Do objects depend on structure?

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Abstract

Ontic Structural Realists hold that structure is all there is, or at least all there is fundamentally. This thesis has proved to be puzzling: what exactly does it say about the relationship between objects and structures? In this paper I look at different ways of articulating ontic structural realism in terms of the relation between structures and objects. I show that objects cannot be reduced to structures, and argue that ontological dependence cannot be used to establish strong forms of structural realism. At the end I show how a weaker, but controversial, form of structural realism can be articulated on the basis of ontological dependence.

1 Introduction

Ontic structural realism (OSR) has been offered first as a position in philosophy of science, and more recently as a position in metaphysics. While the view has received a lot of critical attention, some of the central claims of OSR remain less than fully articulated. In slogan form OSR is the radical sounding thesis that "Structure is all there is" (Ladyman and Ross [2007]). The main idea behind OSR is that the predominant 'ontology of objects' should be replaced by an 'ontology of structure'. According to OSR there really are no objects (and perhaps also no intrinsic properties), structure is the only remaining ingredient to the ontology. This claim proves to be puzzling. If structure was supposed to be understood as something like a web of relations, then how could there be relations without relata (Psillos [2001])?[1]

In light of this problem, ontic structural realists have split into different fractions: those who accept 'thin' objects as part of their ontology, and those who insist on structure as the sole ingredient to ontology.[2] The 'no-object' branch of OSR of course still has to provide an answer to the question how we are to think of relations without relata, whereas the 'thin-object' branch will have to specify just what makes objects thin enough to be acceptable to the structural realist.[3]

These respective problems draw attention to the relation between objects and structures as conceived of by the structural realists. What exactly does that relation amount to? Do objects somehow depend on structure, and if so, will that be enough for structural realism?

The purpose of this paper is to address these questions and to see which forms of ontic structural realism are supported by different relations between objects and structures. I begin to clarify what ontic structural realists are looking for by contrasting OSR with a related, but different dependence claim, the claim that objects depend on other objects. Ontic structural realism has to be the claim that objects depend on structure, not that objects depend on other objects.

A popular strategy for structuralism in general is to attempt to reduce objects to positions or roles within a structure, and then to argue that since objects are just positions in a structure, and a structure is prior to the positions in it, structure is prior to objects. I argue that this strategy does not work for OSR, since the objects of interest to the ontic structural realist, the objects of physics, are not plausibly reducible to positions within a structure. The failure of this strategy motivates the attempt to find a more direct way of using ontological dependence relations to articulate ontic structural realism. Perhaps objects can be said to depend on structures even if they aren't reducible to positions or nodes in the structure?

I argue that such a dependence can be defended, but only certain forms of structural realism can be articulated using ontological dependence. I furthermore suggest that the resulting structural realism might not be sufficiently structuralist - objects continue to be part of the ontology, and dependence even leaves room for non-structural properties. I do argue, however, that a structuralist dependence claim might be defensible with respect to quantum particles.

2 OSR - What is the debate?

Structural realists themselves often see their view as replacing what they perceive to be an outdated 'object oriented metaphysics' (French [2006]). This is not sufficiently precise to identify a particular metaphysical position, but it is clear that structural realists reject something like the following claim: objects are metaphysically primary, structures are secondary. An immediate question, which we will encounter again at various points throughout, is whether structural realists merely reject the priority claim of objects, or whether they intend to reverse it. Is it enough for structural realism to reject the idea that objects enjoy some kind of metaphysical primacy, or do they have to claim in addition that structure is metaphysically prior, and objects secondary? The former is of course much weaker, and can be established by showing that structures are in an important sense not dependent on objects, or that objects and structure are interdependent. The latter, on the other hand, requires an asymmetrical dependence of objects on structures, or perhaps an elimination of objects from ontology altogether.

What are objects and structures in this context? The objects of interest to ontic structural realists are the objects of fundamental physics, in particular the fundamental particles of quantum physics.[4] Quantum particles are notoriously difficult, metaphysically speaking, and there are certainly problems when we try to think of them in the same way we think of ordinary objects. The task for the structural realist, however, is not to convince us that quantum particles are weird, but that we can think of them as purely structural, or that we can replace them by

structure.

Unfortunately, structural realists leave it highly underdetermined just what exactly they mean by 'structure'. Candidates for structure include relations, nomological structure, and modal structure (French [2010]), (Ladyman and Ross [2007]). Entities contrasted with structure include not just objects, but also intrinsic properties. This of course makes it more difficult to narrow down just what exactly the dependence relation required by structural realism might be. Crucially, ontic structural realists insist that the structures they are interested in are concrete, not abstract (French and Ladyman [2003]).

It will be helpful to think of a structure as a web of relations and positions or places, and of an object[5] as anything that can potentially occupy a place or position in such a web of relations. This is still less than precise, but it seems to capture, at least in broad terms, what structural realism is after.[6] The question of the relation between structures and objects at the most general level is then best understood as: what is the relation between a structure, the positions in it, and the occupants of such positions?

