Proposed *Philosophy Compass* contribution: Ontic Structural Realism

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Abstract

Ontic structural realism (OSR) is at its core the view that structure is ontologically fundamental.   Informed from its inception by the revolutions of 20th century science, it is claimed to provide the perspective on ontology most befitting of modern physics. But what precisely its core claim that 'structure is fundamental' amounts to is difficult to articulate, as is what its purported naturalistic credentials should ultimately be taken to be. It is also difficult to sustain OSR's core claim on the basis of our best current physics. What *is* clear, however, is that OSR has brought swathes of relevant material from the sciences to the table of contemporary metaphysics, and that metaphysicians ignore this rich seam of material to their own analytical loss.

This article aims to identify different positions within OSR and the connections between them, and examine the warrant provided by our best current physics for the claim that structure is ontologically fundamental. It will be argued that kind properties continue to pose a challenge to OSR – something that has perhaps been obscured by the fact that ontological priority has primarily been conceived of in terms of ontological dependence and not a relation of ontological determination (or 'grounding'). As such, it is argued, it seems difficult to maintain the fundamentality of structure on the basis of present physics. But another hope is to convey that OSR must incorporate both the fine details of contemporary physics and tools from *a priori* metaphysics in the course of its development, and as such that metaphysicians of all stripes have not only a stake in the standing of its claims but a role to play in the argument behind them.

Ontic Structural Realism

1. Introduction

While a number of distinct positions go under the banner of *ontic structural realism* (OSR), common to them is the insistence that the structural features of reality should be accorded ontologically fundamental status. While structuralist philosophies have resurfaced periodically under a variety of motivations, the chief selling point of OSR today is its claim to be the metaphysic most befitting of 21st century physics.[1] Though its focus on physics and its attendant mathematics can present something of a barrier to entry, OSR often strikes those with a background in the sciences as almost a revelation – as a philosophy that, unlike its more moth-eaten predecessors, at last docks with their existing world-view. Indeed structuralism today is characterized almost as much by its naturalistic credentials as it is by its ontological claims, with leading structuralists and their collaborators having been at the forefront of recent and sometimes excoriating critiques of contemporary *a priori* metaphysics.[2] In that sense, ontic structuralists have rather fashioned themselves both as saviours of the discipline and the metaphysical awkward squad.

Given the centrality of both methodological and fundamentality concerns to so much recent discussion in metaphysics, OSR surely deserves to be engaged with by metaphysicians of all stripes. But what partly accounts for the seeming rediscovery of structuralist theses by each generation is the distressing tendency of those theses to collapse upon close examination. Structuralisms in general have faced a battery of objections, including that they trivialize knowledge, are conceptually or dialectically incoherent, or – if they manage to escape these objections – are insufficiently distinguished from their supposed rivals. We will see some of these allegations surfacing in this context too. We will see also that securing OSR on the basis of our best current science faces some formidable challenges.

But philosophical positions may ultimately fail to stand up and yet leave us profoundly illuminated. In what follows, we will try to isolate what is distinctive and insightful about OSR, and what it can tell us about how to do metaphysics. Rather than focus on the details of any central arguments, the aim will be to navigate though a sometimes confusing dialectical landscape, and hopefully in the process demystify some of structuralism's more recondite claims. While presenting just a cross-section of the literature, and moreover one that highlights only a subset of OSR's applications and concerns, the hope is to convey something true of OSR more generally – namely, that it requires for its articulation concepts drawn both from technical physics and *a priori* metaphysics. In that sense, not only do metaphysicians of all stripes have a stake in whether OSR succeeds, but also an essential role to play in bringing it to the point where it can stand up to scrutiny in the first place.

2. Structures, objects, and 'mainstream metaphysics': characterizing OSR

Structuralist philosophy of science in its modern incarnation is inaugurated by John Worrall's seminal paper on the lessons of theory change in science (Worrall 1989) – the piece that coined the term 'structural realism'. Worrall's basic claim, underpinned by observations on the history of science, was that all we can have any theoretical confidence in is the structural relationships that unobservable objects stand in, not the intrinsic nature of those objects themselves. As the epistemological thesis that structure is all we can reliably know, this isn't OSR. But it helps to have in mind that while (as is frequently maintained) the more fundamental something is ontologically, the more metaphysically secure its status, epistemologically the situation would seem to be completely reversed. The most fundamental elements of the world are understood via theories formulated in an increasingly abstract mathematical language, such that even the best of contemporary physicists oten struggle to put what they know into words. Should structuralism help transform the formalism of modern physics into something that could reasonably be called a 'world view', that alone would secure it a valuable place in the philosophy of science corpus.

