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Physics, metaphysics, dispositions, and symmetries – À la French

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ABSTRACT

Recent philosophy has paid increasing attention to the nature of the relationship between the philosophy of science and metaphysics. In *The Structure of the World: Metaphysics and Representation*, Steven French offers many insights into this relationship (primarily) in the context of fundamental physics, and claims that a specific, structuralist conception of the ontology of the world exemplifies an optimal understanding of it. In this paper I contend that his messages regarding how best to think about the relationship are mixed, and in tension with one another. The tension is resolvable but at a cost: a weakening of the argument for French's structuralist ontology. I elaborate this claim in a specific case: his assertion of the superiority of a structuralist account of *de re* modality in terms of realism about laws and symmetries (conceived ontologically) over an account in terms of realism about dispositional properties. I suggest that these two accounts stem from different stances regarding how to theorize about scientific ontology, each of which is motivated by important aspects of physics.

1. Scientific metaphysics and scientific realism

Steven French's (2014) opus, *The Structure of the World: Metaphysics and Representation*, is the synthesis of a research program that has been pursued with intensity for three decades and which, in that time, has become central to debates concerning two distinct but nevertheless intertwined topics in the philosophy of science. Both topics are integral to the book, but the precise connection between them belongs more to its implicit content than its explicitly examined theses. I believe that a careful rendering of this connection is important, however, to an assessment of the overall import of the research program itself. For one thing, the construction of a grand edifice of systematic philosophy surely calls for an examination of how its pieces fit together! For another thing, as I will suggest, this examination reveals something profound about the project itself. In what follows I will attempt to make this connection explicit and, in so doing, argue for a particular understanding of the current state of the research program it unifies. And in an effort to illustrate what might otherwise seem an abstract diagnosis with a concrete case, I will focus on an example that is key to French's own exposition.

What then are these two topics that frame the work, and how are they connected? The first topic is metaphilosophical: the question of how to do metaphysics in a way that is responsive to and reflective of our best science. In this regard the work is a significant contribution to the recently popular discussion of how to articulate, assuming that such an articulation is possible, a compelling view of how to do metaphysics in a naturalized or scientific way. Here French (pp. 49–50) adopts the attitude of a slightly terrifying yet ultimately kindly philosophical overlord: pure metaphysicians are to be left free to do what they will without fear for their livelihoods, because their theorizing is sometimes ripe for plundering in the interpretation of scientific theories. This is the "Viking Approach" to metaphysics.

The second topic is the question of how to interpret our best scientific theories as furnishing knowledge of the world. Here French explores and defends a version of structuralism according to which our best theories – most obviously in fundamental physics but not limited to this sphere – give us knowledge of the structure of reality, but not knowledge of what one might mistakenly interpret as objects that inhabit these structures, as in (for example) the view that objects like subatomic particles stand in certain kinds of relations. This is the position for which French is antecedently famous and apart from the details to follow, I will assume a basic familiarity with its key tenets: it is intended as a form of scientific *realism*, it is *ontic* insofar as it describes *structure* as comprising the furniture of the world, and it is *eliminative* in denying the existence of objects. Reflecting all of this, I will refer to the position henceforth as 'eliminative ontic structural realism' (EOSR).

Thus we have two proposals – a view concerning scientific metaphysics and an account of scientific realism. What is the connection between them? EOSR clearly incorporates a striking and controversial metaphysical thesis, *viz.* the idea that the sorts of objects (and properties) naively thought to be the subject matters of fundamental physics are in fact ontologically illusory and should be reconceptualized as features of the structure of the world, which is itself something ontologically substantive. The village of the metaphysicians is full of

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hypotheses, formal tools, and argumentative strategies that may be plundered so as to render this metaphysical thesis defensible and ultimately plausible. In this way, French's attitude toward metaphysics ostensibly helps to facilitate the case for his preferred view of realism. The overarching question I would like to pose here is simply, does it?

