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TRACING THE DEVELOPMENT OF STRUCTURAL REALISM

Ioannis Votsis

1. Introduction

This chapter traces the development of structural realism within the scientific realism debate and the wider current of structuralism that has swept the philosophy of the natural sciences in the twentieth century.[1] The primary aim is to make perspicuous the many manifestations of structural realism and their underlying claims. Among other things, I will compare structural realism's various manifestations in order to throw more light onto the relations between them. At the end of the chapter, I will identify the main objections raised against the epistemic form of structural realism. This last task will pave the way for the evaluation of the structural realist answer to the main epistemological question, an evaluation that will be central to the rest of this dissertation.

Generally construed, structuralism is a point of view that emphasises the importance of relations. It takes the structure, i.e. the nexus of relations, of a given domain of interest to be the foremost goal of research and holds that an understanding of the subject matter has to be, and most successfully is, achieved in structural terms. The following quote from Redhead (2001a) nicely conveys this intuition: "Informally a structure is a system of related elements, and structuralism is a point of view which focuses attention on the relations between the elements as distinct from the elements themselves"(74). This vision has shaped research programmes in fields as diverse as mathematics, linguistics, literary criticism, aesthetics, anthropology, psychology, and philosophy of science. It is the last-mentioned that I am concerned with in this chapter.

The first explicit statements of a structuralist programme in the philosophy of science can be traced back to Henri Poincaré, Pierre Duhem, and Bertrand Russell. Other structuralists or structuralist-oriented philosophers followed, notably Arthur Eddington, Ernst Cassirer, Rudolph Carnap, Moritz Schlick, W.V.Quine and Grover Maxwell. During the last decade and a half, the position has been revived, reformulated, and vigorously defended, by Otávio Bueno, Anjan Chakravartty, Tian Yu Cao, Bas van Fraassen, Steven French, James Ladyman, Michael Redhead, John Worrall, and Elie Zahar, to a name a few. Given the numerous differences between many of these authors it is not surprising then that there are almost as many structuralisms as there are structuralists.

A terminological remark is required at this point to ward off misapprehensions. 'Structuralism' will refer to the general intuition that the focus is on the relations and not the relata. To identify each individual position I will employ variant terms like

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[1] To the best of my knowledge, the only other attempt to trace the historical and ideological development of structural realism is to be found in Barry Gower (2000). Gower's article is rather narrowly construed, however, for he focuses mainly on Ernst Cassirer and Moritz Schlick.

'epistemic structural realism', 'ontic structural realism', 'structural empiricism', etc. Often, these names are already available but, where needed, I will provide my own names so as to keep track of who is arguing for what.

Before we delve into the different types of structuralism, I must present a definition of the notion of structure that is precise enough to help disambiguate some of the discussions. Although, as we shall see later, matters are more complex, we can begin the elucidation of the various forms of structuralism by presupposing the standard definition of structure:[2] A *structure* S = (U, R) is specified by two things: i) a non-empty set U of objects (the domain of S) and ii) a non-empty set of relations R on U.[3] A structure may also specify one-place properties but these are not essential. In other words, a minimum requirement for setting up a structure is to have a set-theoretically specifiable (i.e. extensionally defined) relation between objects. Notice that many of the mathematical statements central to science, i.e. functions, equations, laws, symmetries, principles, covariance statements, etc., postulate relations between terms that can usually be expressed set-theoretically in the above-mentioned way.

2. The Prehistory of Structuralism

As mentioned above, the history of structuralism starts with Poincaré, Duhem and Russell. Van Fraassen (1997; 1999), however, has recently added an interesting pre-history to the topic that deserves consideration. Drawing from 19th century discussions of how science represents natural phenomena, van Fraassen (1997) traces the beginnings of structuralism to the emergence of non-Euclidean systems of geometry. The discovery of such systems led to the realisation that no system is privileged, i.e. to a 'relativisation of representation'. The applicability of these systems to physics, van Fraassen claims, resulted in a parallel relativisation. For obvious reasons, this result challenged the naïve realist view that there is a unique way to represent physical space and, more generally, the physical world. In light of these developments, van Fraassen argues, Russell was led from naïve realism to structuralism. Though van Fraassen is not very informative about the reasons behind Russell's change of heart, the implication seems to be that because structuralism necessitates the non-uniqueness of descriptions, through the idea that things can be described only up to isomorphism, it supports a kind of 'relativisation of representation'.

In his more recent paper (1999), van Fraassen stretches our imagination even further by attempting to extend the prehistory of structuralism. He entertains the idea that structuralism could have gained support as far back as the 17th century. It is the increasing mathematisation of science, van Fraassen argues, that paves the way for structuralism. He sees Isaac Newton's introduction of non-mechanical, highly abstract and mathematical descriptions of nature as the end of one era and the beginning of a new one. At the same time, he sees in Newton a disdain for too much mathematisation for fear that it may lead to the Aristotelian occult properties he so desperately tried to

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[2] As we shall see by the end of this chapter, John Worrall and Elie Zahar argue against such a view of structure because individuals are taken as more basic than relations, i.e. relations are defined as sets of ordered n-tuples of individuals. They instead call for a new semantics that takes structures and, by extension, relations as more primitive than individuals.

[3] The definition of structure sometimes includes a third condition, i.e. a set O of operations on U (which may be empty). This condition is optional because operations are functions and thus can be regarded as special kinds of relations capturable by condition two.

avoid. Indeed, he sees the same misgivings in James Clark Maxwell. Both Maxwell and Newton, according to van Fraassen, oscillated and agonised between two extreme positions: ‘reification’ and ‘structuralism’. These positions, he argues, “emerge very naturally when science proves itself too complex for philosophical naiveté. We see a clear tendency to reify whatever theories invoke in their representation of nature. But conceptual difficulties and the increasingly mathematical character of science foster the structuralist impulse” (1999: 7). And, he continues, “[t]his is one of the main reasons why, I think, we see the structuralist reaction emerging in the 19th century. As so often happens, what is earlier seen as a failure or shortcoming becomes the glory of a new generation” (12).

