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STRUCTURAL REALISM AND ITS VARIANTS

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1 Introduction

Perhaps the most influential realist view in recent years, structural realism's appeal can be found in the ease with which it seems to explain away certain difficulties that afflict other, more traditional, versions of realism. Roughly formulated, it is the view that our epistemic and perhaps even our ontic commitments must be reduced to the structural as opposed to the non-structural features that successful scientific theories ascribe to the unobservable world. This view can be traced at least as far back as the early twentieth century, when advances in logic and set theory made it possible to express in more exact terms the notion of structure. Among its pioneers, one can count the physicist, mathematician, and philosopher Henri Poincaré, the mathematician and philosopher Bertrand Russell, and the historian and philosopher Ernst Cassirer. In what follows, we survey the conceptual foundations as well as the presumed advantages and presumed disadvantages of structural realism.[1] We start with a discussion of the notion of structure and proceed to explore variants of the view. Only then do we turn to motivations for these variants. The chapter ends with a number of challenges to structural realism and a brief consideration of some further issues.

2 What is structure?

What does it mean to be a realist about structures? Any attempt to answer this question must first put the notion of structure on a proper footing. We can reasonably assume that proposed conceptions of structure should meet two conditions: (i) they should be formal so as to be able to delimit our epistemic and/or ontic commitments in a clear manner and (ii) they should be sufficiently rich so as to be able to adequately characterise the (proper) content of scientific theories. Below we consider four alternative conceptions of structure that appear to satisfy the previous two conditions but are otherwise distinct.

We begin with the well-known and well-understood *set-theoretical* notion of structure. A structure S, according to this conception, is an ordered tuple (U, R), consisting of a non-empty set of objects U, that is a domain or universe of discourse, and a non-empty set of relations R defined over the first set. Set theory is a powerful tool that allows us to express a wide array of relations between objects as well as relations between structures. For example, we can evaluate whether two structures are the same or whether one is part of another. In technical terms, two structures are the same in all their formal features if and only if they are isomorphic. Satisfaction of this last notion requires the existence of a bijective mapping between the objects of two structures, that is a mapping where each and every object in the one domain is mapped to a distinct object in the other and where no object remains unmapped at the end. Moreover, the notion requires that such a mapping respects the presence of relations between objects, that is, any relation between objects in one domain has its analogue between the corresponding objects in the other domain.

Championed by Michael Redhead (2001), the set-theoretic conception of structure offers a seamless entry into structural realism in that numerous philosophy of science discussions already employ set theory. Moreover, since structural realists are realists about the formal features of relations, the notion of a class of isomorphic structures proves apt, as such a class clearly identifies only formal features, abstracting away other details. Take as a toy example the specific, or as Redhead would call it 'concrete', structure S_1 set up by the specific relation R_1. Suppose R_1 exhibits the formal features of irreflexivity and symmetry. If structural realists are realists only about such features, then their realism is circumscribed by the isomorphism class that S_1 is a member of, that is the class of all structures that are isomorphic to S_1 and whose corresponding relations are irreflexive and symmetric like R_1. That is, they cannot be realists about S_1. Rather, they can only be realists about the so-called 'abstract structure' that S_1 shares with all other members of the given isomorphism class.

The set-theoretic conception of structure is controversial, but perhaps much less so than the conception which utilizes a device known as the *Ramsey sentence*. A Ramseyfied scientific theory is a theory that has been logically weakened in a specific way. To apply this procedure to a theory, a distinction must first be drawn between two kinds of non-logical terms. The distinction's typical manifestation pits observational against theoretical terms.[2] Ramseyfication weakens theories by replacing theoretical terms with variables and existentially quantifying over them. The effect is the same as the weakening one gets by moving from the claim that 'A philosopher of science authored this entry' to the claim. Someone authored this entry. The first implies the second but not vice versa.