Structural realists are committed to rejecting the claim that occupants are in some sense prior to the roles they might occupy. Perhaps they are also committed to the stronger claim that roles, or the structure they are a part of, are in some sense prior to their occupants. These two claims have to be clearly distinguished from a different debate in the vicinity, the debate over whether objects are independent of one another.

From structuralism in the philosophy of mathematics, two dependence claims

can be distinguished:

> (ODO) Each object in D [where D is the domain of some mathematical structure] depends on every other object in D.
>
> (ODS) Each mathematical object depends on the structure to which it belongs. (Linnebo [2008], p.67-8)

(ODO) asserts a dependence relation between objects, in this case that each object depends on all other objects in a specified domain. (ODS), by contrast, claims a dependence of each object on a particular structure. Both (ODO) and (ODS) can be found in attempts to articulate structuralism in the philosophy of mathematics (compare, for example, Shapiro [1997], p.72 and 81), but it is important to distinguish the two, especially when we turn to structural realism in other areas.

(ODO) states a certain kind of holism: individual mathematical objects depend on all the other objects in their domain. This is in contrast to claims about ordinary objects, which we take to be largely independent of other ordinary objects: this desk could have existed, without this lamp on it existing. (ODO) suggests that the natural number six is *not* independent of the natural number seven. To characterize the dependence relation more precisely, and to defend (ODO) for particular cases of mathematical objects, is an important task for structuralism in the philosophy of mathematics, but not one we need to concern ourselves with here.

For unless (ODO) is supplemented with additional assumptions about the objects in question, (ODO) by itself isn't a form of structuralism. (ODO) does not claim any priority of structure over objects, it asserts an interdependence of certain kinds of *objects*. That indeed undermines the independence of individual

objects, but through asserting the dependence of one object on others, not by claiming a dependence of objects on structure.

In the philosophy of mathematics (ODO) looks like structuralism because a domain, D, amongst whose objects the dependence claim is said to hold, will typically be characterized in terms of particular structures, for example the complex field. But it is not at all clear what corresponding domains and structures would look like in the case of physical objects. Not just any collection of objects can be a structure in the relevant sense, even if the objects stand in relations to one another. The case from mathematics suggests that it should be possible, at the very least, to characterize the structure independent of any particular objects that occupy positions in it. Moreover, it should be possible to distinguish different structures from one another in purely structural terms, that is, again without recourse to different objects occupying positions in them. Finally, since ontic structural realists are naturalists, and indeed physicalists of a certain kind, the structures in question should be such that they can be discovered by physics. With these clarifications in place, let's look at relation between objects and structures according to structural realism.

3 Reduction and Eliminativism

To characterize the relationship between an occupant and the role it occupies, a plausible candidate from the perspective of ontic structural realism would seem to be reduction. Occupants *reduce* to the role they play within a structure, or, to use an analogy preferred by some structural realists, objects are like nodes in a graph

(Ladyman [2007]).[7]

That objects are just positions in a structure can be understood as the claim that there really are no such things as objects, if objects were meant to be independent, ontologically primary entities. For positions are arguably not independent entities. Positions are characterized by the particular structure in which they occur – their identity is defined in terms of the other positions in the structure, and the relations that hold among them. That suggests a certain kind of dependence of positions on the structure to which they belong. If objects are reduced to positions, and positions depend on the structure they belong to, (re-conceptualized) objects depend on particular structures.

Reduction of objects to positions, then, would suit strong forms of structural realism. If we take the re-conceptualization move to replace objects with something that really, strictly speaking aren't objects, we end up with no-object OSR. If, on the other hand, we understand it as revealing the 'true nature' of objects to be structural we get thin-object OSR. What are the prospects for this strategy?

Reduction is typically taken to require supervenience. For A to reduce to B, A has to supervene on B. For A to supervene on B, there cannot be a change in A without a change in B. Applied to the case of occupants and the roles they occupy, for occupants to supervene on roles there cannot be a change in who (or what) occupies a particular role without a change to the role itself.[8] If the objects of fundamental physics are supposed to reduce to the role they occupy, ontic structural realists will have to make a case that these objects are such that they can be said to supervene on the roles they play.

To get a feel for the kind of concern structural realists will have to address, let's look at a toy example. Intuitively we want to distinguish Barack Obama from the position of president of the United States, even though he currently holds this position. Intuitively, again, Barack Obama can occupy a number of other positions as well, e.g. that of a father and husband as well as that of the president. And of course different people can and have occupied the position of being the president. So it is not true in general that occupants are nothing over and above the positions they occupy.