I think van Fraassen’s claim, that Newton and Maxwell were wavering between reification and structuralism, is reading too much into history. His examples can only establish that these scientists were sceptical about too much mathematisation. Similarly, his colourful and somewhat cryptic remarks about the emergence of reification and structuralism are in need of further elaboration if they are to be taken seriously. Even so, it is certainly plausible that the mathematisation of nature in general and the rise of non-Euclidean geometries in particular, facilitated structuralist inclinations.

3. The Early Years

Poincaré

Poincaré is often thought of as a conventionalist, not only with regard to geometry but also physics, and as such not a realist. However, Grover Maxwell (1968), Jerzy Giedymin (1982), Worrall (1982; 1989; 1994), Zahar (1989; 1996; 2001), David Stump (1989), Stathis Psillos (1995; 1999), Barry Gower (2000), and Redhead (2001a) are all in agreement that Poincaré was an epistemic structural realist.[4] Epistemic structural realism (ESR) is, simply put, the view that our knowledge of the physical world is restricted to structure. I agree that Poincaré was an ESR-ist and, in what follows, present the reasons why I think this is the case.

Poincaré was heavily influenced by German idealism, a philosophical school that, as is well known, considers Kant as its progenitor. More precisely, Poincaré subscribed to the view that the non-phenomenal entities postulated by scientific theories are the Kantian things-in-themselves. Unlike Kant, however, he thought that it is possible to gain indirect knowledge of the things-in-themselves. What is it exactly that he thought we could know about them? Poincaré is unequivocal: “[T]he aim of science is not things themselves, as the dogmatists in their simplicity imagine, but the relations between things; outside those relations there is no reality knowable” ([1905]1952: xxiv). And again later on in the same book: “The true relations between these real objects are the only reality we can attain” (161). Despite the fact that the term ‘structure’ does not appear in these or other relevant passages, we are entitled to call Poincaré an epistemic structural realist for, after all, structures in their simplest form are just collections of one or more relations.

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[4] The term ‘structural realism’ was coined by Grover Maxwell (1968) with reference to Russell’s position. Stump does not use the term ‘structural realism’ but nonetheless understands Poincaré as a structural realist.

As many authors have pointed out, the motivation for Poincaré's structural realism is largely historical.[5] More precisely, he takes the survival of theoretical relations through theory change as indicative of their having latched onto the world. Here's an illuminating passage from *The Value of Science*:

> …science has already lived long enough for us to be able to find out by asking its history whether the edifices it builds stand the test of time, or whether they are only ephemeral constructions.
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> Now what do we see? At the first blush it seems to us that the theories last only a day and that ruins upon ruins accumulate… But if we look more closely, we see that what thus succumb are the theories properly so called, those that pretend to teach us what things are. But there is in them something which usually survives. If one of them taught us a true relation, this relation is definitively acquired, and it will be found again under a new disguise in the other theories which will successively come to reign in place of the old ([1913]1946: 351).

To support his argument, Poincaré draws examples from the history of science that exemplify precisely the survival/preservation of relations. Two main examples are worth citing here:

> This [i.e. the prediction of optical phenomena] Fresnel's theory enables us to do today as well as it did before Maxwell's time. The differential equations are always true… [they] express relations, and if the equations remain true, it is because the relations preserve their reality. They teach us now, as they did then, that there is such and such a relation between this thing and that; only, the something which we then called *motion*; we now call *electric current*. But these are merely names of the images we substituted for the real objects which Nature will hide for ever from our eyes ([1905]1952: 160-1).

> In its primitive form, Carnot's theory expressed in addition to true relations, other inexact relations, the *débris* of old ideas; but the presence of the latter did not alter the reality of the others. Clausius had only to separate them, just as one lops off dead branches.
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> The result was the second fundamental law of thermodynamics. The relations were always the same, although they did not hold, at least to all appearance, between the same objects. This was sufficient for the principle to retain its value (165).

The first passage draws attention to the fact that Fresnel's equations survive the shift from the ethereal theory of light to the non-ethereal electromagnetic theory. The reason for this, according to Poincaré, is that they express real relations (and hence structures) between physical objects. By contrast, the elastic solid ether itself and the conception of light as consisting of disturbances transmitted through the ether are abandoned. The second passage draws attention to the fact that some of Carnot's postulated relations in his ideal theory of heat engines, such as the so-called 'Carnot cycle', survive the transition from the caloric conception of heat to thermodynamics. In this case, it is the caloric, i.e. the conception of heat as a material fluid, which gets abandoned.

In sum, Poincaré's point is that the history of science indicates a preservation of these relations (but not of their relata) from theory to theory. This, he takes to be a good reason why we should be epistemological realists about the relations between which

[5] See the section on Russell for additional insight into Poincaré's motivation.

the objects hold, but not the objects themselves. As we shall see in the following sections, the historical evidence for structural realism becomes less clear-cut as we move from the classical framework to the relativistic and quantum revolutions of the twentieth century.

Duhem

Like Poincaré, Pierre Duhem is often seen as a conventionalist. Recently, some authors (see, for example, Worrall (1989), Chakravarrty (1998), Gower (2000), and Zahar (2001)) have argued that he is either an epistemic structural realist or, at least, has close affinities to the position. I agree that there is a structuralist vein to Duhem's work but do not think the evidence unequivocally warrants his classification as an epistemic structural realist. In what follows I present a short exposition of his views.

A central distinction in Duhem's work is that between the explanatory and the representative parts of a theory. According to Duhem, the *explanatory* part of a theory is that 'which proposes to take hold of the reality underlying the phenomena' whereas the *representative* part is that 'which proposes to classify laws'. Duhem likens the explanatory part to a parasite saying that:

> It is not to this explanatory part that theory owes its power and fertility; far from it. Everything good in the theory, by virtue of which it appears as a natural classification and confers on it the power to anticipate experience, is found in the representative part… On the other hand, whatever is false in the theory and contradicted by the facts is found above all in the explanatory part; the physicist has brought error into it, led by his desire to take hold of realities ([1914]1991: 32).

It is, thus, only the representative part of the theory that is doing the real work, i.e. that is producing the predictions. What, in Duhem's mind, is the epistemological status of the representative part?

