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The interdependence of structure, objects and dependence

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Abstract According to 'Ontic Structural Realism' (OSR), physical objects—qua metaphysical entities—should be reconceptualised, or, more strongly, eliminated in favour of the relevant structures. In this paper I shall attempt to articulate the relationship between these putative objects and structures in terms of certain accounts of metaphysical dependence currently available. This will allow me to articulate the differences between the different forms of OSR and to argue in favour of the 'eliminativist' version. A useful context is provided by Floridi's account of the relationship between 'ontic' and 'epistemic' structural realisms and I shall conclude with some brief remarks on possible extensions of OSR into other scientific domains.

Keywords Structural realism · Information · Dependence · Eliminativism

1 Introduction

Structuralist approaches to science have a long and honorable history, many of the details of which have remained obscured and hence lost to the history of the philosophy of science. Even the standard references to Poincaré and Duhem stand in need of further elaboration and in the case of Cassirer, Eddington and Russell, for example, we are only beginning to understand how their versions of the structuralist programme are tied into their understanding of modern physics. Nevertheless, the past ten years or so have perhaps been the most fertile for such approaches in general and structural realism in particular, with the development of several different versions of the latter, as well as its anti-realist equivalent (see Van Fraassen 2008). A useful review of

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these developments, together with criticisms and associated responses can be found in Frigg and Votsis (forthcoming; see also Ladyman 2007a, b). My intention here is to consider these developments in the context of a particular issue, namely that of the manner in which objects are reconceived as exhibiting a certain kind of dependence on structures. In doing so I shall draw on an obvious parallel with forms of mathematical structuralism and along the way I shall respond to some of the concerns that critics of structural realism have raised, with respect to the role of the metaphysics of identity in these developments. I shall conclude with a brief look ahead to the extension of this position to cover not just physics but other areas such as biology and information science.

2 The twin motivations for structural realism

The motivations for such a view spring from two sets of problems that 'standard' realism is seen to face. The first has to do with apparent ontological shifts associated with theory change that can be observed throughout the history of science. The second is associated with the implications—again ontological—of modern physics. I've emphasized the ontological nature of these problems since it is precisely these features that structural realism addresses in overcoming them. The contrast is with what I have called 'standard' or 'object oriented' realism (OOR; French 2006), where the assumption, typically left implicit but occasionally as we shall shortly see made explicit, is that the relevant ontology is one of objects and their properties. Taking the standard Boyd–Putnam realist 'core' which insists that theories should be regarded as true, or approximately so, and theoretical terms as referring—to objects and their properties—OOR must adopt some manoeuvre in response to the first problem above, such as Psillos' 'divide and conquer' move, in order to separate out those parts of theories to which the realist should be committed, even through theory change (Psillos 1999). Psillos makes the ontological features explicit, noting first that the realist should only take as referring those terms which play an appropriate role in explaining the given theory's success and then arguing that the appropriate theory of reference in such cases is a form of causal-descriptive account, according to which reference is fixed via a 'core causal description' of those properties which underpin the putative entity's causal role with regard to the phenomena in question (ibid.). Crucially, and in addition, what this secures is reference to *individual objects and their properties*, and thus, Psillos insists, '… the world we live in (and science cares about) is made of individuals, properties and their relations.' (Psillos 2001). It is this ontological feature that structural realism rejects, albeit in different ways depending on which form it takes.

3 Two varieties of structural realism

The difference between so-called 'epistemic' structural realism (Worrall 1989) and the 'ontic' form (Ladyman 1998; French and Ladyman 2003a,b; Ladyman and Ross 2007) can be summed up neatly in the slogans, "All that we *know* is structure" and 'All that there *is*, is structure" respectively. The former was primarily motivated by the afore-mentioned ontological shifts in the history of science. The core idea is that

underlying such shifts there remains a form of continuity of structure, as captured by the 'General Correspondence Principle' (Post 1971; Saunders 1993) and it is to this underlying structure that we should be committed as realists. Famously, the historical roots of this epistemic view (ESR) lie in Poincaré's work, and his insistence that the true 'nature' of things remain hidden from us has been carried over into modern accounts (see Cei and French 2006). Although Worrall himself espouses a form of metaphysical agnosticism with regard to the 'true nature of things', this reveals a fundamental difference in philosophical stance between these versions of structural realism: How much metaphysical humility should we adopt with regard to the 'true' nature of the world? (see French forthcoming a) Worrall is content to accept considerable humility in the sense that we not only do not know (and here metaphysicians and epistemologists will engage with the underlying sense of 'know') whether properties should be regarded as instantiated universals or tropes, or whether quantum objects should be take to be individuals or non-individuals, but, according to ESR, we cannot know anything about these 'true natures'. A less humble position would be to insist that we should cut our metaphysical cloth to fit our epistemic access. Thus Cassirer, in neo-Kantian mode, urged that we should take the 'conditions of epistemic accessibility' to be the 'conditions of the objects of experience', in the sense of precisely ruling out epistemically inaccessible objects. Indeed, he insisted that, contrary to Poincaré and Worrall, we should exclude from the 'domain of empirical existence' those presumed objects which are not accessible or determinable by the empirical and theoretical means of knowledge at our disposal. It is this attitude that lies behind ontic structural realism (OSR), which insists that there are no inaccessible objects sitting behind the structure, there is only the structure itself. Thus, although OSR entails ESR, the two remain at odds insofar as the former adopts a definite metaphysical stance that the latter eschews.

Interestingly, Floridi provides an argument to the effect that metatheoretical analysis allows for the epistemic and ontic forms of structural realism to be seen as compatible with one another (Floridi 2008). A crucial notion here is that of 'level of abstraction' (LoA; Floridi and Sanders 2004), drawn from 'formal methods' in computer science.[1] Different LOAs correspond to different perspectives, such that specifying the LoA involves clarifying which questions can be meaningfully asked and which are answerable in principle (Floridi op. cit.). Commitment to certain types of putative objects is then effected by accepting the relevant LoA. ESR may thus be seen as offering a minimalist approach to ontological commitment, since, according to this position '… a theory is justified in adopting a LoA that commits it (the theory) ontologically to a realist interpretation of the structural properties of the system identified by the model that has been produced by the theory at the chosen LoA.' (Floridi op. cit., p. 231). This gives us first-order knowledge of the structural properties of the system, and Floridi suggests that going beyond this first-order commitment may then seem 'metaphysically risky and suspicious'. Indeed, ESR is typically portrayed as the most minimal realism possible, because as Floridi puts it,

[1] For a concrete example given in terms of Roman and Oxonian traffic lights, see Floridi (2008).