What, if instead of taking the relevant structure to be limited to just one particular role, that of US-President, we take 'structure' to mean the conjunction of the different roles Barack Obama occupies? That would seem like a more plausible candidate for structure if reduction to roles within a structure is the goal. One concern about this move is that structural realists would have to find a way of characterizing the relevant structure not through reference to Barack Obama. After all, we are looking for a structure we can characterize independently of a particular object, not a mere conjunction of roles one individual happens to be occupying.

Even if they find a way to do so, however, they are still a step away from reduction. While we can presumably uniquely *identify* Barack Obama through a combination of roles he plays (e.g. being both the president and husband to Michelle), we have not thereby shown that we can reduce him to those roles, or even the various roles taken together. For Barack Obama to reduce to the structure consisting of all the roles he occupies, it would have to be the case that he occupies

all these roles necessarily. Recall that supervenience carries modal force: there *cannot* be a change in A without a change in B for A to supervene on B. Whether we understand the necessity as logical, metaphysical, or nomological necessity, however, it was possible for Barack Obama to lose the 2008 presidential election, and so it was possible that he should not have occupied the role of president. So while a structural description can be used to uniquely identify Barack Obama, that is not enough to make Barack Obama supervene on that structure, and accordingly, it is not enough for a reduction claim.[9]

Of course, ontic structural realists will not be too moved by an example like this, since their thesis, first and foremost, is meant to apply to the objects of physics, not to people and the positions they occupy. The above example doesn't deal with quantum particles, so we shouldn't be too surprised if structural realism doesn't yet look very plausible. But we can see now what it takes for structural realists to make their case, if structural realism is meant to be a reductive claim: they will have to show that the objects of physics are special in that they reduce to positions in structures, unlike ordinary objects.

The claim that certain kinds of objects are special because they are just nodes or positions within a structure is familiar from structuralism in the philosophy of mathematics. Structuralism in the philosophy of mathematics comes in two varieties. *In re* structuralists hold that mathematical objects don't exist at all, whereas *ante rem* structuralists hold that they exist but are objects of a special kind in that their nature is exhausted by the role they occupy in the structure.[10] Can OSR be modeled after either *in re* or *ante rem* structuralism in the philosophy

of mathematics?

In re structuralism is not an option, because part of the *in re* structuralist's strategy is to treat mathematical statements as implicit generalizations about particular instantiations of structures, where the structures are instantiated by collections of concrete particulars. For the *in re* structuralist, if there is no concrete instantiation of the structure, there is no structure. No similar move seems available to the ontic structural realists, since they want to claim that there are concrete structures, but perhaps without concrete particulars.

The *ante rem* structuralist doesn't deny the existence of mathematical objects, he merely claims to have identified what is peculiar about them. In Shapiro's version of *ante rem* structural realism, '[e]ach mathematical object is a place in a particular structure' (Shapiro [1997], p.78). This identification of mathematical objects with places in particular structures seems close to the re-conceptualization move we've seen ontic structural realists propose: objects are just positions in structures.

The *ante rem* structuralist in the philosophy of mathematics, however, thinks of this as a feature peculiar to mathematics and its objects, not as a feature of objects in general. In particular, Shapiro distinguishes between the position within a structure and its occupant. For example, the number 2 is just the second position in the natural number structure, but it can be exemplified by different objects, that is, different objects can occupy the second position in the natural number structure. The canonical example for this are von Neumann ordinals vs Zermelo ordinals. The structuralists' point is that the natural number 2 can only be *identified*

with the position within the natural number structure, *not* with any particular occupant of that position. That is not to deny, however, that there are occupants distinct from the position they occupy. It is just that mathematical objects are positions, not occupants.[11]

Even if the case could be made for the objects of mathematics, it seems a stretch to make a similar claim about the objects of physics. Ontic structural realists don't want to claim that all there is are abstract structures. What they call structures seems closer to what Shapiro would call a system, 'a collection of objects with certain relations' (Shapiro [1997], p.73). Except that for the ontic structural realists, all that seems to remain of such a system are the relations. Objects, it seems, are to be reduced to the position they have, or role they play, within a system.

Is such a reduction claim plausible for the particles of fundamental physics? Structural realists like to appeal to familiar phenomena from quantum mechanics to support their position. Two electrons in a singlet state have opposite spin in any spin direction, but no definite spin in any direction is assigned to either one of them. What tempts structural realists to suggest that the electrons are nothing but positions in a structure seems to be that within a singlet state, electrons are not distinguishable from each other. This is then taken as an indication that electrons are not individuals (Ladyman [2007]).

Is this enough for structuralism, though? The question is not so much whether electrons are individuals, but whether they are reducible to the role they play. If a singlet state of two electrons is the relevant kind of structure in this context, then

for particles to reduce to structure, electrons must not have properties other than the ones described by the state.[12] But particles have state-independent properties in addition to state-dependent properties. True, these don't help to distinguish the two electrons from one another, but they do distinguish singlet states of electrons from singlet states of other kinds of particles. How do we make sense of the difference between muons and electrons if not through the difference in mass between muons and electrons? Mass is a state-independent property, not a state-dependent property.[13] Some properties of fundamental particles, then, do not depend on the state the particles are in. That means that the occupants of these states have properties that aren't reducible to the state. And that in turn means that the occupants themselves cannot be reduced to a particular role within a state, since the roles in the state are described only with respect to the state-dependent properties.