In section 2 I consider French's attitude toward the role of metaphysics in interpreting physics more carefully, and argue that superficially, one aspect of it appears to be incompatible with another. This *prima facie* tension is easily resolved, but the resolution immediately kindles a challenge to the case for EOSR. In sections 3 and 4, I illustrate this challenge with a specific example: attempts to explicate the nature of *de re* modality – the worldly source of modal relations among the phenomena, including causal relations – which French accepts (along with many others) as a desideratum for a viable scientific realism. Section 3 examines his arguments against one attempt to satisfy this desideratum by means of an ontology of dispositional properties, and an examination of his arguments in favor of his own EOSR-inspired view that an ontology of laws and symmetries better satisfies it follows in section 4. In both cases I contend that a clearer understanding of the recourse to metaphysics in filling in our accounts of scientific realism undermines the arguments presented. I conclude in section 5 by suggesting that physics is itself suggestive of different approaches to scientific ontology and, concomitantly, to different approaches to the metaphysics of modality.

2. A recipe for metaphysics of science

The motivation for French's Viking Approach to metaphysics (allow its flourishing for the sake of plundering) is, of course, contestable. Some scientific realists and antirealists alike are hostile to the notion that metaphysical theorizing is appropriate at all in the service of interpreting scientific theories, but French (pp. 48–49) demurs, citing the demand to answer what he generously calls 'Chakravartty's Challenge': the task of spelling out, in a compelling way, the natures of the key concepts involved in describing one's realism such that one then has a substantive understanding of the putative referents of these concepts, thus endowing the relevant version of realism with genuine content. Some significant clarity regarding these key concepts and metaphysical underpinnings (whatever they may be: laws?; causal relations?; structures?) is arguably a prerequisite to understanding what one is proposing to be a realist *about* – and affords the side benefit of defusing antirealist skepticism to the effect that realists often lean on concepts that are empty or incoherent. Let us assume here for the sake of argument that this is a challenge that realists should take seriously.[1]

Doing metaphysics in order to clarify one's interpretation of physics, thus rendering the interpretation more transparent and (hopefully) more plausible and defensible may well be a laudable goal, but at first glance it appears that there is a tension in French's execution. On the one hand, he very reasonably asserts that our best theories in fundamental physics underdetermine our interpretations of the ontology of these theories, which is to say that the mathematical formalism all by itself does not simply tell us what that ontology is. There are different and conflicting interpretations of it, and no one interpretation is *entailed*. Thus French (p. 49) says that 'the question of what metaphysics to adopt cannot be answered on the basis of the physics alone'. This is surely correct.

On the other hand, French often gives the impression of not believing his own correct description of the underdetermination of metaphysics by physics. At various points (e.g., p. v) he advocates an approach according to which we should 'read our metaphysical commitments more or less directly off our best theories'. 'Why not', he asks (for example), 'simply 'read off' the metaphysics of properties from the theoretical context?' Curiosity thus piqued, one naturally wonders which metaphysics this is, and the answer follows: 'the ontology we should 'read off' our physics should be one of laws and symmetries, understood as features of the structure of the world' (p. 64). But as we have just noted, the *correct* answer to the question 'why not simply read off the metaphysics of science from theory?' is that *we cannot*, because physics underdetermines its ontological interpretations. Scientific ontology is inherently meta-scientific. It applies criteria for ontological commitment that are not constitutive or necessarily constitutive of the relevant mathematical formalism and scientific practice.

Thus we have an apparent tension in French's understanding of the relationship between the philosophy of science (in this case, physics) and metaphysics. Though it appears stark on its face, I believe that this tension is merely apparent. It is resolvable in the following way. When French speaks of reading ontology from fundamental physics, what he is doing, in fact, is implicitly appealing to some (one hopes) defensible criterion or criteria which he takes to point toward a *preferred* interpretation of the relevant physics – an interpretation which is (one hopes) demonstrably superior to others. With the luxury of knowing in advance that French's preferred interpretation is EOSR, one may then attempt to reverse engineer these criteria. And while an implicit invocation of criteria that arguably point toward a preferred interpretation is not properly characterized by the notion of simply reading the ontology of the world from physics, we may nonetheless seek to discover what criteria French has in mind and whether a consideration of them does, in fact, lead us inexorably to EOSR.