There are certainly several passages where Duhem ascribes an epistemic structural realist status to the representative part of theories. For example, when he says that physical theory "never reveals realities hiding under the sensible appearances; but the more complete it becomes . . . the more we suspect that the relations it establishes among the data of observation correspond to real relations among things" (26-27). And also a few pages later when he says "…we are convinced that they [i.e. the relations postulated by theories] correspond to kindred relations among substances themselves, whose nature remains deeply hidden but whose reality does not seem doubtful" (29). In another remarkable similarity to Poincaré's position, Duhem claims that science's historical record reveals a preservation of relations through theory change:

> When the progress of experimental physics goes counter to a theory and compels it to be modified or transformed, the purely representative part enters nearly whole in the new theory, bringing to it the inheritance of all the valuable possessions of the old theory, whereas the explanatory part falls out in order to give way to another explanation (32).

Given the context set up by the earlier passages, it seems safe to assume that the relations preserved through theory change reflect relations between physical objects.

Despite these striking examples, we need to take note of some important qualifications that Duhem makes in the same passages. Although he acknowledges the existence of a strongly felt *intuition* that our theories correspond to reality, he holds that the data of observation “cannot prove that the order established among experimental laws reflects an order transcending experience” (27). The belief in this correspondence is merely “an act of faith”, says Duhem, which “assures us that these theories are not a purely artificial system, but a natural classification” (27). Thus, perhaps Duhem was an anti-realist after all.

Critics of this view will undoubtedly point out that no realist holds that we can *prove* the correspondence between theories and reality. That is, realists only claim that there are good reasons for holding such a belief. Moreover, given the centrality of faith to Duhem’s thinking, the ascription of the phrase ‘act of faith’ to the belief that there is a structural correspondence between observation and the world does not seem as threatening. It could even be an indication of Duhem’s strong support for the idea that the representative part of our theories corresponds to reality.[6]

Though the last comment is admittedly speculative, the plausibility of interpreting Duhem as an epistemic structural realist does not seem to be severely undermined, given his unequivocal claim about the preservation of relations through theory change. At any rate, Duhem is at least a structuralist of sorts. Depending on how much weight one assigns to the above qualifications, his position can be seen as a precursor to van Fraassen’s latest position, viz. empiricist structuralism, according to which even the preservation of structure through theory change can be given an anti-realist explanation (see section 8 of this chapter).

Russell

It is quite unsurprising that Russell has a substantial role in the history of structuralism, given that he initiated, developed, and significantly contributed to most important debates in analytic philosophy. What is not widely realised is how strongly the concept of structure permeated his philosophical work.[7] One of his first steps towards structuralism can be found in *The Problems of Philosophy*. Having recently read and been influenced by the British Empiricists, Russell regards the items of perception, which at the time take the form of ‘sense-data’, as the foundation of all knowledge. He argues that we have good reasons to believe that the causes of the sense-data we perceive are physical objects. But what can science tell us about physical objects? Russell’s answer is unmistakably clear:

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[6] Duhem was a devout Catholic who placed great importance on faith. Louis de Broglie, in the foreword to *The Aim and Structure of Physical Theory*, suggests that aspects of Duhem’s faith were also extended to his philosophical concerns. For example he says “It was not that Pierre Duhem, a convinced Catholic, rejected the idea of metaphysics; he wished to separate it completely from physics and to give it a very different basis, the religious basis of revelation”(ix).

[7] It is worth quoting a comment from Hiram McLendon, one of Russell’s students, who said of Russell’s preoccupation with the concept of structure: “In fact, so fundamental and pervasive is Russell’s use of this concept in *all his periods* of philosophizing and throughout each of his systems developed in *each of his major periods* that one might well survey most of his philosophy since 1912, when he published *The Problems of Philosophy*, from the standpoint of his uses of the concept of similarity of structure [i.e. structural isomorphism]” (1955: 88). See also Michael Bradie (1977) where the development of Russell’s use of the concept of structure is traced from *The Analysis of Matter* to *Human Knowledge*.

> Assuming that there is physical space, and that it does thus correspond to private spaces, what can we know about it? We can know *only* what is required in order to secure the correspondence. That is to say, we can know nothing of what it is like in itself, but we can know the sort of arrangement of physical objects which results from their spatial relations… We can know the properties of the relations required to preserve the correspondence with sense-data, but we cannot know the nature of the terms between which the relations hold (1912: 15-16) [original emphasis].

And again a page later:

> Thus we find that, although the *relations* of physical objects have all sorts of knowable properties, derived from their correspondence with the relations of sense-data, the physical objects themselves remain unknown in their intrinsic nature, so far at least as can be discovered by means of the senses (17) [original emphasis].

Thus, Russell argues, we can know only the properties of the relations physical objects stand in, and not, as common-sense realism tells us, their intrinsic nature. This is patently an epistemic structural realist position.[8]

It is worth pausing here and comparing Russell to Poincaré. Russell's Kantian remarks that we can know nothing about what space is 'in itself' and that the physical objects 'themselves remain unknown in their nature' share much with Poincaré's own Kantian undertones. Unlike Poincaré, Russell holds that we only have access to the properties of relations between physical objects, not the relations themselves. This does not seem to amount to a real difference since knowing the relations without knowing the relata simply means knowing the properties of the relations. What does seem, at first glance, different between the two philosophers is their motivation. Russell does not appeal to the history of science but rather to foundational considerations. A closer inspection of Poincaré's work, though, reveals that his motivation too was not *merely* historical but also foundational. In *The Value of Science*, Poincaré stresses that "nothing is objective which is not transmissible, and consequently that the relations between the sensations can alone have an objective value" (348). This idea follows from Poincaré's foundational concern that sensations are private and therefore intransmissible. Interestingly, Russell (1948: 485-6) makes similar remarks about the intransmissibility of everything but structure (see also Carnap (1928: §16) and Quine (1968: 161)). Conversely, it is not difficult to imagine Russell motivating his position with historical considerations. After all, if science identifies the properties of relations between physical objects, we should expect their preservation through theory change.