Different kinds of systems can be in a singlet state, and while it is true that neither particle can be said to be the spin-up or the spin-down particle, it makes a difference for physics what kind of particles are in a particular singlet state, e.g. whether they are electrons or muons. Contrast this with the structuralist claim in the philosophy of mathematics. True, switching the number six and the number seven within the natural number structure doesn't make sense, and that seems to accord with the idea that numbers are only positions in that structure, not the occupants of those positions. But more importantly, it also doesn't matter (the mathematical structuralist claims) what *kinds* of entities occupy the natural number structure, e.g. Zermelo ordinals or von Neumann ordinals. For mathematics that seems at least somewhat plausible, whereas it seems highly implausible to

claim that it doesn't matter for physics whether the particles in a singlet state are electrons or muons.

This brings out nicely what structuralism in the philosophy of mathematics has in common with ontic structuralism, and also where the two views differ. Both views claim, with a certain amount of plausibility, that the respective objects of interest are interchangeable within the structures of interest without it making a difference for mathematics and physics respectively. They differ in that structuralism in the philosophy of mathematics can make the further claim that it also doesn't matter what kinds of objects instantiate the relevant structure, if any. Ontic structural realists, by contrast, cannot make the same claim with regard to the objects of fundamental physics. But it is really this second claim that makes structuralism in the philosophy of mathematics *structuralism*, since it is the second claim that suggests that mathematics is really concerned with structures, not objects.

So OSR cannot simply take over the strategy of structuralism in the philosophy of mathematics. I should make clear, however, that this does not yet mean that ontic structural realism has been defeated. All that has been criticized so far is the idea that ontic structural realism should be offered as the thesis that objects *reduce* to nodes or positions in structures. In the next section I will discuss non-reductive strategies for ontic structural realism, but before I would like to address two alternative attempts at reduction an ontic structural realist might offer. The first is the idea that perhaps the state to which objects like particles are reduced is much larger than just a singlet state of two fermions. The second is the idea that state-independent properties might be given their own structural account.[14]

Let's begin by looking at larger structures. We need to answer two questions in this context: what are candidate structures, and can the goal of reduction of occupants to roles be achieved if we take the structure in question to be larger than a singlet state of two fermions? Recall that the structures in question will have to be concrete, they should be distinguished not by recourse through their occupants, and they should be discoverable and describable by physics.

An easy way to extend the example of two particles in an entangled state is to consider entangled systems of n identical particles. Permutation invariance holds for such systems as well, so they similarly give rise to the idea that the particles in question aren't individuals (see Teller [1995] for discussion). Enlarging the structure in this way does not help the OSRist, however. Even in an n-particle state, the particles still have state-independent properties. So once again it makes a difference which kinds of particles form the system, even if it doesn't matter which particle occupies which position in the state.

The real task for the OSRist, then, is to find a way of getting rid of state-independent properties, provided that the structure he has in mind are states. The problem is not just that state-independent properties are often thought to be intrinsic, but that once the OSRist has declared states to be the relevant structure, anything that could be different without the state being different can't be said to supervene on structure, and hence resists reduction to the structure. If particles have properties that don't supervene on their structural properties that means particles don't reduce to positions in the structure. Is there any reason to expect that we will end up with only state-dependent properties? As Peter Ainsworth ([2010]) has pointed

out, Hamiltonian operators depend on state-independent properties, so it seems unlikely that we should end up with a quantum mechanically described state, even a large one, that somehow doesn't involve state-independent properties as well as state-depended properties.

Let's now turn to the second potential reductionist strategy. Many structural realists will insist that state-independent properties are not a problem for structuralism at all, because a structural account of such properties can easily be given. The starting point for a structural account of properties like mass and spin is the classification by Wigner ([1939]) of particles as irreducible representations of the Poincaré group.[15] Wigner classifies different solutions to free relativistic field equations in terms of different values for mass and spin as different irreducible representations of the Poincaré group. Since this classification seems to privilege the symmetries of the field equations (given by the Poincaré group) over the quantities (e.g. mass and spin), this is sometimes understood as a structuralist account of these quantities, or of the particles (particle kinds) distinguished by these quantities.[16] Very roughly, one might think of it this way: Wigner's classification reveals how the different kinds of particles belong to a common structure, the structure of the Poincaré group, by showing how different kinds of (elementary) particles can be thought of as different irreducible representations of that group.

