunction. As such, even if one rejects viewing structuralism as a grand monistic doctrine—perhaps because one is persuaded by the argument of Section 4—one can still endorse many of the arguments that have been given for it, albeit viewing them now as testaments to the power of the injunction rather than to the truth of the doctrine. To fully support this, several compelling examples of such arguments would need to be given. But here I focus only on one: the argument of French and McKenzie (2012 and 2016), later developed by McKenzie (2016), that quantum field theory supports the doctrine of eliminative ontic structural realism.

## 5.1 THE INJUNCTION IN ACTION

This argument that quantum field theory supports structuralism in its eliminative version began as an attack on the basic premises of the metaphysical system of David Lewis. As is well-known, Lewis' system is regarded as the most sophisticated attempt to reduce modal discourse to purely categorical facts. At the core of the system is the *principle of recombination*, which is, "[r]oughly speaking, the principle… that anything can coexist with anything else, at least provided they occupy distinct spatiotemporal positions. Likewise, anything can fail to coexist with anything else" (Lewis 1986, 88). This is the fundamental principle upon which the reductive success of Lewis' system is built. It presupposes that all the fundamental properties—for Lewis, all the "perfectly natural" properties—are intrinsic; for only if such properties are "independent of accompaniment" can they co-exist, or fail to co-exist, with anything else. Lewis, of course, is aware of this, himself stating that it "seems right" that the fundamental properties should all have this feature, and elsewhere that they are intrinsic "*ex officio*" (1986, 16; 62). However, French and McKenzie argue that many of the perfectly natural properties of this world seem *not* to be intrinsic. Their argument, briefly, is this.

As a physicalist, Lewis is unambiguous that the perfectly natural properties are the fundamental physics properties. What are these? Lewis tells us: "Physics has its short list of 'fundamental physical properties': the charges and masses of particles, also their so-called 'spins' and 'colours' and 'flavours', and maybe a few more that have yet to be discovered" (1986, 60). French and McKenzie proposed that, to truly understand these properties, we cannot simply stipulate what they are like. Rather, we need to look at them through the lens of the theories in which they occur. In particular, to understand what *fundamental physics properties* as a class are like, one needs to consider properties that appear in *fundamental physics theories*. Within the context of QFT, the notion of a fundamental theory is one that has a precise meaning: it is one that is never surpassed even as we probe ever higher energies. As such, these are, first and foremost, theories that stay well-behaved, and hence *mathematically consistent*, in the limit that $E \to \infty$. Staying well-defined in such a limit turns out to be a very demanding constraint, and hence one which very few theories satisfy. Partly as a result, little of a general nature can at present be said about the class of fundamental QFTs. However, there is a special class of these theories, the "asymptotically free" theories, which are well understood. These are theories in which interactions diminish as the energy gets arbitrarily large, and quantum chromodynamics—the theory concerning quark color and flavor—is a real example of such a theory. The approach of French and McKenzie was to take asymptotically free theories as a workable example of a fundamental physics theory, and then argue that doing so reveals that properties such as color can no longer be regarded as intrinsic.

The argument is as follows. Firstly, it can be shown that asymptotically free theories are always *gauge* theories.[21] This means that the interactions between matter in these theories are mediated by gauge bosons. French and McKenzie leveraged this to argue that properties such as quark color cannot be intrinsic, because their very possession by interacting fermions necessitates the existence of something else (in the case of colour, the gluons).[22] Since intrinsic properties are, by Lewis' own definition, those that are "independent of accompaniment," this suggests that quark color is not intrinsic. Furthermore, one can show that the property of asymptotic freedom is destroyed by the inclusion of *too much* matter. For example, in the context of QCD, one can show that, if more than 16 flavors of quark are included in the theory, then the theory "blows up" and mathematical consistency is lost. For French and McKenzie, this represents a further reason to deny that quark color is intrinsic. For, if the fundamental properties of quarks were intrinsic, there would presumably be no restrictions whatsoever on that with which they could co-exist.