> … there is no degree of ontological commitment lower than the one supported by ESR, which holds that structures are knowable, but still higher than the even lower commitment of the instrumentalist, who may be happy to concede the existence of an external world. (ibid., p. 232)

As he goes on to note, this lack of logical space between ESR and instrumentalism has been used by certain critics to squeeze OSR out of the picture. Floridi, however, thinks this is a misguided attack, since the different stances of ESR and OSR place them within different LoAs. The kind of ontological commitment endorsed by ESR is justified as a first-order analysis but that offered by OSR can be supported at a metatheoretical or second-order level. So the idea is that having committed ourselves to the relevant underlying structure, on the grounds that ESR sits upon, we are then entitled to perform a kind of transcendental inference to the effect that whatever the underlying objects are in themselves, they must be such as to allow the theory to appropriately model their structural properties. In other words, the commitments associated with OSR are what make ESR possible, in that the LoA adopted at this second-order level is one that involves commitment to an interpretation of the objects as themselves structural in nature (ibid., p. 233). Since these differing commitments are associated with different levels of analysis, there is no incompatibility.

In effect what Floridi's approach allows us to do is separate out the commitments of ESR from both Worrall's agnosticism and Poincaré's espousal of 'hidden natures'. At the first order LoA, ESR—as the name suggests—offers us an epistemic form of realism to the effect that what we know in science are the relevant structures (and if we are to follow this line of analysis, we should perhaps drop or at least modify the afore-mentioned slogan). Beyond that, Poincaré, Worrall et al. should remain quiet; there should be no talk of natures, hidden or otherwise, no adoption of forms of agnosticism, but rather a 'quietist' attitude to any further commitments. To make those is to proceed to the next level, as it were, and here the appropriately metaphysically minimal attitude is that offered by OSR, which reduces the amount of humility we have to swallow by reconceptualising the underlying (putative) objects themselves in structural terms. Of course, there is more to say here, particularly with regard to the move to metaphysics that OSR represents. A defender of ESR may insist that as the name suggests, this view adopts an epistemological stance and that she sees no need to 'move to the next LoA' as it were, or to accept the kind of 'transcendental feedback' that Floridi suggests in motivating the consideration of the nature of the underlying (putative) objects. At this point meta-methodological concerns intrude and certainly a realism that eschews any consideration of metaphysics may well deserve the label 'ersatz' (Ladyman 1998).

This structure to which OSR is ontologically committed can be understood—somewhat sketchily perhaps—as multi-layered, or multi-aspected, as revealed by the relevant physical theories (and if the 'Grand Unified Theory' were ever revealed one would expect these multiplicities to reduce appropriately), as involving 'webs of relations', represented by the relevant laws, etc. and as effectively tied together by higher order symmetry principles representing the invariants in terms of which the 'nodes' in this structure can be described (and it is these 'nodes' that are manifested as elementary particles). Furthermore, this 'web of relations' is inherently modal and, in particular,

causal. Of course, filling out this sketch and making it philosophically robust remains an on-going programme for OSR but some steps have been taken in that direction (French 2006; Ladyman and Ross 2007; French and Ladyman forthcoming). In particular, the notion of objectless structure remains a central challenge as critics have raised concerns whether the subsidiary idea of relations without relata is conceptually coherent. In response, OSR has further sub-divided into three alternatives: 'eliminativist' OSR, which attempts to do away with objects entirely, metaphysically speaking; non-eliminativist OSR which retains a 'thin' notion of object; and 'Moderate Structural Realism', which takes objects to be mere placeholders but puts them ontologically on a par with structure. Much of this paper will be taken up with an attempt to characterize these alternatives in terms of different forms of dependence between objects and structure.

As Ladyman has emphasised (2007a, b) the motivation for OSR has a number of sources and hence the most general argument in its favour is through a kind of 'consilience': OSR offers a response to the history of ontological change in science noted above—a better response than 'epistemic' SR (Ladyman 1998); it meshes nicely with the so-called Semantic Approach to theories, which represents theories in terms of set-theoretic structures and it offers an appropriate response to the metaphysical implications of modern physics, in the form of both quantum mechanics and, perhaps more contentiously, relativity theory (see Rickles et al. 2006).

Unfortunately this last aspect has been misunderstood in recent critical discussions of OSR, and these misunderstandings have distorted other features of the position, in particular with regard to its apparent similarity to forms of mathematical structuralism. I shall briefly respond to these misunderstandings before moving on to the above characterization.

4 OSR and identity considerations

According to the so-called 'Received View' of quantum objects, which held sway for many years since the early days of the development of quantum mechanics itself, such objects cannot be regarded as individuals. A number of reasons were given for the conclusion—such as the lack of well-defined space–time trajectories—but chief among them were the consequences of the newly developed quantum statistics. This apparently treated permutations of such objects in a different manner than classical 'Maxwell–Boltzmann' statistics and this difference was understood as implying that—unlike the classical case—the particles must be treated as 'non-individuals' in some sense (see French and Krause 2006 for an overview).