Why do we dispose of theoretical terms and weaken theories in this way? Observational terms are meant to denote properties or relations that we are experientially or at least instrumentally acquainted with and are thus thought to rest on more secure foundations than theoretical terms. After all, the latter are more distal with respect to our experience by virtue of denoting unobservable properties and relations. In schematic form, a theory $\Theta(\alpha_1, \alpha_2, \ldots \alpha_n; \beta_1, \beta_2, \ldots \beta_m)$ where α_1 to α_n are theoretical terms and β_1 to β_m are observational ones is turned into its Ramseyfied version thus: $\exists\varphi_1 \ldots \exists\varphi_n\Theta(\varphi_1, \varphi_2, \ldots \varphi_n; \beta_1, \beta_2, \ldots \beta_m)$ where now the theoretical terms have been replaced by an equal number of distinct and existentially bound variables φ_1 to φ_n. The only information about unobservables that survives this process concerns that which is conveyed by the logical relations between the theoretical variables and between those variables and the observational terms. Since logical relations are formal, some take the said weakening to respect structural realist commitments. Others have questioned the association of Ramsey sentences with structural realism, arguing that this formulation amounts to giving up realism altogether. We return to this very important issue in section 5.

Other proposed conceptions of structure include the *partial structures* approach of da Costa and French (2003). This approach aims to liberalise the traditional set-theoretic notion of a structure. Whereas the latter is understood in terms of a set of relations defined over some domain, the former replaces such relations with so-called 'partial relations'. In more detail, each partial relation R_i is conceived as an ordered triple $\langle R_{i1}, R_{i2}, R_{i3}\rangle$, where R_{i1} is the set of n-tuples that satisfy R_i, R_{i2} is the set of n-tuples that fail to satisfy R_i, and R_{i3} is the set of n-tuples for which we do not know whether they satisfy R_i. A partial structure S is defined as a pair $\langle U, R\rangle$ where U is once more the universe of discourse and R the set of partial relations, each member of which is an ordered triple in the sense just specified. As soon as such a notion is in place one can also define a notion of partial isomorphism as a natural weakening of the notion of isomorphism between 'full' structures.

What is the allure behind partial structures? Well, the appellation 'partial' signifies that the available information concerning those relations and structures is incomplete. The allure is therefore that one can represent some structure of the world without needing to specify everything there is to know about it. And what does all of this have to do with structural realism? If even the structural features of the world are only imperfectly reflected in the structures of our best scientific theories, then it seems that the notion of isomorphism is too strong, as it implies a perfect mirroring between the worldly and theoretical structures. The notion of a partial isomorphism, by contrast, is capable of capturing varying degrees of closeness to an isomorphic mapping and, therefore, appears more appropriate. Whether this is indeed true has been the subject of debate – see, for example, Lutz (2015). Moreover, the partial structures approach is not wedded to realism and has in fact been employed as a framework for anti-realist views – see, for example, Bueno (1997).

One final approach is worth considering here. There are those who think that the notion of structure needed to 'do the business' must be much more radically divorced from traditional conceptions of objects and properties. Under those conceptions, properties, including relations, are borne by objects and are thus ontologically secondary to them. Enter category theory, a framework that is at least as powerful as set theory and arguably powerful enough to act as a foundational theory of mathematics – see, for example, Lawvere (1966). According to some readings, this highly abstract framework reverses the dependency relation between objects and relations. Its primitive notions are objects and morphisms. But these are not objects in the commonsense or even in the set-theoretical meaning of the term. Instead, objects in category theory are themselves structures of sorts. Furthermore, even though category theory is rich enough to model set-theoretic elements in terms of morphisms from so-called 'terminal objects' to non-terminal ones, these morphisms are relations, and hence reference to anything like objects (traditionally conceived) seems to be avoided. If that is indeed the case, this framework helps motivate the coherence of at least one form of structural realism – see, for example, Bain (2013).

3 Epistemic and ontic variants

We already touched upon structural realism's curtailed epistemic commitments. Though these are shared by nearly all structural realists, they only constitute the whole story for the supporters of the epistemic version of the view.[3] It thus seems fitting to begin with them. Epistemic structural realism holds that our knowledge of the world never exceeds a correct description of its structural features and that these features are reflected in parts of the mathematical structure of successful scientific theories. As with the other major version of structural realism, that is ontic structural realism, the epistemic one comes in several variants. Two will be explored here.