Russell's version of epistemic structural realism reached maturity in *The Analysis of Matter* (1927). There he argued that there are external causes of our perceptions, even though we should "not expect to find a *demonstration* that perceptions have external causes" (198) [my emphasis]. In fact, he devoted the twentieth chapter of this book to a causal theory of perception, rejecting "the view that perception gives direct knowledge of external objects" (197). We only have direct knowledge of the 'intrinsic character', 'nature', or 'quality' of percepts, i.e. the items of our perception. The only

[8] Even Russell's theory of truth and belief, appropriately named 'correspondence by congruence theory', is structuralist (see (1912: ch.12)). The nature of the correspondence relation is one of congruence, i.e. isomorphism. The truth bearer is assumed to be structurally isomorphic to the physical state of affairs. For more on this see Kirkham (1992).

way to attain knowledge of the external world is by drawing inferences from our perceptions. To underwrite such inferences Russell employed a number of assumptions. The most important of these are:

Helmholtz-Weyl Principle (H-W): "…we assume that differing percepts have differing stimuli" (255). In short, *different effects* (*i.e. percepts*) *imply different causes* (*i.e. stimuli/physical objects*)).[9, 10]

Mirroring Relations Principle (MR): "My point is that the relations which physics assumes… are not identical with those which we perceive… but merely correspond with them in a manner which preserves their logical (mathematical) properties" (252). In short, *relations between percepts mirror* (*i.e. have the same mathematical properties as*) *relations between their non-perceptual causes*.

For a closer examination of H-W and MR, I must ask the reader to wait until chapter three. For now suffice it to say that armed with these assumptions Russell argued that from the structure of our perceptions we can "infer a great deal as to the structure of the physical world, but not as to its intrinsic character" (400). More precisely, he argued that all that we can guarantee is that the structure of our perceptions is at most isomorphic to the structure of the physical world.

The notion of structure received a formal treatment from Russell. According to him, "[t]he 'relation-number' of a relation is the same as its 'structure', and is defined as the class of relations similar [i.e. isomorphic] to the given relation" (250).[11] The concept of isomorphic relations is employed here to convey the idea that the domain of interest is solely that of the properties isomorphic relations share. The motivation behind this idea arises from Russell's view that our epistemic access to the external world is indirect and, hence, cannot involve the unique identification of properties of, and relations between, physical objects.

Redhead (2001a) has called the notion of structure employed by Russell 'abstract structure'. To understand the notion of abstract structure we must first understand what it means for two structures to be isomorphic. A structure $S = (U, R)$ is *isomorphic* to a structure $T = (U', R')$ just in case there is a bijection ϕ: $U \rightarrow U'$ such that for all $x_1, \ldots, x_n$ in U, $(x_1, \ldots, x_n)$ satisfies the relation R_i in U iff $(\phi(x_1), \ldots, \phi(x_n))$ satisfies the corresponding relation R_i' in U'. If, like Russell, one wants to talk about a particular relation being isomorphic to some other relation, one need not go further than the definition of isomorphism between structures, for any particular relation specifies a structure, namely a structure whose set of relations contains one, and only one, member. We can now define the notion of abstract structure: An *abstract structure* Σ is an isomorphism class (or "isomorphism type") whose members are all,

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[9] Psillos (2001a) suggested this name for the principle on the basis of Helmholtz's and Weyl's appeal to it. It is worth noting that Russell sometimes uses the principle in its contrapositive (but equivalent) form, namely same causes imply same effects. Even Hume seems to endorse this principle as he advertises in the *Treatise* that "Like causes still produce like effects" (Book II, Part III, §1).
[10] Stimuli, according to Russell, are "the events just outside the sense-organ" (1927: 227). They are thus classified as physical events.
[11] For more on the reason why Russell's notions of structure and relation-number are co-extensive see Solomon (1989).

and only those, structures that are isomorphic to some given structure (U, R). Qua isomorphism class, it identifies the logico-mathematical properties of its members.

The notion of abstract structure is contrasted with what Redhead calls 'concrete structure'. The former makes explicit that the domain of objects and the relations defined on these objects are not uniquely specified but only up to isomorphism. That is, whereas a concrete structure specifies one domain of objects that comes with a set of relations, an abstract structure just specifies a constraint as to which domains and relations qualify, namely those domains equinumerous to some given number and those relations that share the same properties.[12]

On the basis of these definitions we can now summarise Russell's epistemic commitments as follows:

(REC1) Concrete observational structures.
(REC2) Abstract structures whose members are the concrete observational structures referred to in REC1.
(REC3) The existence of concrete physical structures that 1) have as domain members the causes of the concrete observational structures' domain members referred to in REC1 and 2) are members of the isomorphism classes referred to in REC2.

Russell's view can be presented as follows: Observational data falls into certain patterns allowing us to discover/postulate relations between observables.[13] Taking observables as our domain and collecting these relations into a set gives us the so-called 'concrete observational structures'. They are concrete because their domain is specified uniquely. The abstract structures corresponding to these concrete observational structures can then be deduced in a straightforward manner by a *process of abstraction*. To do that, all one needs to do is to write down the isomorphism class that the given concrete observational structure is a member of. By appeal to principles H-W and MR, we can then infer that to each concrete observational structure corresponds one, and only one, concrete physical structure such that: 1) the two are isomorphic, and 2) the domain members of the concrete physical structure, i.e. the physical objects, are causally responsible for the domain members of the concrete observational structure, i.e. the observables. Being isomorphic just means that the two concrete structures, i.e. the observational and the physical, are members of the same abstract structure, i.e. the same isomorphism class. The figure below illuminates the relationships between concrete observational, concrete physical, and abstract structures.

It is extremely important to note here that Russell's programme leans more towards an epistemological *reconstruction* of scientific knowledge rather than a description of what goes on in science. He does not claim that scientists actually observe first, and, solely on the basis of their observations, posit concrete observational structures that are then abstracted to a higher level, thereby allowing them to posit the existence of concrete physical structures instantiating the same abstract structure. The whole purpose of epistemological reconstruction is to offer a system through which

[12] The equinumerocity requirement simply reflects the fact that for there to be a bijection between two sets, the sets must have the same number of objects.
[13] This involves some sort of inference to the best explanation.

knowledge claims can be evaluated, oftentimes ignoring the actual methods employed in science. In any case, the question whether reconstruction is a desirable enterprise, though interesting in its own right, will not be addressed in this dissertation.

Another important qualification present in Russell's work is that the relations postulated between observables might not always be exact.

> Hence we conclude that we have to do with a correlation which is usual but not invariable, and that, if we wish to construct an exact science, we must be sceptical of the associations which experience has led us to form, connecting sensible qualities with others with which they are often but not always combined (1927:182).

A consequence of this view is that the relations postulated to exist between the observables' probable causes inherit the inexactness. This qualification should be kept in mind when we are evaluating Russell's view in subsequent chapters.