Earlier forms of structuralism developed by Eddington, Cassirer, Born and others, incorporated this understanding of quantum objects as non-individuals. The current form of OSR, however, is grounded on a different metaphysical basis. Following the widespread acceptance of the Received View it was eventually realised that quantum mechanics could also be understood as supporting an alternative metaphysical 'package', according to which the particles could still be regarded as individuals (provided the particle permutations of quantum statistics were understood in a particular way). This then gives rise to a form of metaphysical underdetermination, according to

which the physics can be taken to support two quite different metaphysical alternatives: particles as non-individuals and particles as individuals (French and Krause 2006). The impact of this form of underdetermination on 'standard' forms of scientific realism is contentious. van Fraassen certainly takes it to be negative and—understanding realism to be appropriately metaphysically informed—insists that we must 'say goodbye' to metaphysics, and hence realism itself (Van Fraassen 1991). Ladyman in effect proposed a kind of 'third way' by arguing that we need not give up realism entirely if we refuse to engage with the issue of whether objects are individuals or non-individuals and reconceptualise them in structural terms (Ladyman 1998). Thus this form of OSR is based, not on the Received View, but on the acknowledgment of this metaphysical underdetermination as undermining our conception of 'object'. Further forms of underdetermination also arise in science and can also be undermined or sidestepped by OSR (see French forthcoming b). Again, to accept these kinds of underdetermination would mean accepting a profound form of metaphysical humility, one that van Fraassen, for example, takes to be problematic for OOR, and again, adopting OSR allows us to be appropriately less humble in our commitments since it undercuts the underdetermination by removing its basis in an assumed ontology of objects.

I have emphasised this motivation as it is important to be clear on what the relevant bone of contention is when it comes to OSR's critics, else the boundaries of the debate will be distorted before it even begins. Thus, certain critiques of this view get off on the wrong foot by characterising it in terms of abandoning the concept of the *individual* entity as a fundamental ontological posit of our realism. 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 such as quasi- and qua-set theory (French and Krause 2006) 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. Current forms of OSR are thus more nuanced and either advocate the elimination of objects entirely, in either individual or non-individual modes, or allow for a 'thin' concept of object with individuality conferred in structural terms (I shall return to these conceptions below and shall argue that the second may not be stable).

Nevertheless, even granted the underdetermination, some metaphysical positions are ruled out by QM, as standardly interpreted. The Principle of Identity of Indiscernibles (PII), for example, is violated, if the particles are regarded as individuals (if they are not, then it is simply obviated). Hence it cannot serve as a principle of individuality in this domain and recourse must be made to some principle which 'transcends' the properties of the particles, such as haecceity or some form of Lockean substance (see French and Redhead 1988; French and Krause op. cit.). Now, of course, this conclusion can be challenged (French and Krause op. cit.) and Saunders, for example, has argued that a Quinean form of the Principle can be maintained if relations are allowed to individuate (Saunders 2006). Whether one accepts PII or not may therefore but perhaps not surprisingly depend on various factors, including the interpretation of QM one adopts and the admissibility of certain properties as conferring distinguishability. However, the point I wish to emphasise is that it is not the case that OSR depends on this rejection or acceptance—if the latter then the underdetermination is obviously maintained; and if the former then it continues to hold as long as there is some other principle of

individuality available. Typically the latter has been articulated in terms of some form of haecceity, which is famously problematic, although as noted above, it can be made to mesh with quantum mechanics if the relevant statistics are understood in a certain way (French and Krause op. cit.)

Thus, Morganti, for example, in a paper that Floridi and others have cited as eliminating the conceptual room for OSR, takes PII and its status to play a vital role in the arguments supporting OSR, although French and Ladyman have *never* held that either applying or dropping PII is enough (Morganti 2004). Indeed, Morganti relates the status of PII to the grounding for OSR in a way that is quite odd. He begins by insisting that at best PII is only contingently true and states that '[o]nly endorsing a stronger empiricism would make the consequences of PII necessary truths. But it does not seem that we are entitled to read the necessity of metaphysics off the contingency of our scientific knowledge' (p. 90). This is then used as the basis for the suggestion that OSR is the result of some sort of metaphysical discovery made via PII. However, French and Redhead's work noted above is of course based on the presupposition that PII is only contingently true, the standard counter-examples due to Black and others showing that it cannot be necessary. Given that and French's repeated rejection of PII in a series of papers, the claim that OSR takes the consequences of PII to be necessary is *prima facie* a curious allegation to make but I shall repeat the argument in full, in order to make clear where it diverges from the actual arguments for OSR:

> I believe they [French and Ladyman] argue for OSR on the basis of exactly the strong empiricism I see as incorrect. More specifically, they seem to agree with a Russellian property-only view of reality; to accept as real the properties attributed to things by theories; to observe the empirical data and interpret them in the light of the theory; to apply PII to the considered properties; and to eventually conclude for strong *identity* (and, then, for OSR) on the basis of simple *equality of properties according to a theory* [his emphasis]. But this seems to me an ungranted jump from epistemology to metaphysics. (p. 10)

Here again we can discern a fundamental difference in attitude with regard to the relationship between epistemology and metaphysics. As I indicated above, OSR is grounded on the fundamental principle that we tailor our metaphysics to our epistemology (see again, Ladyman and Ross 2007). Whether that move is 'ungranted' or not obviously depends on the relevant justification. Morganti seems to think it has to do with the application of PII—and if it were, it might be agreed that this is problematic—but as I've indicated the crucial point is that with our understanding of objects so fundamentally underdetermined, the realist should not be committed to them. Thus, the above is not the argument for OSR. More bluntly, there is no argument in French and Ladyman's papers on the basis of the application of PII and a conclusion of strong identity on the basis of 'simple equality' of properties. Let me repeat: in this context the crucial argument for OSR is grounded on the above metaphysical underdetermination between the two 'packages' of particles-as-individuals and particles-as-non-individuals. With regard to the former horn of the underdetermination, only certain principles of individuality are allowed in the quantum context; under the standard interpretation (of QM) PII must be rejected and given the well-known problems with grounding

particle individuality in something like spatio-temporal trajectories, this appears to leave some form of 'Transcendental individuality', such as primitive thisness or Lockean substance as the only alternative.

There has also been some confusion in the understanding of 'transcendental' here. As originally coined by Post (see French and Krause op. cit.) the term simply meant a form of individuality that transcends the properties of the particles, as indicated above. However, Morganti takes it to refer to properties that would render the particles non-identical even though they are indiscernible, in terms of normal, non-transcendental properties. It is not at all clear what kinds of properties these 'transcendental' forms would be. Clearly they would have to go beyond the 'normal' kinds that objects are taken to possess, since it is in terms of these that claims of indiscernibility are made. The best I can make of this is that it appears akin to van Fraassen's invocation of 'empirically superfluous' factors in order to preserve PII in this context (1991; for criticism see French and Krause op. cit.). However, van Fraassen's view is developed in the context of a non-standard understanding of QM, namely his version of the modal interpretation. And of course, if one were to adopt such a non-standard interpretation, the conclusions regarding PII, non-individuality, etc. would be very different.