The most prominent variant is that found in Worrall (1989) and first advocated by Maxwell (1968). We get at the structure of theoretical concepts by Ramseyfying the corresponding terms. This is a 'top-down' approach in that one starts with a scientific theory, which has already been suitably reconstructed in first-order predicate logic, and then peels away the meaning of theoretical terms via Ramseyfication to reveal the essence of that theoretical structure in second-order logic. To give a toy example, suppose our scientific theory asserts that all bodies with mass attract each other. On the further supposition that *mass* is a theoretical term that we denote in our formal language with letter 'M' and *attraction* is an observational term that we denote with letter 'A' we can offer a first-order formal rendition of the theory as follows: $(\forall x)(\forall y)\ [(Mx \wedge My \wedge x{\neq}y) \rightarrow Axy]$. This can in turn be Ramseyfied in the following way: $(\exists\Phi)(\forall x)(\forall y)\ [(\Phi x \wedge \Phi y \wedge x{\neq}y) \rightarrow Axy]$, where Φ is a (second-order) variable. What this aims to achieve is a form of modesty towards the referents of the theoretical terms. Thus, whatever mass is, if two distinct objects have it, they are mutually attracted. That is the extent to which mass can be known.

The other variant of epistemic structural realism can be found in Votsis (2005) and was first advocated by Russell (1927).[4] In contrast to Worrall's variant, this has been classified as a 'bottom-up' approach in that one starts with the structures of observables that are then used to infer (part of) the structure of the unobservables. The operative assumption here is that the latter is by and large faithfully reflected in the former. It is worth keeping a few things in mind when attempting to understand the Russellian approach. The first is that, much like the previous approach, it does not pretend to give an accurate portrayal of actual scientific practice. Indeed, unlike the Ramsey-sentence approach, it does not even take actual scientific theories as a departure point. The second thing to keep in mind is that the observables-versus-unobservables distinction utilised here is more akin to the internal-versus-external world distinction of indirect realism. Roughly speaking, our perceptions of the world are internal, and their proximal causes, the things in the world, are external. Why is the one distinction merely akin but not identical to the other? Actually, in Russell's view the two are one and the same, but one can easily see that the old distinction's conception of what is internal is too narrow by modern standards. After all, most scientific observations nowadays involve instruments. A duly updated version of the distinction takes observables to be the *results* of sensory organs and/or scientific instrument measurement. By contrast, the *objects* of those measurements are 'unobservables'. For example, the needle in a voltmeter pointing to three is observable, but the physical state, that is the electrical potential difference, being measured is unobservable. The third and final thing to keep in mind is that this approach is typically articulated in terms of the set-theoretic notion of structure, though nothing prohibits its articulation by means of another notion.[5]

The attention bestowed on the epistemic version of structural realism in the last fifteen years pales in comparison to that bestowed on its ontic cousin. The latter view holds, first and foremost, that it is our ontological commitments that need curtailment. To be more precise, we should believe only in the existence of structures, thereby excluding objects and monadic properties at least as they are traditionally conceived. Curtailing one's ontic commitments in this way implies a corresponding curtailment of epistemic commitments. After all, if only structures exist, only structural epistemic commitments need to be made. Ontic structural realism, much like its epistemic cousin, has been articulated in several distinct ways. Three variants are explored in what follows.

Radical ontic structural realism, which we may call 'radicalism' here for expedience, makes the highly contentious claim that only structures exist. That is, no objects or object-borne monadic properties should, according to this view, be admitted into our ontology. But, the reader will surely ask, how can a structure exist without the existence of the very things it is meant to structure? Otherwise put, how can something be a relation without the things it relates, that is without its *relata*? Many philosophers find this idea difficult to conceptualise. At the very least, its implementation would require a highly revisionary metaphysical and formal framework. Perhaps that's a moot point. After all, it is not clear whether anyone ever truly supported radicalism, though suggestive comments can certainly be found in James Ladyman (1998) and French (2014).