There are some general worries about this structuralist strategy. For example it is unclear how the Poincaré group can be understood as a concrete structure, unless we take the particles to instantiate this structure, in which case we might worry that the particles are far from being eliminable. More importantly for

the present context, though, even such a structural account of state-independent properties does not yield a *reduction* of state-independent properties to structure. For such a reduction to be the case, we would once more need supervenience, in this case the supervenience of particular representations of the Poincaré group on the group structure of Poincaré group. But once again, no such supervenience relationship holds. In this case this just follows from the relationship between a group and its representations. The different kinds of particles have different values for mass, and accordingly they have to be thought of as *different* irreducible representations of *the same* group. So a change in representation is precisely not a change of the group, or group structure. That means representations do not supervene on group structure, and are hence not reducible to the group.[17] Since the representations differ by the exact values for mass and spin, this structural account of state-independent properties does not help the *reductionist* structuralist.

The strategy of reducing occupants to roles or positions within a structure is not an option for ontic structural realists. Objects are not just nodes in structures. In the next section I will investigate whether an approach based on a direct ontological dependence of objects on structures might be used to articulate ontic structural realism.

4 Ontological Dependence and Identity

An alternative to reduction and supervenience is provided by what is sometimes called 'ontological dependence'.[18] Unlike supervenience, ontological dependence is an explanatory relation, and unlike a reduction claim, a claim of ontological

dependence does not eliminate one of the relata. To say that A ontologically depends on B is to say that both A and B exist, but that B is in some sense ontologically and explanatorily prior to A. To make a claim of ontological dependence, intuitively, is to claim that A exists (at least in part) *because* B exists (Lowe [2005]).

To claim that A exists because B exists is to claim more than to claim that, necessarily, A only exists if B exists. As Kit Fine ([1995]) has argued, to say that A exists because B exists often seems to yield counter-intuitive results. A common move in response is to articulate the dependence relation not in terms of *existence*, but in terms of *identity* or *essence*. E.J. Lowe offers the following:

> (ID) x depends for its identity upon $y =_{def}$ There is a function f such that it is part of the essence of x that x is $f(y)$.(Lowe [2005])

The idea is that the identity of x depends on being $f(y)$, that is, x wouldn't be the x it is, unless it was $f(y)$ for some particular function f.[19] A frequently used example to illustrate this idea is the relation between a singleton and its element. The singleton $\{a\}$ depends on a for its identity – if the element weren't a, it would be a different singleton. But the relationship doesn't hold vice versa – a does not depend for its identity on being the element of the singleton $\{a\}$. If these are the intuitions we are trying to capture with an ontological dependence relation, (ID) might seem like a good candidate, since if we substitute $\{a\}$ for x, a for y, and the singleton function for f, (ID) holds.

Lowe proposes the following principle concerning (ID):

> If x is not identical with y and x depends for its identity upon y, then

y does not depend for its identity upon x.(Lowe [2005])

This principle helps to articulate a sense in which (ID) establishes a priority relation. Unless x is the same as y, if x depends for its identity on y, then that relation is asymmetrical, that is, y does not depend for its identity on x. The motivation behind this principle is the thought that if dependence could be mutual, vicious circularity threatens.[20] (ID) then gives us one way of articulating what a notion of ontological dependence might look like.

Before turning to the use ontic structural realists have made of ontological dependence, let's consider a second candidate for a dependence relation, Kit Fine's notion of ontological dependence. Fine suggests that we take "x to depend on y if y is a constituent of a proposition that is true in virtue of the identity of x, or alternatively, if y is a constituent of an essential property of x" (Fine [1995], p.275). Like Lowe's notion, Fine's ontological dependence is a form of essential dependence. Fine's notion clearly allows for the dependence to hold between one object and several different objects, since a number of different propositions might be true in virtue of the identity of the object, and where these propositions have different constituents, the dependent object will depend on all of them. Accordingly, it also allows for the dependence between the dependent object and any one dependee to be *partial*.

Unlike Lowe, Fine allows that, under certain special circumstances, the dependence between two objects might be reciprocal. The case he envisions is a case where two objects are defined in part in terms of their relationship to one another: it is part of x's essence to stand in relation R_1 to y, and part of y's essence to stand

in relation R_2 to x. If these relations are indeed essential to x and y respectively, then x will (partly) depend on y, and y will (partly) depend on x. Unlike Lowe, Fine doesn't see a vicious circularity here, and introduces a distinction between priority and dependence. An ontological priority relation excludes simultaneous definitions, whereas dependence allows for them.

With these different notions of dependence in hand, let's turn to the use ontic structural realists might make of the idea of ontological dependence to articulate their view. Steven French has recently offered a version of the dependence claim as applied to physical objects:

> ODS$_{phys}$ Each fundamental physical object depends on the structure to which it belongs. (French [2010], p. 104)

So far this is just a straightforward rendering of ODS for physical objects. French goes on to offer three different interpretive options for ODS$_{phys}$, each of which is supposed to correspond to a different form of OSR.