The starting point of contemporary structuralism in its ontic guise is standardly taken to be James Ladyman's 1998 *What is Structural Realism?*, although that was itself a natural continuation of the arguments concerning identity in quantum mechanics developed earlier by Steven French. (While French and Ladyman's views are usually taken to represent the more extreme end of the spectrum, discussions and defences of different OSR positions still tend to be articulated in relation to theirs.) Perhaps because the slogan resonates with that of its epistemic precursor, OSR is sometimes crudely characterized as the doctrine that *structure is all there is*, but this is in fact too narrow. The principal bisection of OSR's doctrines is into what is known as *eliminative* structuralism and what we can call *priority-based* structuralism.[3] Eliminative structuralism gets its name because it holds that physical objects are to be 'eliminated in favour of the relevant structures' (French 2010, p. 89). As such, *this* is the position that 'structure is all there is'. Priority-based structuralisms, on the other hand, promote the view that structure should be accorded an ontologically fundamental status. The 'stronger' position holds that it is *more fundamental* than the objects of physics, and as such *ontologically prior* to them.[4] A more moderate position holds that structure and objects are on an ontological par, with each being as fundamental as the other.[5] All of these versions are taken to contrast with an 'object-oriented' realism that is presented as metaphysical orthodoxy.[6]

One problem that structuralists face at this point is that 'mainstream metaphysicians' are likely to draw a blank if asked to state what this presumed orthodoxy amounts to. Nor do I know of any very clear outline of it in the structuralist literature. In places, the 'object-oriented' position is presented as

involving some commitment to the view that physical objects, such as particles of a given kind, have an 'intrinsic nature', which seems to amount to the idea that they (i) must be differentiated from other members of the same kind by some feature intrinsic to them, and similarly (ii) are such that their properties definitive of their kind are intrinsic properties.[7] But elsewhere structuralists argue that (ii) may not be in tension with structuralism (on which see 4.ii below), and given (for example) the work that spatial relations have done in individuating objects historically it is unclear to me who would insist upon (i). Certainly Lewis – the metaphysician presented as naturalistic bête noir perhaps more than any other – would be one to eschew it. Similarly, while it has been alleged that what OSRists meant by 'structure' has not been clearly articulated, a generous reading of the claim that structure has a fundamental status likewise seems entirely orthodox.[8] For one obvious articulation of 'metaphysical structure' is just the notion of 'joints in nature' that does so much work in Lewis's (and more recently, Sider's) metaphysics, and even the claim that objects are not a fundamental category is denied in Paul's mereological bundle theory.[9] As such, it seems difficult to pin down at the outset what is supposed to be distinctive about OSR.

But the contrasts may come into sharper relief if we take more care to define OSR's basic terms. Whether in its eliminativist or priority-based incarnations, ontic structuralists make claims regarding the relative metaphysical status of two categories – the category of structure, and the category of objects – and more should be said about what these are taken to denote. Unfortunately, however, it seems unlikely that a crisp definition of either is going to be available, or even appropriate. For arguably physics has, in the course of its history, presented us with many different 'kinds of object', for what we call 'objects' in different physical frameworks can be claimed to differ in metaphysically significant ways. Whether in terms of locality, supervenience structure, trans-temporal identity, or ontological vagueness, the wavefunctions and fields of quantum relativistic physics have all been claimed, at least by many philosophers of physics, to differ markedly from their classical counterparts. For this reason, it seems foolish to try and declare once and for all what an object of physics is.

Perhaps for this reason, the ways that structuralist arguments tend to proceed is not by giving an analysis of each category at the outset, but by looking into theories of physics and simply identifying ostensively what should intuitively be counted as examples. Thus *particles*, *field,* and *spacetime points* have all been identified, essentially without argument, as paradigms of objects in physics.[10] Similarly, *extrinsic properties* and *relations* between objects – paradigmatically, entanglement and spatiotemporal relations – have been identified as examples of structure. *Laws of nature* – special sorts of relations between properties – have also been identified as structural entities, as have the higher-order structural features of laws that we denote as *dynamical symmetries.* Thus for all that structuralism has been accused of failing to provide precise criteria for these basic concepts, since it is physics and not the armchair that is supposed to supply us with examples it is hard to see how it could be any other way.