Eliminativist ontic structural realism, which we may call 'eliminativism' here for expedience, is a more modest view. Defended by French and Ladyman (2011), it holds that what needs to be dropped is the commitment to individuals but not objects. What is an individual? Traditionally, this notion has been understood via Leibniz's famed principle of the identity of indiscernibles. The principle asserts that two objects that share all properties are in fact one and the same object. Alternatively put, if two objects are distinct, then there is at least one property possessed by one but not the other. This implies that objects get individuated through their properties. The eliminativist simply denies this and other conceptions of individuality. Objects, on this view, have to be reconceptualised as 'thinner' entities. That is precisely what French and Krause (2006) attempt to do when they argue for a minimal notion of object-hood that can be defined through the use of quasi-set theory. This theory in effect generalises set theory by ensuring that both (traditional) elements that obey the law of identity, that is that every thing is such that it is equal to itself, but also (non-traditional) elements that violate it can form sets. It is, of course, the latter sort of element that is utilised to represent objects as non-individuals. Quasi-set theory thus provides the formal setting where quantifying over non-individual objects becomes possible.

Last but not least, we have moderate ontic structural realism, or 'moderationism' for short, advocated by Esfeld (2004) and Esfeld and Lam (2011). Loyal to its name, this view underwrites traditional ontological categories like objects and individuality in contrast to radicalism and eliminativism. It is, nevertheless, a form of ontological structural realism by virtue of rejecting intrinsic properties. What exactly is an intrinsic property? A hotly debated topic in its own right, the rough idea in this context is that it is a property that an object possesses independently of other objects or things altogether.[6] By rejecting intrinsic properties, moderationists are not only discarding a traditional ontological category but, at the same time and in a more constructive tone, also highlighting the autonomy of relations. An example would perhaps make the point more conspicuous. Take the notion of inertial mass. Roughly speaking, it is a measure of a body's ability to resist acceleration. Inertial mass is standardly interpreted as an intrinsic property. So how do moderationists propose to understand it relationally? Luckily, the notion does make reference to something other than the object in possession of the property, namely acceleration, which itself can be understood in relational terms. Acceleration could not but stem from the presence of other objects or, to be precise, forces, and hence inertial mass seems to be more naturally construed as a relational property.

The foregoing disagreements between structural and other realists, but also among structural realists themselves, are sometimes formulated in terms of the idea of ontological priority. It may be claimed, for example, that structures are ontologically prior to other ontological categories like objects. What this priority amounts to is a much-discussed topic. Some take it to be a form of dependence. For example, x ontologically depends on y means that x would not exist had y not existed. In the case at hand, eliminativists may say that thin objects would not exist had the relations that structure them not existed. Others opt for a weaker conception like supervenience. For example, x supervenes on y means that there could not be a difference in x without a difference in y. In the case at hand, eliminativists may say that there could not be a difference in thin objects without a corresponding relational difference. Yet still others consider the whole discussion a wild goose chase and claim that neither relations nor relata are ontologically prior to one another. For a more informed deliberation on these matters, the reader may turn to Kerry McKenzie (2014).

4 Motivations

Up to now we have kept silent on what motivates structural realism. That is the aim of this section. Several motivations have been proposed over the years. Some were intended to serve the needs of specific variants but have been adapted to serve the needs of others. It is worth noting that not all motivations can be so adapted. We begin with a motivation that was originally proposed to support one of the epistemic variants of structural realism but that has since become a *sine qua non* for all variants of the view. For reasons that will soon become apparent, let us call it the 'historical motivation'.