Option 1 [T]he identity of the putative objects/nodes is (symmetrically) dependent on that of the relations of the structure and vice versa. (French [2010], p. 104)

Option 2 [T]he identity of the putative objects/nodes is (asymmetrically) dependent on that of the relations of the structure. (French [2010], p. 105)

Option 3 [T]he very constitution (or essence) of the putative objects is dependent on the relations of the structure. (French [2010], p. 106)

French himself is going to opt for the third option, but let's look more closely at these three options and at ODS$_{phys}$ itself, all of which are quite puzzling.

First notice the ambiguity between objects and nodes. As I argued earlier, objects are not easily reduced to nodes (or positions), with perhaps the exception of certain kinds of mathematical objects. So the structural realist will have to choose: either his claim is the comparatively tame assertion that nodes depend, for their identity, on the structure to which they belong, or his claim is the wild claim that objects depend on the structure to which they belong, where objects are not just nodes in the structure.

The tame assertion is quite plausible, although there is perhaps a question about whether the relation of nodes and structures is one of dependence or interdependence. But unless it is coupled with a claim that reduces objects to nodes, it doesn't get the structural realists what they want. For objects would still be independent, even if nodes and structures are interdependent. That suggests that if the structural realist wants to get any mileage out of the dependence claims, he should opt for a dependence claim that holds between *objects* and structures. So options (1)-(3) have to be read as pertaining to objects, not nodes.

The first two of French's three options are straightforwardly contrasted, but since both Fine's and Lowe's notions are forms of *essential* dependence, the intended contrast between option two and three is unclear. French carves up the territory as follows: option one yields a moderate structural realism, option two yields structural realism with thin objects, and option three yields eliminative (or no-objects) structural realism (French [2010]). The first problem with this way of carving up the territory is that ontological dependence relations are not eliminative. The only relation that could be considered eliminativist is reduction,

and reduction as we saw above is not available to the structural realist. All ontological dependence relations are non-reductive. Option three, then, is not available if the relation in question is ontological dependence.[21]

That leaves options (1) and (2). Since Lowe's ontological dependence relation is asymmetrical, the dependence relation in option (1) cannot be (ID). As I mentioned above, Fine allows for the possibility of reciprocal dependence relations in cases where two objects are 'simultaneously defined'. This will lead to a mutual dependence, without priority, which might well be what moderate structural realists intend.

It is not so easy to see how such a position is going to be fleshed out, however. If we follow Fine's idea of simultaneous definition and apply it to the case of a physical object and the role it plays, it seems we have to say that the object occupies the role it occupies in virtue of its identity, *and* that the role in question is the role it is in virtue of being occupied by the particular object. The latter seems rather strange, though, since at least the way we usually think about positions or roles is that they are identified purely in terms of their relations to other positions or roles, precisely without taking into account possible or actual occupants.

That seems to leave us with option two as the relevant way of articulating OSR: The identity of the objects is (asymmetrically) dependent on the identity of the relations of the structure to which they belong. Using (ID) from above, the claim can be rendered: There is a function f, the occupancy function, such that it is part of the essence of each fundamental physical object that it is $f(y)$, where y is a place in the relevant structure. To claim that objects depend on structure means that it is part of the essence of each fundamental physical object to play a

role within a particular structure. So if ODS_{phys} is explicated using (ID), we end up with an asymmetrical dependence of objects on structures, through an essential dependence of objects on the roles they play within a particular structure.

Using Fine's dependence relation instead we get a similar result: for each physical object there is a proposition containing (or perhaps better: specifying) a particular role within the structure to which the physical object belongs, such that the proposition is true in virtue of the identity of the object. What this means is that it is a condition for the identity of the object that there is such a role within the structure to which the object belongs. The most plausible way in which there could be such a requirement would seem to be that it is part of what it means to be this particular object that it plays this particular role. As before, this dependence may be partial.

Using either Fine's or Lowe's notion of ontological dependence, then, we can articulate what it means for objects to depend on the structure to which they belong. Two questions remain: how structuralist is the thesis, and how plausible is it as a view of quantum particles?

The minimalist requirements for structuralism are met: structure does not depend on objects, objects instead depend on structure. It is not the strongest form of structural realism, however, since objects are still part of the ontology. Of the three versions of ontic structural realism discussed at the beginning, only thin-object OSR comes close to being articulated using essential dependence as the relation between objects and structures. To judge how structuralist the position articulated by dependence is, then, we need to ask whether dependence on structures

makes objects 'thin' enough for ontic structural realism.

Ideally the identity of an object would be exhausted by the roles it plays. Dependence does not yield such a claim, however. A dependence claim establishes that there are certain propositions which are true in virtue of the identity of the object. Even if such a dependence claim can be established between objects and structures, however, this by no means rules out that there is more to the essence of an object than the role it plays in a particular structure.