With that (somewhat apologetic) clarification in place, turn now to thinking about the rationale for the various forms of ontic structuralism.

3. The arguments for ontic structuralism

3.1 Eliminative structuralism

Eliminative structuralism has been endorsed by both Steven French and James Ladyman, although by this point for different reasons.[11] Suffice to say the claim that there do not exist objects is one over which many have balked. It seems plain after all that we *see* paradigm objects, such as laptops and coffee cups, scattered all around us – thus inviting what we might call the *incredulity objection*. Furthermore, if the structuralist strategy is to proceed as above, and thus characterize what it *means* by the objects of physical theories in physics 'ostensively' (as opposed to analytically), it is hard to see how the claim that 'there are no objects' can even be formulated coherently. Let us call this the *semantic incoherence* objection.[12] And a notorious objection to eliminativism is that if relations are – at least in the entanglement and spatiotemporal cases – relations *between objects*, it seems we cannot say that there exist the former and not the latter without resorting to a perilous Platonism.[13] Let this last be the *metaphysical incoherence* objection, and let us now consider how eliminative structuralists might respond to each in turn.

With regard to the incredulity objection, eliminativists reassure us that they are not denying that it is *true* that your laptop and coffee mug are both on the table, both within reaching distance, etc, only that we need not at any point make recourse to a category of objects in order to *account* for such truths.[14] As such, the claim is that objects constitute a dispensable category when it comes to making sense of the world. The response to the semantic incoherence objection is quite different, however, and raises some distinct puzzles. As noted, the problem is that structuralists seem to convey what they mean by 'object' through looking into physics theories and identifying candidate examples – in the paradigm case, quantum particles – raising the question of how we can coherently deny there are any. It seems their subsequent elimination is predicated on the claim that those putative objects fail to meet some further criterion held to be necessary for specifically 'metaphysical' commitment. While there are perhaps other criteria that could have been cited to this end, that which has been appealed to in this context is the failure of physical theories to determine whether they are *individuals* or *non-individuals*.

Sadly, what precisely is intended by 'non-individual' is something I myself have always struggled to get a grip on. But what is clear is that the concept is intimately related to whether claims about the *identities* and *distinctness* of the members of a set can append claims about the set's *cardinality*.[15] The claim that this issue is underdetermined in quantum mechanics is often predicated on the following facts:

that (1) the generic state of quantum particles is an *entangled state*;[16] that (2) entangled particles seem, as a matter of empirical fact, to only to enter into states with a certain symmetry; and that (3) those symmetries result in every member of a set of *n* entangled particles being attributed precisely the same set of properties (both intrinsic and extrinsic).[17] With no *physical* property – including, it should be noted, position properties – available to render them distinct, it is claimed we are faced with a dilemma. For either we assume that the entangled particles comprise a set of individuals in possession of some primitive metaphysical feature, such as Lockean substratum or 'primitive thisness', which renders them metaphysically distinct from each other despite their physical indiscernibility; or infer that they are not individuals, that the language of identity and distinctness does not apply and all we have is a cardinality claim to the effect that there exist *n* of them.[18] It seems our best theories cannot settle which it is; and for Ladyman, at least circa 1998, it is only "an ersatz form of realism that recommends belief in the existence of entities that have such ambiguous metaphysical status" (Ladyman 1998, p. 420). As such, so the claim seems to go, objects should be cast to the flames.[19]

This discussion concerning individuals forms, to my mind, the single most confusing thicket in all the structuralist literature.[20] For one thing, the very nature of the move is confusing: what methodological principle of metaphysics, least of all a *naturalistic* metaphysics, can trump that we interpret the *physics* as providing us with examples of objects, that we can then metaphysically theorize about? For another thing, the move from 'underdetermination of some crucial feature of' to outright 'elimination of' just seems obviously over-hasty (at least for anyone with any metaphysical sympathies at all), given how pervasive such underdetermination seems to be.[21] More specifically, however, the issue of what is supposed to be metaphysically significant about whether an object can be classed as an individual or not seems never, or at least not to me, to receive a crisp articulation, and seems especially unclear given that no-one disputes either what physical properties particles have or that their associated cardinalities can be applied either way.[22]