This sort of sleuthing requires a concrete case, and in the following two sections I will examine one. Like many scientific realists who commit to exploring the metaphysical underpinnings of a viable realism, French is concerned to give an account of *de re* modality. That is, he wants to explicate, as do many others, what in the world is responsible for the various necessities and possibilities that scientific phenomena seem to exemplify in empirical investigation. (One motivation for this in the present context is to shield EOSR from the charge that without some account of modal or causal relations, a realism about what otherwise seem like purely mathematical structures threatens to collapse into some form of Pythagoreanism.) In keeping with EOSR, French suggests that one such account is furnished by the hypothesis that physical laws and symmetries are constitutive of the ontology of the world, as aspects of its structure, which is ultimately, on this view, all there is. That is the positive proposal. The major rival to this view in French's estimation is one according to which modality in the world is explicated in terms of inherently modal or dispositional properties.

As we will see, the criteria according to which the superiority of EOSR over dispositionalism is meant to follow are these: (1) an innocuous form of naturalism, by which I intend merely a pro-attitude toward views that are compatible with the science at issue or, better still, toward views that are in some sense more compatible than the alternatives; (2) ontological parsimony; and (3) explanatory power. This is to say that the arguments against dispositionalism and in favor of EOSR aim to establish the superiority of the latter over the former with respect to these criteria. If this could be done, it would represent a significant victory for EOSR, for these sorts of criteria are commonly cited as being among the most important desiderata in metaphysical theory choice. I will argue, however, that none of them favors EOSR. And thus, the resolution of the apparent tension in French's attitude toward the metaphysics of science, by means of an unpacking of his criteria for metaphysical plundering, ultimately weakens the case for his version of structuralism. Let us see now why this is so.

[1] My own attempt to answer it is in Chakravartty, 2007. For an extended argument to the effect that at least some metaphysical theorizing is inescapable if one is to give *any* substantive account of scientific knowledge, see Chakravartty, 2017.

3. Putative problems with dispositions

3.1. Naturalism

Let us first consider the arguments against a dispositional view of modality, which I take to stem primarily from considerations of naturalism and explanatory power. There are different versions of dispositionalism and, concomitantly, different notions of dispositional properties (broadly conceived: capacities; propensities; etc.) as well as fine-grained accounts of and distinctions between these notions described by different authors, but it will suffice here to bundle them together. I will use the term 'disposition' as a catch-all, and the intended referent is a kind of property that is commonly discussed in terms of the notion of a causal power in neo-Aristotelian philosophy – that is, a kind of property in virtue of which some thing or things is empowered to act in a certain way or ways. Thus understood, and granting the aim of explicating the notion of modality in the world, what is so terrible about the idea of dispositional properties?

One difficulty suggested by French is that belief in dispositions entails belief in some thing or things to which these dispositions belong – that is, in *objects* which have or exemplify them. Combining this with the further thought that quantum physics problematizes the very ontological category of objects leads to a reductio of the idea of properties thus exemplified, including dispositional properties. In order for this reductio to bite, however, one must accept the thought that quantum physics rules out the very ontological category of objects. Does it? Certainly, if one were to accept EOSR, this would follow, but to assume EOSR antecedently here in the discussion of modality would beg the question, so the argument must proceed in some other way. So let us consider what reason one might have for thinking that quantum physics is incompatible with an ontology of objects. It goes without saying that twentieth century physics is incompatible with an ontology of *classical* objects. But unless the very tenability of the notion of an object is exhausted by some or other classical conception (mechanical modes of interaction, definite spatiotemporal trajectories, etc.), the advent of quantum theory cannot, as I will now suggest, do the work that French assigns it.

A lot hangs here on what one means by 'object'. For instance, French often writes as though it is a truism that the concept of any given object, in order to have genuine content, must include some information regarding whether it is (or is not) an individual. In the absence of such information the concept is inadequate and, given his further contention that quantum physics provides no such information concerning elementary particles, the very notion of ontologically subsistent objects and properties in this domain is fatally flawed. I will not consider the arguments for these contentions here, but simply ask the following question: is knowing whether or not something qualifies as an individual, according to one or another metaphysical definition of the precise nature of individuality, a necessary condition for believing that it is an object? Talk of objects *tout court* is loose. If one were to restrict the use of the term to objects that are individuals, for example, then granted, given permutation invariance and entanglement, there are interesting questions to consider about whether quantum objects are objects in this restricted sense, and many other things that are loosely called objects, such as the referents of mass nouns, may not end up counting as objects in the restricted sense either. None of this suggests an obvious problem for the idea that less-restrictively-conceived objects have properties, some or all of which may be dispositional.