It is possible, of course, that the remaining ingredients to the essence could also be structural, but this wouldn't be established just by finding more roles the object depends on, since further dependence claims would simply add further necessary conditions. What is needed, however, is claim of the form: the identity of the object depends on structure, *and nothing else*.

To show that the objects are 'thin' enough for structural realism, then, OSR needs to claim more than just dependence. An ontological dependence claim by itself yields a weak form of structural realism, one according to which objects depend on structure, but not vice versa. Establishing this relation does not, by itself, show that the objects are thin enough to be acceptable to ontic structural realists.

How plausible is the dependence claim when applied to the case of quantum particles? If we take the relevant structures once again to be particular states, ODS_{phys} entails that each particle ends up in the states it ends up in by necessity, and indeed, that it would not have been that particle if it ended up in different states.[22] That means, for example, that when we talk about the possible states

an electron might find itself in, we are really talking about different possible electrons!

While this claim would seem pretty outrageous for ordinary objects, it might actually be appropriate for quantum particles. We can follow ordinary objects over time, and at least for certain changes in ordinary objects we are willing to say that the object remained the same, all that changed was a particular property it had, e.g. the mug was clean and is now dirty. Quantum particles are notoriously not like that. Did this electron have z-spin up all along, or did we just create a z-spin up electron here by performing a particular experiment? Quantum mechanics is clearly not compatible with the former, so perhaps the latter is not as implausible as it seemed.[23]

Talk of 'creation' and 'annihilation' operators in quantum field theory seems to give further support to this understanding. It seems sensible and in accordance with the use of said operators in physics to take the creation to be the creation of an electron in a particular state, not the creation of an electron simpliciter. That fits with the idea that it is part of the essence of any particular electron that it is in a particular state.

So perhaps *some* sense can be made of the claim that each particle depends for its identity on being in a particular state. This dependence claim does not by itself suffice to make the objects in question 'thin' objects, but it could be argued that quantum particles in fact are thin-objects. Since for the case of quantum particles in particular it also seems to be the case that we can switch particles of the same kind within a state without it making a difference to the overall state, there is at

least one sense in which the identity of a particle is exhausted by the role it plays in a particular state. Particles qua individuals are thin objects. To the extend that we understand their identity as individuals, we understand it in terms of the state they are in.

This leaves unaffected their 'kind identity', that is, their identity as electrons rather than muons. Which kind of particle they are does not depend on any particular state the particles are in. Whether quantum particles are thin enough by structuralist standards, then, will depend on whether it is good enough for structural realism if objects as individuals depend on structure, while not depending on that structure as kinds.

5 Conclusion

In this paper I've tried to make sense of the ontic structural realists' claim that structure is all there is (fundamentally). I've followed two distinct strategies an ontic structural realist might pursue to articulate this puzzling claim more fully, concluding that neither strategy will give the ontic structural realist what he had hoped for.

I've argued that the point of dispute between structural realists and their non-structuralist competitors is the question of the relation between a position or role in a structure, the structure, and the occupant of that role. This issue has to be clearly distinguished from other issues which might also undermine the independence of objects, for instance the question whether objects might depend on other objects.

I showed that one natural strategy, reducing objects to roles they play in structures,

fails for the case of physical objects, because it matters for physics which (kinds of) objects instantiate a particular structure. This is in contrast to the case of structuralism in the philosophy of mathematics, where such a strategy has a certain amount of plausibility at least for certain mathematical objects.

A different strategy, which I looked at in the second half of the paper, is to attempt to argue for a direct dependence of objects on structures. According to structural realism expressed in this way, the identity of any particular object would depend on the structure to which it belongs. That seems to articulate a weak form of structural realism, one according to which objects are at least not entirely independent from the role they play. I suggested that this weaker form of structuralism indeed has a certain amount of plausibility when applied to quantum particles.

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Notes

[1]For further critical discussion of the conception of objects in structural realism also see (Chakravartty [2003]).

[2]James Ladyman is the most prominent advocate of thin objects (Ladyman [2007]), whereas Steven French continues to maintain that there is no place for objects in a structuralist ontology (French [2010]).

[3]Both the thin-object and the no-object branch are sometimes called eliminative ontic structural realism. Even on the thin-object view, there are no traditional objects, if traditional objects are understood as individual independent entities, where by independent entities we mean something like: this desk could have existed even if the lamp on it had not been on it.

[4]For examples of arguments using quantum particles to support structural realism, see (French and Ladyman [2003]), (Ladyman [2007]).

[5]'Object' here is to be understood in the ordinary, not yet re-conceptualized sense. Structural realists are of course trying to persuade us that we have to give up that notion of object.

[6]Ladyman and Ross [2007] sometimes speak of OSR as a 'metaphysics of relations'.

[7]Since there is no established terminology in the literature, I will be using 'position', 'role', or 'node' interchangeably to refer to places in structures available for occupation.