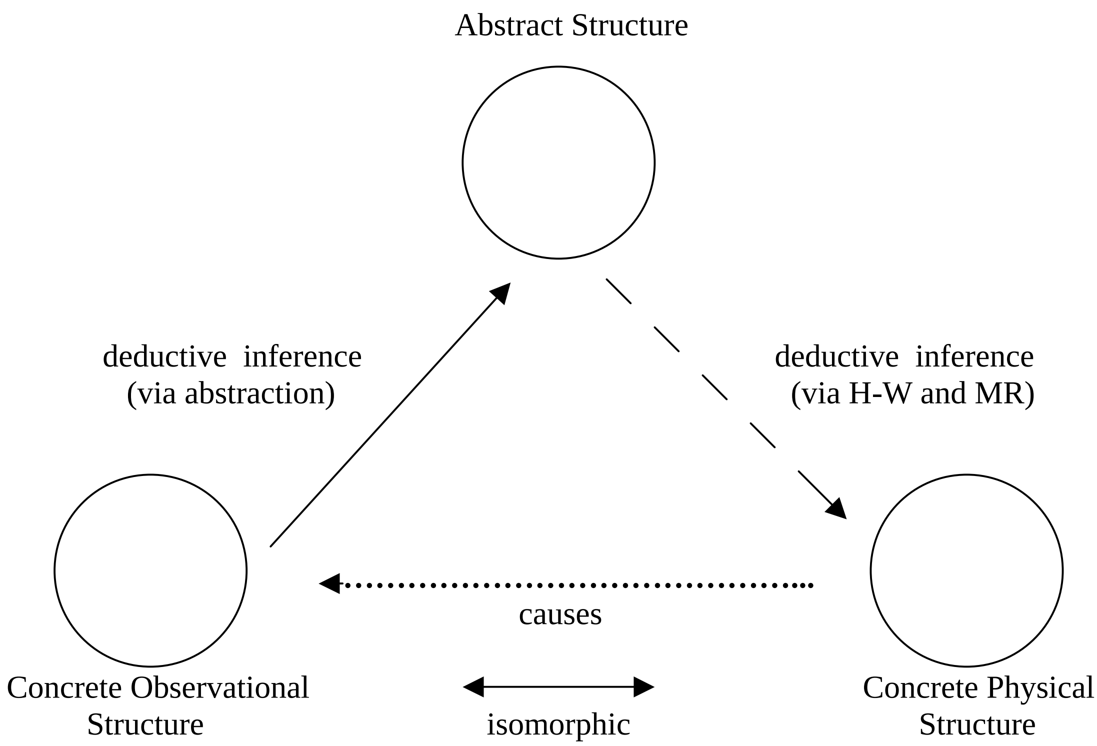

Figure 1: Russellian ESR

As indicated earlier, though Russell's epistemic commitments involve the properties of relations and Poincaré's involve the relations themselves, no real difference seems evident between them. Knowing the relations without knowing the relata simply reduces to the view that we can only know the properties of these relations. That is why we appeal to the notion of abstract structure. According to standard semantics, the interpreted terms of first order structures uniquely pick out individuals. This is something that advocates of ESR cannot sign up to, since they hold that we cannot uniquely pick out individuals. They thus resort to notions such as that of abstract structure. There is, however, another option for the ESR-ist, namely to change our understanding of standard semantics in order to accommodate the non-uniqueness of representation. As we shall see in section five below, Zahar advocates precisely such a change.

The Newman Objection

According to most commentators in the debate, the most serious objection against Russell's version of structural realism has been that of M.H.A. Newman in a critical review of *The Analysis of Matter*. He argues against Russell's claim that we can know only the structure of the external world, alleging that that claim is either *trivial* or else *false*. In the ensuing years, Newman's review received little attention until Demopoulos and Friedman (1985) unearthed it.[14] Let us return to Newman's formulation of the objection and consider the dilemma it poses.

The first horn of the dilemma, i.e. that ESR is trivial, is set up by the idea that Russell's structuralism, according to Newman, amounts to assertions of the following type: "[*t*]*here* is a relation *R* such that the structure of the external world with reference to *R* is *W*" (1928: 144). Newman argues that, aside from indicating the required cardinality, these assertions are not saying anything of importance since we can derive the same assertions for any given class by appeal to the following theorem: "For given any aggregate A, a system of relations between its members can be found having any assigned structure compatible with the cardinal number of A" (140). In other words, given the right number of objects we can set up any structure we like. Yet, we expect knowledge of the external world to be the outcome of empirical investigation not of *a priori* reasoning. Indeed, the only information that requires empirical investigation under Russell's view, according to Newman's argument, is information about the size of a given class.

The second horn of the dilemma, i.e. that ESR is false, rests on the idea "that it is meaningless to speak of the structure of a mere collection of things, not provided with a set of relations", and "[t]hus the only important statements about structure are those concerned with the structure set up … by a given, definite, relation" (140). The sole way to avoid trivialization, according to Newman, is by specifying the particular relation(s) that generate(s) a given structure. That is, if we specify R, instead of just saying 'There is a relation R that has a certain structure W', the fact that R has structure W is no longer trivial. The problem is that to specify R, one inevitably goes beyond the epistemic commitments of the structural realist so that ESR is rendered false.

In their article, Demopoulos and Friedman take Newman's objection as the definitive refutation of structural realism. They parade Russell's concession of the point in a letter to Newman (see Russell (1968: 176)) and his subsequent abandonment of the idea that our knowledge of the physical world is *purely* structural.[15] Interestingly,

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[14] Solomon (1989) points out that Newman's objection had been unsuccessfully employed by R. B. Braithwaite (1940) in a review of Arthur Eddington's *The Philosophy of Physical Science*. Solomon argues that Braithwaite did not correctly understand Newman's objection. Moreover, he argues that Eddington (1941), in his reply to Braithwaite, despite being confused about the notion of structure, should have realised that the objection was inapplicable in his case. See below for some brief remarks on Eddington's account. Finally, I have discovered that McLendon (1955), as it seems independently of Newman, also raises the triviality accusation against Russell's position.