If for whatever reason one dislikes less restrictive uses of the term 'object' – uses that would include things that are individuals and non-individuals alike, according to some or other definition of individuality – perhaps another term will do for the subject matters of quantum physics. The ontology of quantum field theory, for instance, is a matter of dispute; in this context one might contend that what are loosely referred to as subatomic particles are, in fact, modes of excitation of a quantum field. Perhaps the most appropriate ontological category here is that of events; or perhaps these things are better described in terms of certain kinds of processes. Whatever one finds most congenial, the important point is that all of these ontological categories (objects, events, processes) are ones whose members are traditionally thought to have properties. Physics appears to associate these putative things with properties such as mass, charge, and spin, and it is difficult to see how a more forgiving or looser conception of objects could be incompatible with this. Dispositionalism is simply one among other theories of the nature of such properties. Thus, the idea that an ontology of objects with dispositions violates a weak principle of naturalism according to which compatibility with physics is a desideratum seems unmotivated.

One account of scientific realism (for which I have argued elsewhere: 2007), 'semirealism', is a realism about properties in the first instance. Talk of objects, events, and processes – not to mention individuals, non-individuals, and so on – can be constructed after that as may be appropriate to interpreting the science at issue. When one finds as a matter of empirical detection that certain properties seem to be (in some cases always and only) found together, there is no harm in labeling such facts by saying that one has detected an object. More broadly I prefer the generic term 'entity', since it is amenable to thinking about things such as events and processes as well – again, as may be appropriate to the science at issue. On such a view, this is often all that object-talk or entity-talk entails: we have identified certain properties that seem to hang out together. Thus, when French (p. 254) states that 'Chakravartty's position … retains a robust notion of object', one might well respond that this all depends on what one means by 'robust' and 'object', and to invoke Inigo Montoya from *The Princess Bride*, 'you keep using that word; I do not think it means what you think it means'.

This leaves open the more precise ontology of quantum entities at finer-grained levels of analysis, and there is always the worry that this kind of openness falls foul of the goal of elaborating the key concepts on which one's realism depends. But there is such a thing as worrying too much, and I submit that this particular application of the worry goes too far. It is *always* possible to ask finer-grained questions – for example, in this case, to worry about whether collections of properties are bundles, or something else, or intrinsic or extrinsic, or something else. These are fascinating issues worth pursuing, but it is surely a mistake to hold *scientific* realism hostage to settling *every last* conceivable metaphysical question. This would not only set the bar for describing a plausible account of realism implausibly high, but would, by the same token, have the dubious effect of rendering every last metaphysical topic in the field of ontology a subfield of the epistemology of science.

3.2. Explanatory power

A second putative difficulty facing dispositional views of modality, according to French (p. 231), concerns an inability to explain phenomena that are commonly described in terms of symmetries and conservation laws armed only with an ontology of dispositional properties. By symmetries here we intend those transformations (or groups of transformations) of an entity that make no difference to it according to the applicable laws; such transformations "preserve" the laws as well as certain quantities that are associated with the properties of such entities. Transformations such as reflections, rotations, translations in time or space or spacetime, boosts in velocity, and permutations of entities leave certain things invariant. The collection or group of transformations that leaves something invariant is a symmetry, and states of systems related by symmetries have the same values of certain quantities associated with properties such as mass, charge, and spin.

Emmy Noether is famous for proving a theorem in 1915 that says that for every one of a certain class of symmetries (continuous symmetries of the Lagrangian) there is a corresponding conserved quantity, and *vice versa*. Quantities such as mass-energy, electric charge, spin, and momentum are conserved – they are constant – in so-called closed systems. Even friends of dispositions have sometimes worried about

whether dispositionalism can explain this sort of conservation.[2] For example, Alexander Bird (2007, p. 213) holds that '[i]t is difficult to see why …, when two charged objects interact, it is a manifestation of a dispositional essence that the total charge should remain constant', and French (p. 249) concurs: 'it is hard to see what it is about the disposition itself that ensures that charge is conserved'. In other words, one might wonder why or how the dispositions of (say) an electron, associated with its having negative charge, can explain the fact that charge is conserved in the interactions of more than one electron in a closed system, for the charge of an electron confers (*ex hypothesi*) certain dispositions for behavior on *it*, whereas the conservation of charge in a system of electrons is a feature of *the system*, not any given electron. It is this distinction between features of entities and features of systems of entities that fuels the worry. How could the former explain the latter?