In any case – as might come as something of a relief – the discussion over eliminativism has largely retreated from the supposed underdetermination of the status of particles with respect to their individuality. Principally on account of Saunders' analysis of identity in quantum mechanics (on which more below) – an analysis that most take to have secured that particles are unambiguously individuals, and without any imposition of 'primitive thisness' – even Ladyman has abandoned underdetermination as an underpinning for OSR.**[23]** Instead**,** the focus has shifted instead onto what *makes it the case* that particles may be distinguished from each other (and hence, apparently, secured as 'individuals'). Nevertheless, despite the (almost) abandonment of the argument that inaugurated it, the language of eliminativism persists, as other arguments have been given for the eliminativist point of view – both of which have been marshaled as responses to (what we have called) the 'metaphysical incoherence' objection. This objection, recall, is that if relations are *relations between objects* then we cannot commit to the former without also committing to the latter. One response eliminativists have flirted with is that

objects might decompose into relations *ad infinitum*: that what seems to us to be an object might be 'structures all the way down'.[24] While the anti-fundamentalism gestured at here is arguably a coherent possibility, there is at present no empirical reason to think that it is true.   Thus the route more typically taken against the charge of incoherence is to say that, while the objects *are* there, they are merely 'points of intersection' of the relations between them – a claim of course different from that in which putative objects resolve themselves into relations distinct from those in which they occur as relata.   Either way, they are 'offering a reconceptualization of ontology, at the most basic metaphysical level, which effects a shift from objects to structures.'[25] In invoking such explicitly reductionist language, eliminative structuralism leads naturally to the priority-based view, and in particular, the 'strong' view that structure alone is fundamental. Indeed strong priority-based OSR simply *is* eliminative structural realism if we adopt the seemingly popular metaphysical view that only that which is fundamental is real.[26] But whether or not we share that view, structuralism's success is now seen to hang on the viability of some priority-based view. Let us then consider the priority relations in which objects and structures may be taken to stand.

3.2 Priority-based structuralism.

Priority-based structuralisms hold that relations and other structures of physics have a claim to fundamental status. To recap, according to the 'strong' (sometimes called the 'radical' position), structures enjoy a one-way priority over objects; according to the 'moderate' position, the so-called 'priority' is reciprocated.[27]   As we have seen, eliminative structuralism, if based on a claim to reduce objects to structures, aligns with the former camp. Now to be clear, in saying that structures are 'more fundamental' it is not being claimed that structures occupy a lower *level* than that in which the most fundamental objects feature. For all that structuralism has been vaguely associated with anti-fundamentalist thinking, it is completely consistent with both versions of priority-based OSR to hold that there is a fundamental level *and* that fundamental particles feature in it. Rather, structuralists discern metaphysical structure *within* that most fundamental level, arranging the categories of entities that feature there into relations of ontological priority.

Given that (at least on a non-eliminativist view) everyone can agree what the fundamental laws, objects, and relations are, and what the levels structure of the world is, some will see the transition from a realism in which objects are primary to one where they are not to constitute a mere metaphysical gestalt switch – a change in perception that fails to correspond to any alteration in the world itself. Since the *physical* structure of the fundamental level is not in question, and the sole point of disagreement is the relative standing of ontological categories, OSR is an unabashedly metaphysical thesis, and one that must utilize some of the most thickly metaphysical concepts of the day.   As such, OSR at its best will likely involve collaboration between *both* mathematical whizzes and science-types, *and* their

more dusty philosophical colleagues, for whom making fine distinctions of precisely this sort has been paying the rent for years.