Morganti himself goes on to advocate a form of Lowe's 'hybrid' view of object individuality, according to which there are circumstances under which quantum particles may be said to be determinately identified and others under which they may not (Morganti op. cit., p. 93). Now, before we even get to consider Lowe's account, it is clear that the 'facts' alluded to as support here—that, for example, particles may be grouped into different kinds and that so-called paraparticles which obey non-standard statistics, may under certain circumstances and in a certain peculiar way not violate PII, unlike their 'standard' counterparts—have no bearing upon it. Lowe's view is that particles always have determinate self-identity, even if under certain circumstances talk of their numerical identity or diversity is meaningless (Lowe 1998). Obviously such self-identity cannot be conferred by membership of a kind; equally obviously, Lowe meant his account to apply to 'ordinary' bosons and fermions and not just paraparticles (and even then, it is unclear whether the above sorts of consideration could underpin the kind of self-identity Lowe is thinking of). The possibility of indeterminate identity statements is not in the least 'balanced' by such considerations (ibid. p. 94).

Furthermore, Lowe's view of quantum particles as having 'quasi-individuality' is based on a semi-classical interpretation of the theory, according to which talk of their identity/diversity is meaningful when the particle is not in an entangled state, becomes meaningless when in such a state and becomes meaningful again when it emerges from such a state. However, such a view is obviously problematic and it comes as no surprise that Lowe himself subsequently abandoned it.

Now, the point here is that there are alternative ways of understanding the individuality of quantum particles. Morganti seems to think that the justification for OSR involves ruling these out. Thus he suggests that French and Ladyman reject haecceity for being 'philosophically old-fashioned' and unclear whose use might appear ad hoc (ibid., p. 94). But, leaving aside the deficiencies in some of these positions, they simply reinforce the underdetermination on which OSR is (partly) based.

One of these alternatives is subsequently explored in the context of Loux's account of 'individuating constituents' (Loux 1978), which Morganti takes to undermine OSR

because it reintroduces individual entities into the quantum realm. However, again, this is based on the assumption that OSR is grounded in the rejection of individuality, so that if a metaphysics of individuality could be re-introduced, the motivation for OSR would be lost. But, again, the motivation for OSR is to avoid the metaphysically crippling underdetermination between the particle-as-individuals and particles-as-non-individuals packages. All that reintroducing a metaphysics of individuality does is to provide another exemplification of the former horn of the underdetermination, and since it says nothing about the non-individuals alternative, the underdetermination itself remains. Indeed, someone might well ask 'what is this individuating constituent which 'guarantees the numerical diversity of indiscernible objects', even under particle permutations?' The mysterious nature of bare substrata and haecceities disappears, only to be replaced by another metaphysical mystery. Thus, when Morganti insists that '[a] substance-theory like Loux's is undeniably and patently in agreement with what physics itself tells us about the alleged ultimate constituents of reality …' (ibid., p. 96), some care must be taken. Given that, unlike PII, it accounts for individuality in terms of something over and above or, *transcending*, the properties of the particles, such a theory could hardly be in *disagreement* with empirical physics (as long as we say something appropriate about particle permutations of course). But then nothing has been said to rule out the non-individuality package either and so—and this is the important point—the underdetermination can still be appealed to by the anti-realist and the motivation for OSR remains.

Similar confusions persist in the criticisms of the structuralist view of quantum field theory (op. cit., pp. 96–98; see French and Ladyman 2003a). Here there is a further underdetermination between fields as substances and fields understood in terms of properties of space–time points (see French and Krause 2006, again). The structuralist account is again precisely put forward to overcome this underdetermination. Now, it has been claimed that such a structural description of a field does not correspond to the appropriate structural reduction of it as a concrete entity to a net of causal relations, as something must be left out of such a reduction. However, it is not at all clear what it is that has been left out. Cao (2003), for example, has criticised OSR for being a form of structural Platonism of some kind, which suggests that what has been left out is the concrete 'physicality' of the field in some sense. However, this characterisation has been rejected (French and Ladyman 2003b; French 2006) and ontic structuralists can certainly acknowledge that the field-as-structure is not merely mathematical—it possesses causal properties for one thing! This last point of course is crucial for appreciating the differences between OSR and mathematical structuralism.

5 Structural realism and mathematical structuralism

The apparent implication that quantum objects must be regarded as non-individuals in some sense has led to repeated comparisons with mathematical objects. Cassirer, for example, in describing electrons as "points of intersection" of certain relations' drew an explicit comparison with geometrical objects; a comparison that goes back to Poincaré and the influence of the *Erlangen* programme. Of course, this comparison was effected, in large part, by the rejection of physical substance, a move that formed

such a fundamental component of early twentieth century structuralism. And so it should not come as much of a surprise to find that with substance out of the picture, as it were, and an emphasis on the structural aspects of the relevant theories, commentators should compare physical objects with mathematical ones. This comparison has been used to both support and attack OSR. Floridi deploys it as an example of what he calls the 'portability' of an ontology (op. cit. pp. 22–24): this is a term imported from computer science where it refers to the ease with which some software can be 'ported' to a new platform or operating system. In the present context it captures the sense in which a given ontology—here, one of structures—may be applicable to more than one domain—here quantum physics and mathematics. The greater portability of OSR over object-oriented realism, say, can then be taken as an advantage of the former.

On the other hand, the comparison can also be used as a platform for launching criticisms against OSR (Busch 2003; Psillos 2006; for a detailed response see French and Ladyman forthcoming). The basis of the comparison is apparently straightforward:

> Mathematical structuralism: a number is a place in the number structure and the number structure exists independently of any exemplifying concrete system.
>
> Ontic structural realism: an electron is a node in the electron structure and the electron structure exists independently of any exemplifying concrete system.