The historical motivation originates with Poincaré ([1905] 1952).[7] To fully appreciate its pull, consider the following general remarks about scientific revolutions. Suppose it is true that scientific revolutions bring about all sorts of changes at the theoretical level. Suppose, moreover, that not everything changes at that level and indeed that some things remain the same. If it is reasonable to maintain that the things that change are not likely to truthfully represent any real features of the world, then, it may be claimed, seems to some extent reasonable to maintain that the things that remain the same are likely to truthfully represent such features. This is especially the case when those things that remain the same do so across not just one but all subsequent revolutions. The historical motivation for structural realism identifies the structure of unobservable posits as that which remains (and ought to remain) invariant across revolutions. More precisely, in so far as it is only the structure that is responsible for any genuine contribution made by theoretical parts to the empirical success of a theory, it can be claimed that, with reference to the theoretical parts, it is structure alone that ought to be preserved in successor theories. Hence, it is structure that ought to be deemed worthy of realist commitments.

Worrall (1989) casts this argument to promote a middle way between the realist *no miracles argument* and the anti-realist *pessimistic meta-induction argument*. Structural realism, according to this view, does not make the success of science a miracle because it maintains that successful scientific theories have got some part of the structure of the world right. But it also does not ignore the fact that various theoretical components of theories get discarded in the aftermath of a scientific revolution. Note, crucially, that this motivation for structural realism can be held accountable against the historical record of science. This includes the future course of science, thereby turning structural realism into an empirically falsifiable hypothesis.

Does the history of science vindicate structural realism? A number of case studies have been conducted in support of the view. Worrall (1989), for example, argues that the structure attributed to light by Fresnel's theory survives the dismissal of the ether in the form of the equations that are derivable from Maxwell's mature theory of electromagnetism and are still valid today. Another example is Ladyman (2011), who argues that part of the structure of the phlogiston theory of combustion survives into the modern theory of oxidation – see also Schurz and Votsis (2014). A third example can be found in Votsis and Schurz (2012), who argue that part of the structure of the caloric theory of heat is reflected in the modern kinetic theory of gases. Beyond the natural sciences, a small number of case studies have been carried out in the special sciences – see Ross (2008) for examples from the field of economics and French (2014) for examples from biology.

These and other case studies are obviously insufficient to demonstrate beyond doubt that some form of structural realism is correct. At best, they are meant to inductively lend credence to such a view. But even this form of support has not escaped the critics. Saatsi (2005), for example, argues that the Fresnel-Maxwell case supports a form of realism that is arguably different from structural realism. More generally, each and every case study presented in favour of structural realism, or any other form of realism for that matter, can be contested on interpretational grounds. That's why now more than ever there is greater need for interpretational clarity. To conclude the discussion concerning the historical motivation, whether case studies support one as opposed to another version of structural realism, or indeed one as opposed to another version of realism (or even anti-realism) is an unresolved matter.[8]

An altogether different motivation, closely tied to Russellian structural realism, has as its source a foundational approach to epistemology. We may thus call it the 'foundational motivation'. Suppose that the foundation of all knowledge is observational. Clearly, this means that any knowledge of the unobservable world – understood in the broader sense explicated earlier – must be based on observational knowledge. The operative assumption here is that by and large the structure of the observables faithfully reflects (part of) the structure of the unobservables. Thus, some information about the latter can be inferred from the former. The reflection is established through some principles, one of which will be discussed in passing here. Keeping in mind the revised meaning of the terms 'observable' and 'unobservable', the principle holds, roughly, that differences in observables track differences in unobservables. This and related principles are defended by pointing out that their violation would make the successful tackling of the world around us, including the vital functions of survival and learning, virtually impossible.[9,10]

How much knowledge can such inferences license? If the unobservable world is no more than mirrored in our perceptions then such knowledge is merely structural. To use a well-worn example, consider a map of the London underground. The dots in the map signify stations, but they are obviously not identical to those stations. At best, what such a map preserves are the relations between the target elements. In other words, such a map preserves only structure. In the case at hand, that means, very roughly, some indication about the relative distance between the stations and the locations where one can change lines. Similarly, observable elements are obviously not identical to unobservable elements, and hence, at best, the two sets of elements share structure.