Both French and Bird are familiar with at least one response: attempting to link the dispositions of a particle with what appears to be a constraint on the behavior of a system of particles is not the best way to think about this situation. Why not think of the relevant dispositions regarding conservation as properties of the system itself, as opposed to properties of the things constituting or inhabiting it? This is the sort of idea that John Bigelow, Brian Ellis, and Caroline Lierse (1992, pp. 384–385) had in mind when they suggested that the world itself is a member of a natural kind, and that symmetry principles and conservation laws are part of the essence of that kind. Granted, this sounds like a grand claim – the world is a rather large entity around which to wrap one's head – and dressed up in the language of scholastic metaphysics ('natural kinds', 'essences'), it may seem a long way from the empirical context of modern physics. This appearance of arcane grandiosity fuels the yet further worry that the response is *ad hoc* – a maneuver undertaken simply to square conservation laws with dispositionalism. Perhaps worst of all, it may also appear explanatorily empty, for one might wonder whether the claim that conservation laws are part of the essence of the world amounts to anything more than the claim that 'that's just the way the world is'.

I am not immune to the initial, apparent force of these concerns, but it seems to me that on careful consideration, they are ultimately revealed as unfounded. On reflection, it is clear that the basic idea of the response suggested by Bigelow *et. al.* can be recast in terms that dispense with much of the metaphysical jargon. We experiment on and theorize about different kinds of systems. It is a hypothesis subject to empirical inquiry that certain quantities are conserved in systems that are appropriately closed. Investigation of this sort confirms that this is part of the nature of these systems; they are disposed to behave that way. If it so happens that the world as a whole is trivially a system of the relevant type, because there is nothing else with respect to which it could be open, so be it. How does this amount to a problem for dispositionalism? The response is not *ad hoc*, for the attribution of a disposition here is made on precisely the same basis on which such attributions are made in other cases where entities or systems of a particular type are found to behave in regular ways in certain kinds of circumstances. Neither is it empty: for one thing, the notion of a closed system is a physically substantive concept; for another, it is only by means of empirical investigation that we confirm hypotheses regarding the natures of these systems.

Turning defense into offense, one might leverage this response into a challenge and ask how it could be more grand or less substantive to say that certain kinds of systems have dispositional properties than to say instead, as French (p. 300) contends, that symmetries and conservation laws are simply 'aspects' or 'features' of 'the structure of the world'. Recall that according to EOSR, the world *just is* the structure of the world. Thus, according to this view, symmetry and conservation are simply properties (or property instances, or parts) of the world. Thus we have properties of systems on the dispositional view and properties of systems on the EOSR view, both as possible *explanantia* for conservation phenomena. Described in terms of this sort of comparison, it is unclear on what basis the latter should represent a preferable metaphysics of physics, and this brings me, at last, to French's positive argument for an ontology of laws and symmetries.

Before proceeding and for the sake of completeness, it is only fair to note that French does cite other concerns about dispositions. These, however, are applicable not to dispositionalism generally but to idiosyncratic commitments regarding the semantics and epistemology of dispositional predicates and properties. Such commitments are optional for the dispositionalist and I will not consider them here. For instance, one might take issue with conditional analyses of dispositional ascriptions, but not all dispositionalists subscribe to this analysis and some think it problematic (e.g. Mumford, 1998, chapter 3; Vetter, 2014). Or one might take issue with the kinds of thought experiments sometimes offered in support of the existence of dispositions, such as contemplations of possible worlds inhabited by an electron *in vacuo*. Can one make sense of the idea that a lonely electron has properties at all except in terms of how it is disposed to act and would, were it not so lonely? French (pp. 255–256) dismisses this speculation and perhaps rightly so. It is unclear whether one can reasonably speculate about a particle existing independently of spacetime, fields, etc. But as I will suggest in section 5, the primary motivation for a dispositional ontology has everything to do with the actual world.