These arguments were initially deployed by French and McKenzie against the system of David Lewis. But I later tried to develop them into a positive argument for eliminative structuralism (McKenzie 2016). I claimed that the above facts give reasons to think that *no* fundamental property of current physics qualifies as intrinsic by Lewis' definition. On the assumption that the category of "structure" includes extrinsic properties (on which more in a moment), the conclusion that our best physics supports eliminative structuralism follows immediately. Granted, this argument was soon criticized in terms of the interpretation of the relevant physics, with some arguing, for example, that spin and the vacuum expectation value of the Higgs field must still be regarded as intrinsic features even if the argument works for some other properties (Berghofer 2018). However, note that even had the argument succeeded in establishing that all the fundamental physics properties were extrinsic, it would establish the truth of eliminative structuralism *only on the assumption* that extrinsic properties qualify as "structure." And while there is certainly historical precedent for taking this to be the case, there are also some reasons not to.[23] For example, structure is often contrasted with *monadic* properties, of which extrinsic properties are a subset (see, for example, Wallace 2021, 361). And while extrinsic properties—paradigms of which are properties like *being a sister*—are clearly different from other monadic properties in that they involve relations of some sort, these relations are better conceived of in terms of *ontological dependence relations*, rather than more straightforwardly *physical* relations, such as *being 3m apart from* or *being entangled with*. This prompts the question of whether they should count as instances of "relational structure" acceptable to structuralists *about physics*.[24]

This, then, was the argument given for how gauge theories in QFT support a form of ontic structuralism: Taking seriously the requirement of mathematical consistency in the highly demanding limit appropriate to fundamental theories leads one to the extrinsicality of (at least some) fundamental physics properties. But note that even if the interpretation of the physics were to succeed, it is clear that someone who wishes to use this argument to support structuralism faces the same classificatory impasse that we met above in Section

21 This assumes that the theory concerned includes interaction, which is, of course, a necessary condition on any world in which physics is possible.

22 Note that this conclusion does not follow from assuming interactions *simpliciter*: interactions in QFT can include self-interactions.

23 For example, in the paper that coined the term "structural realism," Maxwell states that "Structural characteristics may be taken to be just those that are not intrinsic" (Maxwell 1970, 88).

24 I have been informed on this point by the discussion in Lorenzetti (2022). (Note also that here we have another point of contact between structuralism and materialism *qua* physicalism: what is it that counts as a *physical* relation?)

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4. For are extrinsic properties to be classified as instances of structure, or not? *On what grounds are we to decide?* In keeping with my view of structuralism as a stance, I propose that rather than searching for answers to this Procrustean question, we simply abandon it entirely. But this does not mean that the argument given in the earlier work is suddenly of no value. On the contrary, it seems that whatever else was important about the status of fundamental properties *qua* intrinsic or not remains untouched, even though we no longer take the argument to be a confirmation of the monistic doctrine of structuralism. Most saliently, the argument clearly still works as well as it did to undermine the principle of free recombination so crucial to the modern incarnation of Humeanism. And one can, in fact, continue to mine this example if one wants to argue that there is something about the concept of asymptotic freedom that challenges received ideas in metaphysics. Take, for example, the metaphysics of fundamentality itself, something that has, in recent years, been subject to a wealth of discussion. Work by Porter Williams can be read as arguing that there is something about asymptotic freedom that deeply challenges the idea that the non-fundamental is simply an "abstraction" from the fundamental.[25] Non-fundamental objects are after all held together by and participate in different kinds of physical interactions. How, then, can the world around us be conceived of merely as an abstraction from the fundamental, given that according to such theories, examined in the limits that take us to fundamental domains, the fundamental objects are *free*?