Psillos (2001) has questioned the foundational motivation and in particular the aforesaid principles, deeming that they are either too strong when taken at face value and in their totality, or too weak when reduced in number and amended so as to be more sensible. In turn, Psillos' critique has been contested by Votsis (2005), where more sophisticated versions of the principles are proposed and where it is argued that these principles were never meant to guarantee isomorphic relations between the observable and unobservable worlds, at least not in all cases. The claim instead is made that we gain *some* information about the structure of the unobservable world through the structure of the observable world. Whether this is the view originally defended by Russell is a further question. Moreover, and more importantly, whether the foundational motivation can deliver the goods is a non-trivial and highly contested topic.

Proponents of ontic structural realism rely more on motivations coming from modern physics; these do not seem capable of supporting epistemic variants of structural realism. Recall that eliminativists argue against the conception of objects as individuals. They do so because individuality does not seem to sit well with quantum mechanics. It has, for example, been argued that quantum particles fail to satisfy the principle of the identity of indiscernibles. In more detail, there are pairs of entangled particles that appear to have all and only the same properties, including spatial ones. If this holds, perhaps particles cannot be said to possess individuality but are at most bare particulars of some sort – a thin conception of object-hood if there ever was one.[11] On the other hand, it has been argued that quantum particles in entangled states can nevertheless be 'weakly discernible' by irreflexive relations between them (e.g. the relation of *having opposite spin*), and that this suffices for individuality (Saunders 2006). Similar concerns regarding objecthood and individuality arise in relation to spacetime points in the context of the general theory of relativity – see, for example, Bain (2013) and Stachel (2006).[12]

These motivations are no less controversial than the motivations for epistemic structural realism. In fact, given the uncertainties surrounding the interpretation of quantum mechanics they are arguably even more controversial. One reaction, for example, has been to point out that if it turns out that a hidden variable interpretation of quantum mechanics is correct, then the principle of identity of indiscernibles may still be satisfied by quantum particles. That's because such an interpretation envisions a disentangling of particles on the basis of their 'hidden' properties, for example location in Bohmian mechanics. Unless such interpretational disputes are empirically resolved, it would thus appear unwise to put much weight on the individuality motivation. Having said this, the motivation is not for naught, as it helps lay the conceptual groundwork for the philosophical view that best fits some interpretations of quantum mechanics, one of which may turn out true.

A final motivation worth noting is what we may call the 'representational motivation'. It has been employed in support of both the epistemic and the ontic forms of structural realism. Simply put, representation in the natural sciences is accomplished through the use of mathematical objects and the relations between them. Such objects, as structuralists in the philosophy of mathematics have been pressing, are nothing but places in a structure. That is to say, mathematical objects are structurally conceived or specifiable only up to isomorphism. By extension, the domains they represent are also structurally conceived or specifiable only up to isomorphism. Hence, mathematical modelling or representation naturally leads to structural realism. This seems to be the case irrespective of whether there is something over and above the abstract structure physical objects instantiate, that is irrespective of whether one supports the epistemic or ontic form of structural realism.

As with all the others, the representational motivation has not gone unchallenged. One line of criticism is that mathematical objects should not be understood in structuralist terms. Indeed, although the structuralist view holds great sway in the philosophy of mathematics, it is not a foregone conclusion. Another line of criticism is that the same motivation can be, and has been, utilised for anti-realist views – Bueno (1997), for example, fuses empiricism with structuralism – and hence does not uniquely favour structural *realism*.

5 Challenges

Arguably the most famous argument against structural realism is the so-called 'Newman objection', named after the mathematician M.H.A. Newman, who first raised it in a critical review of Russell's *The Analysis of Matter* (1927). Newman (1928) spotted that, on a certain natural reading of Russell's view, structural realism appears to offer no substantial information about the world. That's because the claim that a collection of objects can be structured in a certain way follows purely as a matter of set theory. In more detail, for a set S with cardinality c, set theory implies that provided c is large enough *any* relation and hence *any* structure can be defined on S.[13] Thus, if the structural realists claim that we can identify the abstract structure Σ_D (but not its concrete structure S_D) of a certain domain D with cardinality c_D, that seems tantamount to saying that *there exist relations*, we know not which, that have the formal features identified by Σ_D. But the existence of *all* relations compatible with cardinality c_D is guaranteed by set theory. Hence, if, on the one hand, that is what structural realists claim, then the only non-trivial component of that claim concerns the cardinality of the domain. If, on the other hand, structural realists attempt to say something more about those relations, then the structural restriction of their realism does not hold anymore, and hence the view is strictly speaking false.