Nevertheless, although OSR shares with mathematical structuralism the core 'intuitive thesis' that objects have no more to them than can be expressed in terms of the basic relations of the structure (Reck and Price 2000; Linnebo calls it the 'Scarce Properties Intuition'; thus these putative objects have no identity or distinguishing features beyond what is conferred by the structure), it differs in key respects, notably with regard to the roles of abstraction and causality. The latter is obvious but curiously overlooked: the quantum structure that we are concerned with does not exist independently of any exemplifying concrete system, it *is* the concrete system and as such it can be considered to be 'causally empowered' (for details see French 2006; French and Ladyman forthcoming). Rather than rehearse these differences again, I want to focus on a further 'compare and contrast' exercise with regard to the relevant metaphysical dependence that is taken to hold between the putative objects and the structures.

6 The dependence intuition

This is one of the more contentious sets of issues, as critics insist there is a lack of clarity regarding the relationship between objects and structures, and it is also one that effects a separation between the eliminativist and non-eliminativist forms of ontic structural realism. Let us enter the thicket by considering the following claim regarding the relationship between objects and structure: putative physical objects, such as elementary particles of various kinds, are dependent, in some sense, upon the relevant structures (understood as causal in the terms sketched above). How, then, is this notion of dependence to be understood?

We might begin with the following intuition that appears to hold for 'ordinary', everyday objects:

object a could have existed even if object b did not

and if this is the case, we can say that a is ontologically independent of b. Setting aside any modal complications here, this intuition is apparently supported by our being able to imagine possible worlds containing (at least) certain objects and nothing else: a chair, for example, and nothing else or an electron, and nothing else. Of course, such imaginings have to be taken with two pinches of salt (and here we might recall Leibniz's famous admonition in his debate with Clarke about distinguishing 'genuine' possibilities from 'mere chimera'): first of all, there is one item that we typically forget in such imaginings, namely the role of the background space–time. This can obviously make a crucial difference when examining the impact of such imaginings on certain metaphysical principles such as PII. Secondly, and as it turns out, relatedly, we typically forget that certain properties of these objects in our imaginings may be crucially dependent on other entities. Leaving aside the issue of how intrinsic properties are to be understood from a structuralist perspective, take the example of an electron and its mass: it may be argued that within the framework of General Relativity, mass is dependent on the existence of the spatio-temporal background and hence imagining a single electron and strictly nothing else would not be a genuine (physical) possibility.

The point then is that care must be taken when we move from intuitions based on the everyday to the world presented by modern physics. Nevertheless, this example gives us a useful basis for approaching the issue of characterizing dependence: if we understand an 'object' in terms of a substance that 'has' in some sense, properties, then we can see that the dependence relation will decompose into that applicable to substances, and that appropriate for properties. One can envisage, in the case of the electron for example, that the underlying substance may be regarded as ontologically independent, but the relevant properties, such as mass, spin, etc., are dependent, either on the 'background' space–time in the case of mass, or on other instantiations of these properties, in the case of spin. And of course, if one were to reject substance and adopt some form of bundle theory of objects, then objects, regarded as such bundles, would 'automatically' lose any ontological independence on the latter view of property dependence.

The question of characterizing ontological dependence is one that has attracted considerable attention from metaphysicians in recent years but without engaging with the intricacies of the debate, a useful account can be found in Lowe (2005), who considers the issue in terms of the above understanding of objects in terms of substances and properties. Again skipping over much of the detail, he begins with the following quite general and apparently plausible characterisation:

(EDR) x depends$_{\mathrm{R}}$ for its existence upon y $=_{\mathrm{df}}$ Necessarily, x exists only if y exists (Lowe 2005)

Now, as he notes, this allows for symmetric dependency relations between one kind of object and another. Consider, for example, Socrates and his life: it can be said that Socrates' life depends on the existence of Socrates and vice versa, yet Socrates and his life are not identical since they each possess properties (weighing so many pounds, being so many years long) that the other does not. As we shall see, such a symmetric relation may be applicable in the case of objects and structures, but Lowe's primary

concern is to obtain a characterisation appropriate for the notion of substance and here some form of asymmetric relationship seems more in order. Thus he suggests,

> (ID) x depends for its existence on y = (necessarily) the identity of x is dependent on the identity of y

Lowe then goes on to suggest that something's identity is constituted by that thing's essence, so that identity dependence is then a species of essential dependence, another species of which is 'essential existential dependence':

> (EDE) x depends$_{\mathrm{E}}$ for its existence upon y $=_{\mathrm{df}}$ It is part of the essence of x that x exists only if y exists.

Although Lowe argues that it is only (ID) that is suitable for capturing the manner in which substances are ontologically *in*dependent entities, we shall find it helpful to keep EDR and EDE in mind when we consider objects and structures.

Let us approach such considerations via mathematical structuralism, again. And again, if we consider mathematical objects at least initially in the way we thought of everyday objects, then we might swiftly conclude that such objects cannot be ontologically independent in the way that 'everyday' objects may be; indeed, it is difficult to get our considerations off the ground because we cannot imagine a possible world with, say, just the number '2' in it and nothing else. It is the plausible belief that the number '2' cannot exist without '1' and '3', etc., that helps motivate the structuralist view that numbers are in some way dependent on the relevant structure.

Linnebo's recent discussion of dependence in this context offers a useful entry point into the debate and provides a number of points of comparison with structural realism (Linnebo 2008). Thus he begins by noting that mathematical structuralism involves two central claims: 'Incompleteness' and 'Dependence', but then argues that once we pay attention to the relevant properties involved, the first appears to collapse into the second. Thus, Incompleteness is based on statements of the 'Scarce Properties Intuition' such as the following:

> [There] is no more to the individual numbers "in themselves" than the relations they bear to each other. (Shapiro 1997, p. 73)

Such claims support two forms of 'incompleteness': according to the first, mathematical objects are incomplete in the sense that they possess no non-structural properties and according to the second, they possess no intrinsic properties. As Linnebo notes, the first runs into obvious counter-examples such as 'the number 8 is my favourite number', or, crucially 'mathematical structure is abstract', where being my favourite and being abstract are not themselves structural properties. An obvious way round this concern is to make a distinction between 'fundamental' and 'non-fundamental' properties, and restrict 'incompleteness' to the former. Thus one might re-express the Scarce Properties Intuition as stating that the only fundamental properties of natural numbers are arithmetical and hence structural. A similar objection has been raised against OSR, to the effect that physical objects such as chairs, people, etc. possess numerous kinds of non-structural properties (Psillos 2006); the response is essentially reductionist: all such properties can be reduced to those that fall within the remit of

modern physics (which are then regarded as 'fundamental') and hence can be regarded as ultimately structural (French 2006; French and Ladyman forthcoming; of course, if one thinks there is an ultimately fundamental level, one must then given an account of how the properties at this level can be considered to be structural but articulating that is currently a part of the OSR project).