[8]Supervenience is of course typically defined in terms of property-supervenience, although there are also cases of using supervenience as a relation among states, or among events. In the context of ontic structural realism, the intended supervenience relation may be understood as follows: as a supervenience basis we have roles in a structure. According to OSR, the occupants of these roles supervene on them in the sense that changes in which occupant occupies which role are not possible without a change of the structural features of the roles themselves. In particular, there are two types of (apparent) changes we have to consider: swapping occupants

within the same structure, and different classes of occupants filling the positions in the structure. Both of these would intuitively seem to be cases of changes in the occupants that can happen without changes to the roles in the structure. For the OSRist's supervenience claim to hold, the OSRist needs to make a case that such changes are not possible (or aren't really changes) for the structures of interest to the ontic structural realist.

[9]Similar considerations apply if, instead of characterizing the structure in terms of the relations Barack Obama stands in, we take the structure to be all of space-time. For even if we can uniquely identify people and ordinary objects by their space-time trajectories (or world-lines), we have not thereby shown that they reduce to their space-time trajectories. For the objects of interest to the structural realists, quantum particles, we have to confront the additional problem that these particles don't have well-defined space-time trajectories.

[10]These two positions sometimes go by different names: eliminative vs. non-eliminative structuralism, or hard-headed vs. mystical structuralism. To avoid confusion with the distinct branches of OSR, I will stick to '*in re*' and '*ante rem*' as labels for structuralisms in the philosophy of mathematics.

[11]It is of course debatable whether structuralism can succeed as a view of all mathematical objects, but that's a debate beyond the scope of this paper. See (Burgess [1999]) for discussion.

[12]One reason to take the state to be the relevant structure are arguments like the one Ladyman offers. Another reason is that states are arguably concrete structures. Finally, states are also one of the few places where we are tempted to talk about

individual particles, whereas in many other contexts, what is at issue are kinds of particles, not individual particles. So if the individuality of particles (or lack thereof) is the main target for structural realism, then states are a natural candidate for structure.

[13]I will come back to the question of a 'structural' analysis of state-independent properties below. Notice, though, that the argument does not require that state-independent properties be thought of as intrinsic properties. All that is needed is that they are properties by which particles can differ, even where the state they are in is the same.

[14]I would like to thank two anonymous referees for inviting me to consider such broader structures.

[15]For a similar structuralist approach to internal symmetries and particles, see (Kantorovich [2003]).

[16]For a critical account of the resulting concept of 'particle', see (Falkenburg [2007], pp.229-33).

[17]To avoid confusion: this is a point about the philosophical notion of reduction, not the group theoretical notion according to which the representations in question are irreducible representations.

[18]Some philosophers may balk at the idea of a notion of 'metaphysical' dependence or priority, and perhaps rightly so. For the purposes of the paper, however, I will assume that at least some sense can be made of such a relation, to see whether such a relation might be suitable to articulate the priority of structure envisioned by structural realists. For a defense of the idea that metaphysical priority relations

are suitable tools for articulating positions in metaphysics, see (Fine [2001]).

[19]As one referee points out, it is not entirely clear what this function is on Lowe's picture. I follow Lowe's treatment of ontological dependence since some structural realists have actually tried to use his proposal in particular, see (French [2010]).

[20]The worry is that if dependence is meant to be an explanatory relation, then just as we find it unacceptable to explain A in terms of B *and* B in terms of A, we should find mutual dependence unacceptable.

[21]French argues against the thin-object version of OSR that it is unclear what is left of particle once its identity is completely dependent on the structure. The question is legitimate, but it seems to me that if thin-object OSR is understood in terms of essential dependence, it has a clear answer: existence. To say that an object depends for its identity on its role in a particular structure is to say that it wouldn't be the very object it is if it didn't play that role. It means that it is a necessary condition for the object's being the object it is, that the structure in question exists, and that the object plays the particular role in the structure. None of this shows that the object can be dropped from the ontology, though; the object remains an element of the ontology.

[22]OSR articulated in this way would not, strictly speaking, be committed to the claim that *all* states a particles ends up in are essential to it, but that opens the question which ones are essential, and it is not at all clear how that question is going to be addressed.

[23]As one reviewer points out, this is still a very controversial thesis, since it

seems to make change impossible. This charge has been raised against structural realism before (Chakravartty [2003]), so it is not unique to the weak structuralist thesis. I think what this means is that ontic structural realists owe us an account of what change is like on their view, but I think it would be unfair to demand that change has to be understood in terms of objects changing their properties, or correspondingly that particles go from one state to another. After all, since OSR is trying to offer an alternative ontology with no particles, or no independent particles, it seems unsurprising that they have to develop a different account of change. Given the problems with our ordinary notion of change when applied to quantum mechanics (quite independent of structural realism), it seems to me that this is not a fatal flaw in structural realism, but an area where further work is needed.

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