Though it went largely unnoticed in the decades that followed, the objection was re-discovered by Demopoulos and Friedman (1985) – see also Ketland (2004) – who recast it in the context of the Ramsey-sentence approach to structural realism. Provided a theory is consistent and its observational consequences are true, the only non-trivial information about a domain of unobservables conveyed by the Ramsey sentence of that theory concerns its cardinality. For, just as in the original objection, so long as the cardinality of the unobservable domain is large enough (and the suppositions about consistency and observational truth hold) *any* relation and hence *any* structure can be defined on it. Thus, saying that *there exist relations between unobservables* possessing formal features identified by the corresponding Ramsey sentence is not saying anything we don't already know through set theory or second-order logic. To be clear, the triviality charge concerns only the unobservable content of Ramseyfied theories. The observable content is presumably still made true by facts about the world. But, as Demopoulos and Friedman emphasise, curtailing one's epistemic commitment to the latter content is as good as giving up on realism.

As expected, a number of replies have arisen in a bid to save the view. Here we consider three. The first can be found in a letter Russell wrote to Newman – reproduced in his ([1968] 1998). In it he concedes that the claim that we can only know the (abstract) structure of the unobservable world is indeed trivial but points out that in the same book he had already framed the whole discussion around several metaphysical suppositions about the unobservable world. In short, Russell seems to be suggesting that we 'know' things in addition to structure. It may be objected that such a view is no longer a form of structural realism and therefore that this is a capitulation to other forms of realism. We need only note here that it is a non-trivial matter whether the result is a collapse of Russell's impure form of structural realism into an existing form of realism.

The second has been put forth by Worrall. Less conciliatory than Russell, Worrall thinks that the trouble lies with the orthodox interpretation of the Ramsey sentence's content. According to him, another interpretation must be adopted, one in which it turns out that the non-observational part of that content covers much more than claims about cardinality. That's because some claims constructed merely out of observational terms are in fact non-observational in the sense that we are incapable of directly checking their truth value through observation.[14] Epistemic commitment to such statements is thus something that no empiricist would sanction. If correct, this move would defuse the charge that Ramsey-sentence structural realism collapses to anti-realist empiricism. Though, once again, one wonders whether the view construed this way does enough to differentiate itself from existing competitors.

The third response is due to Melia and Saatsi (2006). They argue that the best chance of rescuing the Ramsey-sentence approach to structural realism involves its augmentation with intensional operators, that is operators such as 'it is nomologically necessary that . . . '. That's because, in their view, the Achilles' heel of that approach is the purely extensional treatment of theoretical terms. Such a treatment is incapable of expressing modal relations between properties like the counterfactual dependence of some properties on others. That's where the aforesaid intensional operators can be of help. Once in place, they bind the theoretical variables of a Ramsey sentence in a way that allows them to convey not just information about the cardinality of the unobservable domain but also information about its modal properties. This is certainly a move that attempts to do justice to modal intuitions, but whether these intuitions are grounded in reality and whether realism needs modality are topics that have long been disputed.

Ontic structural realism is presumably immune to the Newman objection and therefore needs to provide no response to it. This is not only because it never espoused the Ramsey-sentence formulation but also because it (often) incorporates a commitment to modality. Ladyman and Ross (2007), for example, take physics and, more broadly, science to describe modal structure. In so doing, their epistemic commitments clearly take them beyond the frugal commitments of empiricist anti-realists. That being said, the exact richness of those commitments is unclear, as the structure to be described is sometimes construed as a structure of phenomena. This raises concerns about the extent to which such a view can be legitimately portrayed as a version of realism. Indeed, proponents of the view have openly flirted with empiricism.