[15] For Russell's post-1928 work on structuralism, see his *An Inquiry into Meaning and Truth* and *Human Knowledge*.

their presentation of Newman's objection is mainly a reconstruction that focuses on the Ramsey-sentence approach to theories. Following Grover Maxwell's suggestion, they argue that "it is possible to extract from the book [i.e. Russell's (1927)] a theory of theories that anticipates in several respects the Ramsey-sentence reconstruction of physical theories articulated by Carnap and others many decades later" (1985: 622).[16] After all, if all we can know about the external world is that there are relations that have certain properties, then the Ramsey-sentence seems like a good candidate to express such statements because it existentially quantifies over all theoretical predicates – remember that relations are merely 2+*n*-place predicates – thereby allowing only assertions about properties of such properties or properties of such relations. Demopoulos and Friedman argue that if a theory is consistent and all its observational consequences true, then the truth of its Ramsey-sentence follows as a theorem of set theory or second-order logic. On the basis of the above association between the Ramsey-sentence and structural realism, they claim that Russell's position collapses into phenomenalism.[17] Given the gravity of Newman's objection and associated results, I will devote chapter four to a thorough analysis of these issues.

4. The Years in Between

After Russell, the next systematic epistemic structural realist was Grover Maxwell. In between the two, a number of eminent philosophers espoused different forms of structuralism, but these were not systematically developed and have not contributed much to the current debate. In this section I briefly note their views.

It was Demopoulos and Friedman who first pointed out that Moritz Schlick's position in *General Theory of Knowledge* is quite similar to Russell's structural realism. Like Russell, Schlick distinguishes between structure and quality/content and holds that our knowledge of the world is restricted to its structure. Unlike Russell, Schlick rejects the idea that we know the structure of our experience. For him, the term 'knowledge by acquaintance' is an oxymoron. We can know the structure of the world but we are only acquainted with the content or quality of our experience. Schlick thus draws a line between knowledge and acquaintance that perfectly coincides with his distinction between structure and content/quality.

One of the oddest types of structuralism ever proposed is that of Arthur Eddington (see his (1939)). In Eddington's mind, our knowledge of the world is structural. Thus far his epistemological stance is in agreement with Russell's and not at all unreasonable.[18] The oddity can be found in his rejection of an idea common to most scientists and philosophers of science, i.e. that our knowledge of the physical world is at least justified *a posteriori*. According to Eddington, our knowledge of the physical

[16] Ladyman (1998) has argued that the Newman objection is identical to an argument put forward by Jane English (1973).

[17] The only thing that distinguishes phenomenalism and Russell's structural realism, according to them, is that the latter makes a cardinality assumption with regard to the external world.

[18] Steven French (2003) offers a more detailed analysis of Eddington's structuralism. Among other things, he argues that Eddington's structuralism has both epistemological and ontological implications, the latter leading to a position similar to the one advocated by French himself, viz. ontic structural realism. This form of structural realism is discussed in a section below.

world is purely *a priori*![19] Needless to say, it is hard to get used to the idea that a statement as implausible as this one comes from a physicist of such grand stature.

The implausibility of his position notwithstanding, it is worth bringing up one of the main motivations for Eddington's structuralism, namely group theory. The spread of group theory in the twentieth century, from geometry to quantum mechanics, seems to have made a lasting impact on his philosophy.[20] As Eddington acknowledges, his understanding of the notion of structure is group-theoretical. He thus says: "What sort of thing is it that I know? The answer is structure. To be quite precise it is structure of the kind defined and investigated in the mathematical theory of groups" (147).

Another structuralist from the same period as Schlick and Eddington is Ernst Cassirer. French and Ladyman (2003a: 38-41) recently resuscitated Cassirer's views. More precisely, they make a convincing case that Cassirer advocates an ontological version of structuralism, according to which relations, and hence structures, are the primitive ontological components of the world. Cassirer certainly drew ontological lessons from the developments of the quantum and relativistic revolutions. He thus asked questions like "Is there any sense in ascribing to them [i.e. electrons] a definite, strictly determined existence, which, however, is only incompletely accessible to us?" (1936: 178). His answer to this question and others like it is a resounding 'no', since he conceives of electrons not as individuals but simply "describable as 'points of intersection' of certain relations" (180). He thus seems to reject the traditional object-based ontology for a relation-based ontology that reconceptualises an object in terms of relations.[21]

At around the same time as these authors, Carnap made several decisive steps towards structuralism. That Carnap had structuralist inclinations was first suggested by Demopoulos and Friedman (1985). In the *Aufbau*, as is well known, Carnap advocates the reconstruction of all scientific concepts on the basis of private experience. Yet, it is unclear what precisely Carnap wants to achieve (see Creath (1998)). Some, for example, suggest that Carnap simply tried to reduce physical objects to observable phenomena, implying a phenomenalist project. Against this interpretation, Demopoulos and Friedman suggest that there is an undeniable structuralist streak in the *Aufbau*. More specifically, they claim that for Carnap, only those statements that express the structure of experience reveal the objectivity of science. Here's a telling passage quoted by Demopoulos and Friedman:

> Science wants to speak about what is objective, and whatever does not belong to the structure but to the material (i.e., anything that can be pointed out in a concrete ostensive definition) is, in the final analysis, subjective. One can easily see that physics is almost altogether desubjectivized, since almost all physical concepts have been transformed into purely structural concepts (1928, §16).

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[19] As Solomon (1989) has pointed out, this rejection makes Eddington's structuralism immune to Newman's objection because the latter is directed at claims that our knowledge of the external world is purely structural and a-posteriori.

[20] For more on this, see Steven French and James Ladyman (2003a: 50-51) but also French (2003). French and Ladyman argue that one other major motivation for Eddington's structuralism was the implications quantum physics had for the issue of the individuality of particles.

[21] See also Cassirer (1944).

Carnap, they point out, sets up a program of defining scientific concepts as ‘purely structural definite descriptions’. The important point to note is that these definite descriptions contain only logical vocabulary. This is a move similar to the Ramsey sentence, the only difference being that Carnap turns all the terms, i.e. not just the theoretical ones, into variables.