4. Putative virtues of symmetries

4.1. Parsimony

Let us turn now from the arguments against an ontology of dispositions to the arguments in favor of an ontology of laws and symmetries. French (p. 264) holds that one of the main virtues of the latter (relative to the former) is that it is more parsimonious. After all, theoretical descriptions in contemporary physics are thoroughly infused with symmetry principles. In contrast, one would be hard pressed to find a physicist who describes the invariants of symmetries as dispositional properties. While French makes no explicit claim to this effect, it is all too easy, perhaps, to think that on the basis of the language of physics, an ontology of symmetries is "already there" in scientific practice, as opposed to an ontology of dispositions which, if one were to invoke it, would have to be added on to this practice, thereby representing an inflationary ontological commitment. But there is some sleight of hand here. Any appearance of symmetries "being there" is entirely misleading, and the suggestive reasoning about symmetries presented above moves too quickly from a description of linguistic practice to an ontological conclusion. As we have noted, drawing conclusions about the ontology of physics requires an *interpretation* of the language of physics. It is one thing to describe a domain of interest in terms of symmetry principles. It is quite another to subscribe to an ontology of symmetries.

Quantum physics does not entail or even suggest, all by itself, that laws and symmetries should be interpreted ontologically. There are several traditions of interpretation (empiricist, pragmatist, even dispositionalist) that view laws and symmetries as simply descriptive of certain regularities as opposed to things in the world as such, let alone things that are properly reified as aspects or features of some further thing, the structure of the world. To invoke symmetries as *things* is to introduce a substantive ontological posit. Furthermore, it should be clear that the proponent of EOSR cannot deflate this posit by suggesting, as do some neo-Humean accounts of laws, that the things in the world that answer to the description 'laws and symmetries' are nothing over and above the regularities themselves. For recall, on French's view, laws and symmetries are the seat of *de re* modality: 'we should take laws and symmetries – and hence the structure of which these are features –

[2] The question immediately arises here whether the implicit alternative – that *symmetries* explain conservation – is preferable. I will return to this question in section 4.2.

as inherently, or primitively, modal' (p. 231); 'these laws and symmetries encode the relevant possibilities and in so far as they are stable or robust under certain changes to initial conditions can be regarded as necessary' (p. 302).

There is a palpable sense of *déjà vu* in this. The advocate of EOSR posits aspects or features of the world – properties or property instances or parts by other names – which are imbued with a primitive modality. This, of course, is exactly what the dispositionalist does. Dispositions are powers to behave in particular ways in particular circumstances; they "encode" possibilities and necessities pertaining to this behavior. The term 'power' here is clearly metaphorical. What can one say if pressed to give a deeper explanation of what a power is, precisely, apart from noting that it is a primitive of the interpretation? Think of a dispositional property as the ontological correlate of a function, which takes an entity or collection of entities from one state of affairs to another. Arguably, this contributes little more to the illumination of the primitive than to say that dispositions are powers. It is doubtful, however, that there is more to be had at this foundational level of ontological depth. Having accepted the task of identifying the locus of modality in the world, one must ultimately identify something to play that role, and there are no "low-fat-ontology" options. On careful reflection, it would appear that the symmetry view is no more austere, ontologically speaking, than the dispositional view. One cannot be preferred to the other on the basis of Occam's razor-type considerations alone.

4.2. Explanatory power (again)

Luckily, considerations of parsimony are not all there is. At least part of French's preference for an ontology of symmetries over an ontology of dispositions stems from explanatory considerations. It is undeniable that symmetry principles, expressed using the mathematics of group theory, beautifully describe the differences between the things that make up the particle zoo of the Standard Model. So here we have a mathematical apparatus of transformations and invariants that can be employed to describe particles and to distinguish different kinds from one another. As we have seen, French (cf. p. 250) holds not only that symmetries afford beautiful descriptions but that they are things in the world – things whose existence *explains* the diversity of particles. Let us grant for the moment the reification of symmetries proposed. What sort of explanation of particles then follows? It is one thing to define and to describe the differences between particles in terms of the invariants of symmetry groups; it is another thing to *explain*. Explanation is not, of course, a trivial relation. Things do not explain merely by existing – or rather, descriptions of things do not become explanatory merely in virtue of the existence of those things.