Several other worries have been voiced. One concerns the cogency of the structure-versus-non-structure distinction. It has been claimed by Psillos (1999) that the two categories form a continuum, and therefore the distinction cannot be drawn in a crisp way. A related worry is that structural realists can only identify structure as that which survives scientific revolutions – if this were true, the historical motivation would of course be hollow. Attempts to address these worries have been made. Alas, considerations of space do not permit us to explore these in depth here.[15] Suffice it to say that one way to draw the distinction that seems to put the brakes on the continuum worry is in terms of descriptions that are restricted to abstract features of the unobservable domain and those that seek to go beyond them. What is more, and to defuse the second worry, one can argue that abstract features and in particular those that contribute to the success of the theory are discernible prior to any scientific revolution by considering what is required to infer the relevant successful predictions – see, for example, Chakravartty (2007) and Votsis (2012).

A final worry concerns the scope of the view. Almost without exception, cases motivating structural realism centre on the natural sciences and in particular on physics. To what extent, then, can it be said that the view applies also to the other sciences? This is a theme pursued by Kincaid (2008) who argues that structural realism can be fruitfully applied across the social sciences, indicating, for example, that it fits nicely with causal modelling and equilibrium explanation cases. Unfortunately, this is not a simple matter to solve. For one thing, many social science theories are not mathematised. For another, many such theories cannot be said to posit unobservable entities. Neither issue is conclusive in its indictment of structural realism – after all, theories can be implicitly mathematisable, and the observable-versus-unobservable distinction can take different forms – but they certainly raise serious doubts. There is, needless to say, an easier way out. If physical reductionism is true, then the final ontology of social science reduces to the final ontology of physics, and scope no longer poses a threat. But we simply cannot assume this to be the case. Instead, we must add it to the long list of issues that need to be resolved before any concrete answers can be given.

Notes

1 For a review of structural realism's historical trajectory, see Gower (2000).

2 How exactly it is drawn and whether it can be drawn at all is of course a major issue in this debate – see, for example, Putnam (1962). For now suppose that all of this is uncontroversial.

3 The sole exception is Katherine Brading and Elaine Landry (2006). They advocate what they deem to be a methodological version of structural realism, which, among other things, focuses on the role shared structure plays in relating predecessor to successor theories as well as high-level theories to low-level data.

4 Maxwell traces his own view back to Russell, among others. Though some elements of his view certainly derive from Russellian ideas, this attitude cannot be maintained with respect to the Ramsey-sentence formulation, which is demonstrably absent from Russell's own writings.

5 For example, the Russellian view can be given a Ramsey-sentence articulation – see Maxwell (1970).

6 See Lloyd Humberstone (1996) for some of the many possible ways of construing the distinction between intrinsic and extrinsic properties.

7 For a recent analysis of this motivation see Votsis (2011).

8 For more case studies see Chakravartty (2007) and Kitcher (1993).

9 See Frigg and Votsis (2015) and Russell (1927) for a lengthier exposition and critical evaluation of the requisite principles.

10 It is hard to imagine how this motivation can be of use to anything but the Russellian brand of structural realism. This is because the conception of observables and unobservables utilised here is different to those employed in other brands of structural realism.

11 One version of the argument (see French 2014: §2) sees the individuality of quantum objects as being underdetermined by the evidence. When faced with underdetermination, it is argued, the most prudent action is to drop the category for which no determination can be made. In the current case, the offending category is individuality.

12 Comparable arguments have been given for group theory and quantum field theory – see, for example, Cassirer ([1936] 1956) and Ladyman (1998).

13 A modern reconstruction of this set-theoretic reasoning goes like this: Extensionally understood, relations are ordered sets or sets of subsets. Thus, a relation in a domain of objects can be identified with some set of subsets of that domain. We know from the axiom of power set that every subset of a domain of objects exists. That means every relation of that domain exists.

14 As an example he offers the following assertion: "Nothing is older than 6000 years old" (2011, 167).

15 The reader is urged to consult Frigg and Votsis (2011: §3.2.1 & §3.5), where a brief discussion and further references are given.

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