In any case, to claim that structure is prior to objects (or vice versa) clearly requires the identification of a relation of priority. Most of the work on priority in structuralism has focused on the idea that objects *ontologically depend* (perhaps reciprocally) on structures.[28] While this extant literature is rich in insights, good arguments can now be given that ontological dependence is *not* a relation of ontological priority after all.[29] Instead, it is increasingly understood that priority is a relation of *ontological determination* (as connoted by notions of 'building', or 'bringing about'), without the need for any concomitant dependence on that which does the determining. As is by now almost universally acknowledged, such a relation must be more fine-grained than mere modal correlation, and it has become customary to denote this relation 'grounding'.[30] Thus the supervenience of x on y, while still necessary, is no longer sufficient for the priority of y over x. Unfortunately, how to conceive of the extra ingredient that takes us from mere correlation to genuine grounding – indeed even whether such an ingredient can be specified at all – is much disputed in *a priori* metaphysics. Like it or not, OSR will presumably have to take sides on this issue too.[31] Nevertheless, let us consider how far the physics alone can get us in defending the fundamentality of structure. Luckily, many of the insights of the dependence-based discussion can be straightforwardly adapted here.

Here our focus will be on matter physics (rather than spacetime physics, the other main arena of structuralist argument). Let us take it that in order to be classed as an object a particle must be the sort of thing that can, at least in principle, admit of qualitative duplicates with which it is not identical – for otherwise, one might hold, the contrast of a *particular* with a *universal* is lost. As such, we will take it that what OSRists must account for – 'build' – are *entities with kind properties distinct from other members of the same kind*. Our focus will be on issues of synchronic identity, and to keep things simple let us focus on states of just two particles. As noted above, the generic state of a set of quantum particles is an entangled state, and the properties ascribable to an object in such a state are shared by all with which it is entangled. As such, no property – either intrinsic or extrinsic – can differentiate them. Saunders' insight, alluded to above, was that particles may nevertheless be numerically discerned from one another via the structure of the entanglement relation, whose irreflexive nature ensures that either particle is not identical to that which with it is entangled. Thus of all the physical features that could secure an object's distinctness from qualitative duplicates, it can in this case be only the relations that exist between them. Moreover, one can show that entanglement relations are strongly non-supervenient on the properties of the relata, and hence cannot be grounded in them.[32] As such, it seems that we have reason to claim that these relations are fundamental and that particles – at least stripped of their kind properties – are not: for unless we are to sanction a primitive and naturalistically problematic identity-conferring constituent, their distinctness and particularity is determined by the relations between them alone.[33]

Crying out for comment here is the fact that this argument feels somewhat out of step within the broader OSR dialectic. After all, the identity considerations originally used to support it explicitly invoked the option of an irreducible identity-conferring feature, such as Lockean substratum or 'primitive thisness': for in advance of Saunders' insight, it was only these that could support the 'individuals' interpretation that the physics was held to underdetermine. Why is it that haeccieties are now simply ruled out *ab initio* as a ground of numerical distinctness, especially given that (as noted) structuralists are happy to posit other unabashedly metaphysical relations in the fundamental level? But in any case, the problem of securing the diversity of members of a given kind has historically been taken to be more favourable to OSR than that of accounting for the kind properties themselves. Here the issue is that the fundamental kind properties – such as mass, charge, and the (absolute value of) spin – are taken to be essential to what particles are, yet they also standardly taken to be intrinsic properties of them. Since intrinsic properties are taken to be paradigm non-structural features, critics have claimed that the idea particles are 'built' from structures is for this reason untenable. [34]

But structuralists have in fact always had a story to tell about the fundamental kind properties, even if its rather more mathematically involved has perhaps led to it being somewhat overlooked. Broadly speaking, two strategies have been adopted to deal with the problem posed by kind properties: these have been either to argue that the kind properties are not in fact intrinsic after all, or that – whether they are intrinsic or otherwise – they may nevertheless be accounted for structurally.[35] Of these it is the second strategy that seems to have generated the most discussion historically, and it places the notion of *symmetries in physics* centre-stage.[36]

Whether on account of their role in particle prediction, numerical computation, the heuristics of theory construction, or just scientific understanding in general, the importance of symmetries to modern physics is impossible to overstate. Largely in consequence, how to conceptualize symmetries has become a philosophical topic in its own right.[37] Roughly speaking, when one speaks of a symmetry in physics one typically has in mind a set of operations, acting on the state variables of a theory, that leave the form of the dynamics unchanged. (For example, when applied to the equations of special relativity, the transformations that map between inertially-moving observers in Minkowski spacetime will leave the structure of those equations unchanged.) Such sets of transformations may be shown to form a *group* in the mathematical sense, and the group(s) under which a given equation remains invariant represents a structural feature of it. Both the meaning of these operations and the significance of any resulting invariance are in general matters of much dispute. But what *is* clear is that a core part of the structuralist package is that symmetries do not have a merely epistemic or heuristic import, but rather the status of fundamental ontology.