However, as Linnebo points out, when it comes to the natural numbers, say, these 'primary' properties are essentially those that matter for identity, and hence such attempts to save the incompleteness claim by appropriately restricting the properties threaten to transform the claim into something approaching dependence.

As for the second form of incompleteness, this too is problematic. If we understand 'intrinsic' as 'shared by every duplicate of the object concerned', then as Linnebo notes, we run into obvious problems in conceiving of duplicates of mathematical objects. If, however, we understand it along the lines indicated above, in terms of those properties an object would still possess if it were the only object in the world, then for the relevant mathematical properties at least, a number cannot be conceived of as having any such properties beyond those conferred by the relevant structure, so again this form of 'incompleteness' collapses into dependence. Note that for mathematical objects, there is an implicit assumption that a property, whether intrinsic or not, can only be ascribed to such an object if the object belongs to the relevant structure. This will obviously not be the case for physical objects, and the issue of how one treats intrinsic properties from a structuralist perspective is a significant one. Furthermore, when it comes to the first form of 'incompleteness', although there are obvious grounds for restricting the relevant properties under consideration for physical objects, it is by no means clear that this will leave us with only those that matter for identity. What this suggests, of course, is that a version of the incompleteness claim for physical objects will not straightforwardly collapse into dependence in the way Linnebo notes for numbers. Further justification will be required to support the claim that physical objects possess no non-structural properties.

Moving on to the 'dependence' claim, this is encapsulated in such statements as,

> The structure is prior to the mathematical objects it contains, just as any organization is prior to the offices that constitute it. (Shapiro 1997, p. 78)

Again, this resonates strongly with the ontic structural realist. However, it is in explicating the notion of 'priority' here, and the associated notion of dependence, that quite subtle issues arise. Shapiro, famously, articulates this latter notion in essentialist terms:

> … the essence of a natural number is its relations to other natural numbers (ibid., p. 72)

As both Linnebo and Lowe point out, the essence of an object is closely bound up with its identity, and indeed we can straightforwardly apply Lowe's EDE here:

> (EDE) x depends$_{\mathrm{E}}$ for its existence upon y $=_{\mathrm{df}}$ It is part of the essence of x that x exists only if y exists.

where 'x' will be some number and 'y' is the relevant structure. So, a mathematical object, such as the number '2', has its identity only by virtue of occupying a certain

position in the relevant structure. We shall consider whether this approach can be extended to physical objects shortly.

Usefully, Linnebo teases out two aspects of dependence in this context:

(ODO) Each object in D depends on every other object in D.

where D is some mathematical domain; and

(ODS) Each mathematical object depends on the structure to which it belongs.

As he says, taken together, these mean that if one object from a mathematical structure exists, then so do all the others. Again it is worth considering whether something similar could hold for physical objects. In the mathematical case, the claim crucially involves the intermediate claim that a structure cannot exist without all of its 'positions' existing as well, since a structure 'involves', in some sense, all of its positions. In the mathematical case that seems obvious—although, again, if we try to tease out what lies behind its obvious nature, we might suspect that, in the case of numbers for example, it has something to do with the relevant relations, in this case the successor relation—but clearly when it comes to physical objects, some obvious differences might be discerned. Thus, for example, when it comes to 'succession', the very nature of this relation presupposes something that succeeds something else. However, it is not so clear that 'charge', for example, presupposes something—in the sense of an object—that is charged. It would appear—on first analysis at least—that I can conceive of a world containing a single charged body. Of course, that analysis may be questioned and the structuralist may then claim that charge *is* ultimately relational, but this needs some argument, unlike the case of succession where it follows from the very concept of the latter.[2]

Linnebo takes ODO to imply that mathematical objects are subject to a form of what he calls 'upward dependence', in that they depend on the structures to which they belong. He contrasts this with the 'downward dependence' that he takes to apply to physical objects, since structures composed of the latter depend on their constituents. Of course, this is not the case for the most fundamental physical objects we are concerned with here, and in this case we would expect 'upward dependence' to apply as well.

However, a number of objections have been raised to mathematical structuralism in this context. The first is that ODO may lead to unacceptable circularity in the relations of priority and dependence, unless some set of mathematical objects is identified as privileged in some way, and it is not clear how to do that without undermining the structuralist thesis. We recall Lowe's example of Socrates and his life above and the symmetric dependency that EDR can accommodate. There appear to be two concerns here: the first is that if mathematical objects are allowed to depend on other objects in the way ODO suggests, then 'circular' or 'symmetric' dependence may obtain; the second is, as Linnebo notes, the stronger concern that in the absence of a privileged set the dependence relation may not be well-founded, so that we have objects dependent

[2] Thus Cassirer, for example, argued that charge should be understood as a self-subsistent and permanent relation but also that the constancy of such a relation is not sufficient to infer the existence of a constant carrier, or relata.

on other objects, themselves dependent on still other objects and so on ad infinitum. It is not clear to me quite what is unacceptable in either of these possibilities. In the first case, although we lose priority, we still retain a form of dependence, even if it is of a mutual or symmetric kind and again, as we shall see, this is precisely what has been proposed in the physical context. In the second, objections to non-well foundedness tend to be based on little more than metaphysical repugnance and certainly formal frameworks exist for accommodating this notion.[3]