It seems undeniable, then, that there is something about the distinctively *mathematical* aspects of fundamental theories in physics that carry important implications for metaphysics. But notice that *none of this would be visible* if we took the theories concerned to be toy predicate reconstructions of the real physics. For, given predicates for the six *quark flavors*, the three *quark colors* of *red, green, and blue*, and the n-ary predicate *interacting*, it would be a trivial exercise to write down a consistent well-formed formula in these terms that says *there are six different flavors of quark with color interacting with each other*. This is in total contrast with how difficult it is to find a mathematical theory of these entities that stays well-defined in the high-energy limit. There is, moreover, nothing in such a construction that would ever suggest that it is suddenly not well-defined were one to keep adding such terms beyond the limit of 16 flavors. Thus, the kind of constraints on matter content that seem anathema to Lewis' system are therefore simply invisible, *if we do not apprehend the language of physics injunction*. Furthermore, it seems abundantly clear that Lewis himself did *not* apprehend the injunction. Consider, for example, the following quote: "We can distinguish our world from one in which, say, one of the quark colours has traded places with one of the flavours. The two possibilities are isomorphic, yet different" (Lewis 1986, 162). Anyone familiar with the mathematics of color and flavor will know that they are isomorphic only insofar as color and flavor are unary predicates. That is, these theories are isomorphic only if we think of the theories as expressed in *words*.

It therefore seems undeniable that failing to apprehend physics in its own language has a distorting effect on the metaphysics of physics. It is, moreover, easy to argue that prominent metaphysicians often do not abide by it. For these reasons, I do not think that the language of physics injunction is a trivial one, for all that it may seem innocuous: On the contrary, it arguably represents a significant course correction in metaphysics. I grant that for philosophers of physics, however, already accustomed to dealing with physical theories as they appear in real science, the injunction may sound wholly uninteresting—rather as if I had simply said "do philosophy of physics!" if asked how one was to do metaphysics.

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25 See Williams 2019, Section 4. (I emphasize that this is my own reading of what he writes, not necessarily his.)

Perhaps, then, to those already adhering to the injunction, the interesting question here concerns what it is about mathematics that makes it such a powerful language for theorizing. There is, after all, a tradition in the history and philosophy of science, often taken to stem from Cassirer, which holds that it was not mechanization but rather the mathematicalization of nature that represents "the central and overarching achievement" of the scientific revolution (Friedman 2022, Section 2). Perhaps, then, we should say that to adopt the structuralist stance is, in part, to view the mathematicalization of nature as being of fundamental significance, and to aspire to develop a philosophy that enables us to understand why this is.[26]

## 6 CONCLUSION

I have argued that ontic structural realism, standardly taken to be a doctrine concerning the fundamental nature of the world, should instead be regarded as a stance. I did so by proposing that structuralists, however implicitly, themselves regard it in these terms, because by making this *ansatz* we get a better explanation of the shape of the existing debate.

As stated, my argument is primarily based on descriptive claims about how structuralists think, rather than normative claims to the effect that one ought to think of structuralism in this way to avoid certain problems or pitfalls. My argument as stated could therefore be refuted given the right sort of input from structuralists about why they do what they do. One could perhaps also agree that the arguments of Section 4 suggest that certain questions about the category of structure are not important to structuralists, but deny that this motivates abandoning doctrinal interpretations of ontic structuralism. David Wallace's recent intervention in structural realism, for example, invites us to consider a form of ontic structuralism that aims at "represent[ing] the world at the most fundamental level" but that explicitly prescinds from engaging in traditional questions concerning the priority of metaphysical categories (Wallace 2021, 365).

Despite these weak points of the argument just given, I hope that by inviting structuralists to reconceive their position as a stance, a fuller understanding may be had of it, even if the stance interpretation is ultimately rejected. I believe that what is attractive and valuable about the position is independent of the obscurities swirling around its central notion, and that it may be refreshing, and productive, to move past them.

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## COMPETING INTERESTS

The author has no competing interests to declare.

26 If this is right, other projects in the philosophy of science, such as the problem of the applicability of mathematics (cf Bueno and French 2018), and the metaphysics of quantities (cf Wolff 2020), emerge as more constitutive of ontic structuralism than they may have seemed before. I defer to another occasion a fuller characterization of the commitments of structuralist stance, however.

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