Needless to say, the statement that a structural feature pertaining to the world's dynamics constitutes a fundamental element of reality is one that requires a fair bit of intellectual digestion: there is simply nothing obvious about what it means at all. One thing that *is* clear, however, is that symmetries are not simply 'relations between particles', such as entanglement or spatial relations. Hence the relationship between *these* structures and the associated particles cannot be that the latter are mere 'points of intersection' of the former. Rather, the relationship between symmetries and particle kinds themselves can only be understood by grinding through the mathematical machinery of *group representation theory* – something we will not do here. For now, suffice to say that the most basic field and particle content that we currently know of is *intimately related* to the symmetries we find in the most fundamental dynamics we know of – namely, the Standard Model of particle physics: the symmetries of the Standard Model tightly constrain the possible combinations of particle content (and indeed vice versa). Nevertheless, it remains that that particle content we find in the world does not, as a matter of mathematical fact, *supervene* on those symmetry structures.[38] To be sure, one can certainly argue that there is an *ontological dependence* of particles on symmetry structures, *and* that symmetries have to be placed front and centre of how it is that we understand the metaphysics fundamental particles for a host of other reasons.[39] In particular, symmetry gives us reason to think that kind properties do not simply cohere (or 'socialize') as a matter of primitive metaphysical fact, and that fundamental entities are not, at least not without a great deal of argument, amenable to the sort of free recombination blithely assumed in countless metaphysical projects.[40] For these and other reasons, there are compelling reasons to credit OSR with offeroing 'a stronger explanatory framework than that based on object-oriented metaphysics' (French 2014, p. 391-2). But on account of the demonstrable failure of supervenience – something necessary (but not sufficient) for grounding – that doesn't mean that the sort of determination needed for OSR to ground objects in structures ultimately goes through.

In sum, then, it seems that at present we cannot affirm that the most fundamental objects we know of are secondary to symmetry structures. Thus while structuralists have had a great deal to say about kind properties and how they are understood in physics, their claim that kinds are grounded in symmetry structures fails to go through. OSRists therefore must do something else if they are to continue to maintain their core claim – the claim that structures have priority over the fundamental objects of physics.[41]

4. Concluding remarks

What, then, to say? We might hold that, while arguably stuck in the mud right now, OSR could well be shown to be true in the future. After all – and for all that metaphysicians tend to act as if things were otherwise – we are not yet in possession of a fundamental theory, and so far structuralism has seemed only to grow ever more plausible as we progress into more fundamental regimes. However,

such a nakedly speculative and self-flattering claim will hardly do much to convert OSR's opponents. But one thing we *do* know is that the fact OSR faces real challenges at present does not imply that it has brought nothing of value to the table, hence nor that metaphysics may revert to business as usual accordingly. For independently of whether (for example) the particles in your favourite theory of particle physics may be shown to supervene on a certain symmetry structure, it can hardly be denied that structuralists have shown symmetry to at least be replete with metaphysical *implications*, and hence that metaphysicians ignore the structures through which physicists understand the world to their own loss. Indeed, to me structuralism is, more than anything, simply an exhortation for a certain *methodological approach* in metaphysics – one that may, echoing Lakatos, be conceived of as a conjunction of heuristics.[42]   The *positive* heuristic is the injunction to incorporate the mathematics relevant to the physicists' conception of the fundamental when engaging in metaphysical theorizing about it; the *negative* heuristic is to relentlessly police our tendency to impose concepts belonging to the world of macroscopic experience upon that which lies beneath. And to me the literature amply affirms the power of these heuristics again and again. Thus unless we want metaphysics to continue as a satellite discipline, wholly disconnected from other enquiries into unobservable reality, we should follow OSR's lead and engage more directly with the language in which those other disciplines express themselves. For it is surely hard to take seriously philosophy's claimed respect for the sciences if it cannot do even that much.

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[1] See Saunders and McKenzie 2014 for an overview of these motivations; also van Fraassen 2006, French 2014.