Nevertheless, even if ODO is dropped, the structuralist still has ODS, which offers asymmetric dependence and appears to give her all she needs. However, this too is subject to criticism, which can be seen as aspects of a familiar complaint in the structuralist context. The first has been expressed in the context of the Peano–Dedekind structure and the associated ordering induced by the successor function:

> But if the relata are not already given but depend for their very identity upon a given ordering, what content is there to talk of 'the ordering'? (Hellman 2001, pp. 193–194)

So the idea here is that a conceptual circularity arises: the identity of the relata (e.g. numbers) is taken to be grounded in the relevant relation (e.g. the relevant ordering) but the identity of the latter depends on the identities of the relata having already been themselves grounded. This is a concern that goes back at least to Russell, who objected to relations being included in the grounds of an object's identity, and which has been raised repeatedly as a criticism of structural realism. Linnebo is dismissive in the mathematical case, insisting that the underlying presupposition—to the effect that the identity of the relevant relation must be grounded in that of the relevant relata, whose identities are themselves independently grounded—has not been adequately defended in a non-question begging manner. It is not clear that it can likewise be dismissed in the case of physical objects.

The second criticism is related and insists that the numerical diversity of the relata (again numbers in this case) must be presupposed before any relation can be said to obtain between them (MacBride 2006, p. 67). Here again, a form of downward dependence is assumed according to which the obtaining of any relation presupposes the prior grounding of the identities of the relevant relata and again, this requires non-question begging defence. One such defence might be provided via some argument to the effect that there is a form of conceptual dependence between relations and relata, such that the above presuppositions can be defended, but this has yet to be articulated in anything more than simple intuitive terms.

Linnebo's own view offers a 'compromise' according to which some mathematical objects are dependent on structures, while others are not. In particular he argues that *sets* are not subject to the upward dependence expressed by ODO and ODS, since the relation between a set and its elements is asymmetric (at least according to the standard iterative conception) in that the set depends on its elements but not vice versa. So, for example, the identity of a singleton depends on its element but, or so it is claimed, the identity of the element can be given independently of any consideration of the set

[3] Here at Leeds we have been looking at ways in which such frameworks might be put to the service of certain forms of structuralism.

theoretic hierarchy. I shall not pursue this account any further here except to note that this asymmetric dependence between sets and their elements 'bleeds' into the structural realist context when we suggest the deployment of set theory as the appropriate representational device via the Semantic Approach; and further that when the element concerned is a physical object, it is not the case that there is any non-structural way of grounding its identity and hence the space for such a compromise view vanishes in the physical domain.

Let us now move on to that domain, and consider how the above issues play out.

7 Priority and dependence in OSR

I shall take as a core feature of OSR the claim that the putative 'objects' are dependent in some manner upon the relevant relations (and hence these putative objects can be reconceptualised as mere nodes in the relevant structure). We can express this in terms of a form of ODS above:

> (ODS_{phys}) Each fundamental physical object depends on the structure to which it belongs.

There are then three obvious options in terms of which the notion of dependence can be articulated.

> Option 1: the identity of the putative objects/nodes is (symmetrically) dependent on that of the relations of the structure and vice versa.

With this option, neither 'objects' nor the relations are held to have ontological priority; both are inter-dependent on the other. In this case a form of Lowe's EDR would appear to be appropriate:

> (EDR) x $depends_R$ for its existence upon y $=_{df}$ Necessarily, x exists only if y exists

An example of such inter-dependence can be found in Eddington's structuralist writings. Thus, in 1928 he wrote,

> The relations unite the relata; the relata are the meeting points of the relations. The one is unthinkable apart from the other. I do not think that a more general starting-point of structure could be conceived. (1928, pp. 230–231)

More recently, a similar view has been espoused by Esfeld and Lam (2008) who call it 'Moderate Structural Realism' (MSR). At the core of this position is the insistence that the putative objects, as fundamental relata, are conceptually necessary and hence cannot be reconceptualised away, but nevertheless all there is to these objects are the relations that they bear. In other words, their intrinsic properties and identity are given entirely by these relations and thus by the structure. Now, MSR must assume numerical diversity as a primitive in order to account for certain features of physics and one might wonder if this is tantamount to re-introducing some form of primitive identity. There is also the worry that if, according to MSR, all there is to objects are the relations

in which they stand, then there is nothing to objects at all, and the position collapses into the eliminativist form of OSR to be discussed below. Let me elaborate: we recall the above criticisms of ODS and the underlying presupposition that the obtaining of a relation requires the prior grounding of the identity of the relata. If this is how the claim of the conceptual necessity of such relata is cashed out, then not only must this view face Linnebo's concern that the presupposition itself needs a non-question begging defence but a tension also arises with the further claim that the very identity of the relata is given via the relations. Indeed, it seems difficult to maintain a symmetric inter-relationship in this case but once we acknowledge the relevant asymmetry, we move to the second option:

> Option 2: the identity of the putative objects/nodes is (asymmetrically) dependent on that of the relations of the structure.

Here a form of Lowe's ID appears to capture the relevant sense of dependence:

> (ID_{phys}) fundamental physical objects depend for their existence on the relations of the structure = (necessarily) the identity of such objects is dependent on the identity of these relations

Thus, for example, it has been argued that the identity of space–time points is appropriately given by the relations that hold between them, yielding a form of 'contextual' (as opposed to 'intrinsic') identity (Stachel 2002; Ladyman 2007a, b). This in turn can be understood as sufficient to support a 'thin' notion of object. Thus Saunders has deployed Quine's notion of 'weak discernibility', which holds just in case there is a two-place irreflexive relation satisfied by the putative objects, to argue that certain kinds of quantum particles—namely fermions—are weakly discernible since their joint states are always antisymmetrised (Muller and Saunders have recently extended this argument, 2008). If this form of discernibility is used to underpin—and hence restore—a version of the Principle of Identity of Indiscernibles, then such particles can be regarded as acquiring a form of relational or contextual identity and hence, again, as 'thin' objects.