Perhaps it is unfair to press this notion that symmetries explain, rather than merely codify, the diversity of particles. After all, at a certain point in both science and philosophy we inevitably run out of explanations. It may be that there is no explanation *per se* of why we have the particles we do. One might reasonably entertain the thought that the symmetry principles and particles characteristic of our world are simply that: characteristic of our world, full stop. That is to say (as considered in section 3.2 in the context of conservation laws), this is just the way the world is. Let us stop demanding explanations for things that do not admit of explanation, one might say! But if that is the right thing to say, there is no advantage here to be had on the part of EOSR over any other view with respect to explaining the diversity of particles.

Indeed, if anything, pending further experimental investigation, one might worry that current physics suggests that any explanation symmetry principles might afford in this context – imagining that some substantive notion of explanation could be articulated after all – must be deficient. Consider permutation symmetry. Group theory enters in the form of a relationship between the irreducible representations of the permutation group and subspaces of the Hilbert space that represent states of the system at issue; the representations correspond to mutually orthogonal subspaces in Hilbert space. As French notes (pp. 76, 265–266), while this yields symmetric, bosonic representations and anti-symmetric, fermionic representations corresponding to Bose-Einstein and Fermi-Dirac statistics, respectively, there are also a host of paraparticle representations corresponding to parastatistics, and paraparticles do not appear to inhabit the actual world.[3] Why is that? If permutation symmetry is not merely a description of the world, which a scientific realist is at liberty to regard as only partially or approximately true, but also part of the *furniture* of the world, why the conspicuous failure of the symmetry to "produce" (in whatever sense of production applies here, in accordance with the imagined explanation) the missing particles?

French (p. 268) is aware of this concern, and responds in a way now familiar from this discussion: 'perhaps the only answer we can give is, that's the way the world is!'. But if that is the way the world is, surely one must wonder why (descriptions of) the ontologically reified symmetries succeed in doing whatever explanatory work they do in some cases but not in others. It is unclear what the proponent of EOSR can say here. In contrast, the dispositionalist has an explanation: one might say of an electron, for example, that it has dispositions to behave in ways that are neatly described by the antisymmetric representation of the permutation group; conversely, if there are no paraparticles there are, *a fortiori*, no dispositions of paraparticles, and their mathematical representations may be regarded simply as surplus structure.

Are there further things that one might hope to explain with an ontology of symmetries? It comes as no surprise that French's claim that dispositionalism cannot explain conservation phenomena (see section 3.2) is conjoined with the assertion that EOSR can do better. But here the substance of the assertion is unclear, for not only is it generally a matter of contention whether symmetry principles explain conservation laws, but furthermore, views according to which they do involve commitments to substantial positions regarding the nature of laws and symmetries that go well beyond EOSR.[4] I will not consider these views here, for the present point is simply that it is not obvious how EOSR's reification of symmetries would or could explain conservation phenomena all by itself, for the same reason that it is unclear how it would or could explain the diversity of particles, as argued above: existing in conjunction with something else is not tantamount to one thing explaining the other. Something more is required.

5. Physics, top down and bottom up

I have suggested that in advocating an opportunistic attitude toward metaphysical theorizing in the service of scientific realism, *The Structure of the World* implicitly appeals to a number of criteria for assessing possible ontologies in connection with theories in fundamental physics. These criteria – satisfying an uncontroversial form of naturalism; erring

[3] This is true only so far as we know, but if they are out there one might have expected them to turn up by now. At best we have the detection of paraparticle-like, collective modes of excitation in fluids constrained to move in two dimensions (e.g. see Camino, Zhou, & Goldman, 2005, with thanks to Øystein Linnebo), not elementary particles or their composites. Switching from quantum mechanics to quantum field theory, it is arguable that paraparticles can be redescribed as bosons or fermions (see Baker, Halvorson, & Swanson, 2015), but even if this is so, an analogous challenge stems from the continuous spin representations of the Poincaré group (see Wigner, 1939; Weinberg, 1995, pp. 66–72, with thanks to Nic Teh).