[2] See, most notoriously, Ladyman and Ross 2007; also French and McKenzie 2015.

[3] For an overview of the positions one could take in OSR, see Ladyman 2014.

[4] Sadly there is no settled terminology here. McKenzie 2015 denotes this 'radical' structural realism, whereas van Fraassen 2006 reserves that term for the eliminative version; French 2010 on the other hand prefers the term 'strong' for that!

[5] 'Moderate' structuralism is most closely associated with the work of Micheal Esfeld and Vincent Lam: see eg Esfeld and Lam 2011.

[6] See eg. French 2006, who takes Psillos 1999 as a representative.

[7] See Ladyman 2007, Section 2 for perhaps the clearest discussion of this issue I know of.

[8] For a recent discussion of the problems in defining 'structure', see Arenhart and Bueno 2015.

[9] Cf. Lewis 1983; Sider 2011; Paul 2012.

[10] On structuralist treatments of fields, see e.g. French and Ladyman (2003a), Lyre 2004.

[11] See French and Ladyman (2011), Section 2.3 for a statement of their points of agreement and disagreement with respect to identity.

[12] Note that I have never actually seen anyone make this objection in the literature.

[13] See e.g. Psillos 2001.

[14] See French 2014, Chapter 7, for a discussion drawing explicitly on recent work in *a priori* metaphysics.

[15] See eg French and Krause 2006, Section 1.4 *et passim.*

[16] For a succinct discussion of why this is, see Ismael and Schaffer (forthcoming), Section 3.2.2.

[17] For a particularly hand-holding presentation, see Butterfield 1993, Section 5.

[18] The classic reference here is French and Redhead 1988.

[19] It should be noted that the 'non-individuals' claim was primarily motivated not through entanglement, but considerations of quantum statistics. These arguments are related, but not the same: see French and Krause (2006) for extended discussion.

[20] Indeed even the chief protagonists seem not to have their ducks in a line here! For example, Ladyman (2007, Section 4) claims that 'eliminativism does not require that there be relations without relata, just that the relata not be individuals'. But French, on the other hand, holds that this 'confuses OSR with the views of the earlier structuralists who equated structuralism with the abandonment of individuality. With the development of non-standard formal frameworks… that can accommodate a metaphysics of non-individuality while retaining sets of objects, simply abandoning individuality won't necessarily yield a non-object oriented ontology' (2010, p. 94).

[21] Cf. Chakravartty 2003.

[22] French has protested that without some policy on this matter we don't know what logic to use. But that (to me at least) doesn't answer the question of what the metaphysical significance is supposed to be.

[23] See Saunders 2001.

[24] See Ladyman (2007), Section 4.

[25] French and Ladyman 2003, p. 37.

[26] See Sider 2011 and Fine 2001 for distinct but related views.

[27] Since 'priority' standardly connotes an asymmetric relation this langauge is rather unfortunate, but it's language that we're stuck with.

[28] See e.g. French 2010; Wolff 2011; McKenzie 2013.

[29] I cannot go into the details of the argument here. But see e.g. Barnes (2012) for (to my knowledge) the first published argument to this end.

[30] See eg Audi (2013).

[31] See French and McKenzie (2015) for a discussion of the supportive role played in OSR by *a priori* metaphysics.

[32] Cf Teller 1986. For a particularly accessible presentation on the non-supervenience of quantum states, see Maudlin 2007, Chapter 2.

[33] Of course, a fuller analysis must incorporate the various interpretations of the QM formalism: for some of this, see Belousek 2003.

[34] See e.g. Chakravartty 2012, p. 204.

[35] For discussion of the first strategy see McKenzie 2016.
[36] French 2014 is particularly explicit on the centrality of symmetry to OSR.
[37] For a snapshot, see Baker 2010.
[38] Wolff *op cit*. makes this point for spacetime symmetries, and the argument of McKenzie 2016 implies it in the case of fundamental gauge symmetries.
[39] See eg McKenzie 2014.
[40] See e.g. French 2014, Chapter 9.
[41] As noted above, however, the denial that the fundamental properties are intrinsic may be a more promising (if so far less discussed) route to establishing OSR, although not be one that makes symmetry structure fundamental.
[42] Cf Lakatos 1978.

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