Note that such a claim is still incompatible with the 'thick' conception of individuals in opposition to which OSR was originally proposed. Saunders's position in particular is thoroughly structuralist insofar as objects are not assumed to be individuated independently of the nexus of relations in which they stand; rather their identities are dependent on those of the relevant relations in accordance with ID above. Nevertheless, the concern remains that such a 'thin' notion of object may amount to no notion at all. As in the case of MSR, if one must conceive of quantum particles and space–time points as bare relation bearers with nothing to them, as it were, over and above the relevant relations, one starts to lose one's grip on what the 'thin' notion of object is, and how these views are really different from the supposedly more 'radical', eliminativist form of OSR given below. In particular these alternative forms posit objects as relata on conceptual grounds only, to serve as bare relation bearers, but all their properties are cashed out in relational terms, so the question arises, what precisely is it that is doing the bearing? One can posit whatever you like on conceptual grounds but for it to have any worth in this context, it needs a physical correlate and there is no physical

correlate to this aspect of the putative objects. In other words, 'thin' objects appear to be merely conceptual objects only.

If, on the other hand, one buys into the metaphysical underdetermination that supports the original form of OSR, then Saunders' new defence of PII can be understood as supporting the particles-as-individuals package and thus further reinforcing the underdetermination and consequently, the dilemma for the realist. The way out, of course, is to reject the underlying object-oriented presupposition to begin with, and adopt a position according to which there are no objects at all, whether thick or thin.

> Option 3: the very constitution (or essence) of the putative objects is dependent on the relations of the structure.

Essentialism has not typically been viewed all that favourably in the context of modern physics but if we take it in the comparatively innocuous sense in which it is understood in mathematical structuralism, then we can introduce Lowe's EDE here:

> (EDE) x depends$_{\mathrm{E}}$ for its existence upon $y =_{\mathrm{df}}$ It is part of the essence of x that x exists only if y exists.

Our putative objects only exist, in a sense, if the relevant structure exists and the dependence is such that there is nothing to them—intrinsic properties, identity, constitution, whatever—that is not cashed out, metaphysically speaking, in terms of this structure. What exists then are not objects in any ontological sense, so by extending the dependence so completely, this account amounts to claiming a form of mere conceptual dependence between objects and structure.[4] This yields what has sometimes been called the more 'radical', but which I would prefer to call 'strong', eliminativist form of OSR according to which there are no objects, thick or thin, and no identity, contextual or otherwise.

8 Extending OSR

As I indicated at the beginning, OSR is motivated by, first, cases of ontological change in the history of science; and secondly, the implications of modern physics for the individuality and identity of putative objects. The question has long been asked whether this view can be extended beyond the physical sciences. And the apparent lack of 'portability' of OSR (to use Floridi's term) beyond the physical, and in particular to the biological, has been held against it. Now of course, structuralist approaches—in the form of the Semantic Approach to theories, for example—have been adopted towards biological theories. The issue is rather whether a structuralist ontology can be motivated for biological *entities*. Interestingly, certain issues to do with identity and individuality also arise within biology (see French forthcoming c). At least three such issues may offer opportunities for structuralist analysis in this regard: gene identity; gene pluralism versus the hierarchical approach; metagenomics and the general problem of biological individuality.

[4] Thanks to one of the referees for emphasising this.

The first centres around the claim that the notion of 'gene' has undergone such a radical transformation that there are simply no straightforward identity conditions that it could be said to satisfy. One response is to argue that it can be functionally identified via its biological roles and relationships and can be regarded as a 'thin' object in the above sense. Alternatively, one might conclude that talk of identity conditions is inappropriate here and that one should drop the object-oriented approach and regard genes as nothing more than nodes in the appropriate structures. Such a stance may be supported by consideration of the second issue, where the units and levels of selection debate appears to offer a form of underdetermination in terms of empirically equivalent but interpretationally distinct models (see French forthcoming c). If we take the relevant distinction to be fundamentally metaphysical, we can view this debate as opening the door to a structural understanding of the unit of selection, allowing us to move away from what appears to the outsider as little more than metaphysical quibbling over the *entities* underlying selection.

The final issue arises from what has been identified as the fundamental presupposition of biological individuality which underpins many of these debates (Dupré and O'Malley 2007). Instead, we are urged to regard individual organisms as nothing more than abstractions from or nexuses in the underlying biological structures, a suggestion that invites an obvious structuralist response.

Beyond the biological, Ross has also developed a form of OSR appropriate for economics (Ross 2008). The key 'bridge' lies in the claim that just as OSR regards physical objects as merely heuristic, 'book-keeping' devices, so economics from a structural point of view should regard economic agents (i.e. people) as they figure in economic theory and social science. Thus what is represented by economic models should not be regarded as individuals, their properties or even proxies thereof, but rather 'aggregate properties' of idealized markets and agents. At best there is a 'thin' notion of agent that identifies such with 'the gravitational centres of consistent preference fields'. And the central claim, common to both epistemic and ontic structural realism of course is that insofar as one can say that progress has been made in economics this has consisted in 'deepening our knowledge of abstract structures'. What is cumulative through such progress are the relevant patterns, in particular of optimization and maximization.

This focus on patterns—in terms of which objects can be reconceived—also features in Wallace's incorporation of structural realism into the Everett interpretation of quantum mechanics, with the 'macro-', everyday world understood in terms of the structures which emerge from quantum theory (Wallace 2003). And likewise Floridi draws on Dennett's view that macro-objects should be regarded as patterns in the development of his 'Informational Structural Realism' (op. cit.). Here in particular he gives the example of 'Object Oriented Programming' in which discrete informational objects are constituted by data structures and computational procedures and systems are formed from collections of such objects. This concept of an 'informational object' can then be usefully applied to the relata of OSR and ISR can be seen as a flexible methodology for making precise the Dennettian view. The scalability of a structural ontology is then effected by computational approaches, such as the methodology of OOR, with portability underpinned by group theory. From the perspective of ISR, 'the ultimate nature of reality is informational', providing a 'full-blooded ontology of objects as structural entities'. Cashing out such an ontology whilst avoiding the

criticism that this amounts to the hypostatization of an abstract noun, in this case, 'information' (Timpson 2008), is yet another challenge that structural realism must face. Nevertheless, we have the tools to meet such challenges and this approach has the flexibility and, as Floridi notes, the portability to apply across a range of domains in science.

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