[4] For example, Brown & Holland, 2004, pp. 1136–1138, argue that classical conservation laws are not explained by spacetime symmetries given that Noether's theorems apply only in cases of continuous, variational symmetries; there is no general correlation between conservation and dynamical symmetries. Lange, 2007 suggests that there may be an explanatory relationship, but this stems from a very particular account of the nature of laws. French is primarily interested in quantum symmetries, but noncommittal with respect to the precise characterization of laws.

on the side of ontological parsimony; favoring greater explanatory power – are widely accepted as desiderata in both scientific and metaphysical theory choice. I have argued by means of a specific example, *viz*. the project of locating the source of modality in the world (which many realists undertake), that these criteria do not obviously point in the direction of the particular ontology of physics, as described by EOSR, that French prefers. In conclusion I would like to offer a diagnosis of why, nonetheless, from the perspective of a certain stance regarding how best to interpret fundamental physics, the ontology of laws and symmetries that French advocates is enticing. And yet this appreciation comes at a cost, for from the perspective of yet another stance, the ontology of dispositional properties he rejects is *also* enticing, and both stances, I contend, are motivated by important aspects of physics.

Earlier I resolved the seeming tension between French's recognition that fundamental physics underdetermines its ontological interpretations and his simultaneous recommendation simply to "read" the ontology of EOSR from physics itself, by suggesting that the latter simply communicates his sense that an ontology of laws and symmetries is "closer" to the physics than an ontology of dispositions. I submit, however, that physics is no one thing. Indeed, it is a number of impressively disparate practices fused together. What may seem "close" to some aspects of this fusion may reasonably seem further away from others, and all of these practices are genuinely part of science.

Everyone will agree that the Standard Model incorporates descriptions of certain invariants of symmetry group transformations: irreducible representations of the groups. In the spirit of French's project let us assume the task of explaining the nature of *de re* modality – of pinpointing the source of modal (including causal) relations among the phenomena – which many take to be revealed by way of empirical investigation and deserving of explanation in terms of a fulsome account of scientific realism. How should one interpret the mathematical formalism so as to yield this sort of knowledge?

On one reading, we endow the formalism itself with some ontological clout, locating the modal force of the theory in the laws and symmetries, from which the properties of particles may then emerge in the form of elliptical descriptions or artifacts, or conceptual placeholders, or derivative entities of some kind. Let me characterize this approach to ontological theorizing as *top down*. It describes the modal force of the theory in terms that proceed from a set of mathematical relations downward, to the natures of properties and the putative entities that have them in the world. The appeal of this stance regarding how best to interpret the ontology of at least some theories is difficult to deny, not least in an era when physics and mathematics are so deeply intertwined. In the context of contemporary theoretical practice it is sometimes difficult to extricate the ostensibly mathematical content from the ostensibly physical; it is not at all clear how to separate one from the other. The resulting emphasis on mathematical theorizing is at the heart of the top-down approach, and the ontological interpretation of physical theory that naturally accompanies this emphasis reflects a kind of stance.

On another reading, we think of the invariants of symmetries as descriptions of properties, like charge and spin, and take seriously locutions of the form 'the electron behaves this way and that *because* it has charge *e*, spin ½, and so on'. That is, we take the 'because' of the locution as indicating that these properties play substantive roles in determining the behaviors of the particle. It is in virtue of these roles that one may naturally think of these properties as ontologically significant in their own right. Let me characterize this approach to ontological theorizing as *bottom up*. It describes the modal force of the theory in terms that proceed from a consideration of properties associated with objects and events and processes in the world, upward, to a consideration of how these things are portrayed in mathematical descriptions. This approach comes naturally to anyone whose primary concern is to work not primarily or exclusively with theories but intimately with the world, in contexts of detection and experiment and manipulation and the creation of systems serving specific purposes and designed to perform certain kinds of work. In these contexts, changing the magnitudes of properties so as to affect the behaviors of entities is everything. This emphasis on the manipulation of properties to do work in the world is at the heart of the bottom-up approach. Once again, the ontological interpretation it naturally affords can be regarded as reflecting a kind of stance.

It is not uncommon to hear that the concept of a disposition is alien to science – superficially, perhaps (as noted in section 4.1), because the term 'disposition' is not itself native to modern contexts of scientific theorizing and description. This is a mistake. A healthy wariness of outmoded metaphysics in the realm of modern science is only sensible, but if we are to take the project of scientific ontology seriously, we should also be wary of superficial appearances. No doubt, it would be an unproductive leap to go all the way back to Aristotle. Instead, one might say this: a disposition is a modal property; it links states of affairs. Whenever one explains some happening in physics or otherwise by citing the properties involved – not as elliptical for something else but as ontologically significant aspects of the world – that is, on a minimal construal, a dispositional explanation. This is but one exemplification of a bottom-up approach to scientific ontology.

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