Recent work by Psillos (1999; 2000) has uncovered that Carnap defended a more robust form of structuralism in the fifties and sixties. For example, in ‘The Methodological Character of Theoretical Concepts’ Carnap holds that theoretical variables range over natural numbers but only because the domain of the naturals has a kind of structure that is isomorphic to the structure of the domain of the theory. Carnap signifies the importance of structure over its elements, saying that “the structure [of the domain of the theory] can be uniquely specified but the elements of the structure cannot” (1956: 46). In the years that follow, his structuralism becomes even more pronounced. The most important development is his reinvention of the Ramsey-sentence approach, under the name of ‘the existentialised form of theories’.[22] He avoids a realist interpretation by holding that in Ramseyfication the theoretical terms are to be replaced by variables that range over mathematical entities.

Carnap’s agenda, throughout this period, seems to have been to uphold a neutral stance towards the realism-instrumentalism debate. As made obvious above, however, his insistence on the interpretation of theoretical variables ranging over mathematical entities, as opposed to physical entities, tips the balance in favour of the instrumentalist side. In a move to avoid instrumentalism, Carnap explains that the variables in his system have two interpretations, one extensional and one intensional.[23] From an extensional point of view, the theoretical variables of the Ramsey-sentence range over mathematical entities. From an intensional point of view, the theoretical variables of the Ramsey-sentence can be seen as ranging over physical entities in that the intensions of theoretical terms are physical concepts not mathematical ones. This tips the balance in favour of the realist side since he allows the Ramsey-sentence to make existential statements about unobservable entities.

Carnap struggles with these issues through various manuscripts, letters, and articles.[24] As Salmon (1994) indicates, it is not until Grover Maxwell’s intervention that Carnap’s attitude towards the Ramsey-sentence settles. Through Maxwell’s influence, Carnap comes to see the Ramsey-sentence as incompatible with instrumentalism, since it can both attain a truth-value and make existential statements about physical entities. Even though Carnap adopts this view by 1974, he, unlike Maxwell, neither associates the Ramsey-sentence with structural realism nor embraces the latter. With these brief remarks on Carnap’s structuralism completed, it is time to turn to the Ramsey-inspired structural realists, starting with Maxwell.

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[22] Psillos cites a letter from Carnap to Hempel (dated February 12, 1958), where Carnap reveals that he had read Ramsey many years before he developed his own existentialized form of a theory but had completely forgotten about it.

[23] See Psillos (1999: 54) where he cites a letter from Feigl to Carnap (dated July 21, 1958).

[24] In the end, Carnap manages a type of neutrality, but one that is between realism and the Ramsey-sentence, not realism and instrumentalism (see Psillos (1999: 58-61)).

5. Epistemic Structural Realism, Ramsey-Style

Maxwell

In the late sixties, Grover Maxwell published a number of articles, defending an epistemic version of structural realism that owes much to Russell himself. Maxwell traces the position to Poincaré, Schlick, Wittgenstein and, naturally, Russell himself.[25] Echoing his predecessors, he speaks of the inability to have direct knowledge of the external world in distinctly Kantian terms:

> On the one hand there is the realm of phenomena. These are wholly *in the mind* (in our sense). Of the phenomena and only of the phenomena do we have *direct knowledge*. On the other hand, there are the things in themselves, and here our divergence from the views of Kant is great; although we have no *direct* knowledge of the latter, the bulk of our common sense knowledge and our scientific knowledge *is* of them… all of this knowledge is purely structural (1968: 155).

Closely adhering to Russell's version of structural realism, Maxwell urges commitment to the view that "all of the external world including even our own bodies is unobserved and unobservable" (152). He is thus using the term 'unobservable' in a way that is different from its use today. Like Russell, he does not discriminate between macro and micro-physical objects. For them, the term 'unobservable' denotes the set of all things inhabiting the external world, i.e. the set of all non-mental entities. Their claim, of course, is not that our observations have no causal origins in the external world, but rather that what we directly observe is 'wholly in our mind'.

Despite their agreement on what 'unobservable' denotes, there are certain differences between Russell and Maxwell that are worth pursuing. One difference is that Maxwell dissociates himself from reifying observable units, avoiding reference to things like sense-data, sensibilia, percepts, etc. (151). Instead, he places the spotlight on the linguistic level, with observation sentences and predicates as primitives. Somewhat paradoxically, Maxwell is best known for his critique of the distinction between observational and theoretical terms (see his (1962)). Yet, he here seems to advocate a strong distinction between observable and unobservable that is essential for his version of structural realism. The apparent tension is dissolved if one takes into account that, for him, the entire external world is unobservable. That is, this way of delineating the observable from the unobservable avoids the kinds of objections Maxwell raised in his earlier work. For example, seeing through instruments is no longer a threat to the observable-unobservable distinction since *all* seeing is restricted to the perceptual world.

Given the sense of 'unobservable' just sketched, how can knowledge of a wholly unobservable external world be had? The answer, says Maxwell, lies in the causal theory of perception. An important feature of this theory is that "it is *not* essential to the position [i.e. structural realism] that the sense impressions or perceptual experiences, or whatever we decide to call them 'resemble' the physical objects which may be among their causal antecedents" (1968: 155). What is necessary is that "at least a certain subset of the features of the [sense] impression are isomorphic with a

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[25] He also mentions Beloff (1962), Mandelbaum (1964), Aune (1967), Pepper (1967). Maxwell (1970b: 24) also claims that it is similar to the 'critical realism' of, among others, Roy Wood Sellars as well as to the representative realism of Locke provided certain modifications are made.

subset of the features of the physical object" (156). Without this type of 'resemblance', Maxwell insists, there can be no knowledge of the external world. His justification for this requirement proceeds via familiar Russellian techniques such as the claim that causal chains leading up to our perceptions are structure-preserving (1970b: 25) and the H-W principle (1968: 156).

Maxwell, like Russell, argues that the motivation for the causal theory "is virtually forced upon us by common sense as well as by science" (1970b: 23). In some limited sense, this is right. Most of us, after all, would agree that the causes of our perceptions originate in the external world. However, there is no widespread agreement on how the 'information' coded in our perceptions represents the external world if it does so at all. In other words, the claim that perceptions preserve the structure of their causes is more difficult to swallow. Maxwell admits that "there are no purely logical or purely conceptual reasons that there be structural similarities between objects in the external world and items in our experience" (25). Nevertheless, he claims that well-confirmed theories support this assumption, arguing that "if such [structural] similarities were fewer or, even, virtually nonexistent, knowledge of the physical realm would be more difficult to come by but not necessarily impossible" (25).

In line with Russell, but contra Poincaré, Maxwell claims that we cannot know the first-order properties of physical objects; we can only know their second or higher order properties, what he calls 'structural properties' (18). This is supposed to follow from the idea that first-order properties of phenomena, like colours, need not resemble the first-order properties of their causes. Maxwell's conclusion is that "[w]*hat holds of colors must also be true for all of the first order properties that we perceive directly*" (19) [original emphasis].

Maxwell praises Russell, among other things, for the reconciliation of realism with the logical positivist verificationist principle. This is achieved, Maxwell claims, through Russell's principle of acquaintance and his distinction between knowledge by acquaintance and knowledge by description. The principle of acquaintance is a close relative of the verificationist principle, for it states that to understand a proposition we must be acquainted with all of its constituents. With some perhaps not so trivial adjustments to the terminology, Maxwell transposes this idea to the current context, claiming that all descriptive terms in a meaningful sentence must refer to 'items' of our acquaintance, i.e. all descriptive terms *must* be observation terms (as opposed to theoretical terms).[26] Yet realism requires that we have knowledge of items with which we are not acquainted. This is where Russell's knowledge by description comes in, for it allows an object to be known by a list of descriptions – i.e. without our first being acquainted with it. Needless to say Maxwell takes knowledge by description to be the same as knowledge via theory.

As I mentioned earlier, one of Maxwell's contributions to the debate is the bridge he forges between the Ramsey-sentence approach and structural realism. It is at this point that the utility of the principle of acquaintance and the acquaintance vs. description distinction becomes evident. According to Maxwell, knowledge

[26] He thus assumes that the terms 'observation' and 'acquaintance' are co-extensive (1970a: 182). Notice that his deliberate choice of the term 'item' reflects his avoidance of what exactly the nature of the objects of our acquaintance is.

representation via the Ramsey-sentence approach validates both the principle and the distinction. This is so, because the Ramsey-sentence approach existentially quantifies over all theoretical terms but leaves all observation terms intact. Maxwell explains:

> [We] can formulate propositions that refer to unobservable properties or to classes of unobservable things by means of existentially quantified predicate variables and other purely logical terms plus terms whose direct referents are observables. Fortunately any theory whatever can be transformed without loss of significant content into such a proposition. It is only necessary to replace the conjunction of the assertions of the theory by its Ramsey sentence (16).

In accordance with Russell's principle of acquaintance, the 'items' that theoretical terms supposedly refer to, unlike the items of observation terms, are not 'ingredients' of a proposition. For Russell, this means that sentences expressing such a proposition will not contain a name or descriptive constant that refers directly to the alleged items. Diverging from Russell's viewpoint, Maxwell argues that there is a sense in which a proposition *refers* to the items that its theoretical terms prescribe. It refers to them indirectly, through "(1) terms whose *direct* referents are items of acquaintance and (2) items of a purely logical nature such as variables, quantifiers and connectives" (1970a: 182-3).

The advantage of employing the Ramsey-sentence approach is that its assertions are restricted to properties of properties of unobservables, i.e. it does not uniquely identify the properties of unobservables. This seems in accord with Maxwell's view that we do not have epistemic access to the first-order properties of unobservables.[27] Nonetheless, "our (Ramseyfied) theories tell us that they exist and what some of *their* (second and higher order) properties are" (1970b: 19) [original emphasis].

To appreciate the marriage between structural realism and the Ramsey-sentence approach, it is worth considering one of Maxwell's examples. Suppose that given numerous observations we pronounce the truth of the following sentence: $(\forall x)(\forall y)[(Ax \& Dx) \supset (\exists y) Cy]$ where *A* and *D* are theoretical predicates which stand for 'is a radium atom' and 'radioactively decays' respectively, and *C* is an observation predicate which stands for 'is an audible click in a Geiger counter'. If this sentence is true then its Ramsey-sentence, namely $(\exists \psi) (\exists \varphi) (\forall x) (\forall y) [(\psi x \& \varphi x) \supset (\exists y) Cy]$ where 'ψ' and 'φ' are predicate variables, will also be true. The principle of acquaintance holds that we cannot know sentences like the first one, because they mistakenly include fully interpreted theoretical predicates, i.e. *A* and *D*. The Ramsey sentence version circumvents this problem by merely asserting that such properties exist. Maxwell explains that our knowledge of these properties "is by description and, as in all such cases, we refer to them not by predicate constants, but indirectly by means of purely logical terms plus an observation term, in this case, 'C' " (1970a: 186-7).

Despite the strong case that Maxwell makes, Russell's version of structural realism and the Ramsey-sentence approach are inconsistent. True, both Russell and Maxwell advocate a notion of structure that identifies properties preserved by isomorphic

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[27] As I argue in the next chapter, the Ramsey-sentence approach is not in accord with Maxwell's idea about first-order properties.

mappings.[28] It is also true that the notion of abstract structure I presented earlier seems ideal for the purposes of both. In spite of this agreement, the Ramsey-sentence of a theory preserves the *logical structure* of the whole theory, something directly at odds with Russell's insistence that we infer the structure of the world from the structure of our perceptions.

To elucidate the point, consider the following example. Suppose that we have in our hands a theory, call it 'K', and that all it says about the world is captured by the claim: $(\forall x)\ [(T_1x \supset T_2x)\ \&\ (O_1x \supset \neg O_2x)]$.[29] Now, according to Russell, we find out about the structure of the physical world through the structure of observations. First of all, we take the concrete observational structure of K, i.e. $(\forall y)\ (O_1y \supset \neg O_2y)$, call it '$O_K$'. We then deduce the abstract structure of O_K, i.e. $(\exists\Phi)(\exists\Psi)(\forall y)\ (\Phi y \supset \neg\Psi y)$, call it '$A_K$'. Finally, via principles H-W and MR we postulate that there is a unique concrete physical structure, call it 'P_K', which instantiates A_K and whose domain members are the causes of the domain members of the concrete observational structure. We can express P_K as $(\forall y)\ (Fy \supset \neg Gy)$, where F and G are predicates referring to physical properties. Qua structural realists, we do not have epistemic access to the properties F and G are referring to, so we cannot say that we know P_K. All that we can say is that we know that there exist two predicates that: 1) refer to the physical properties that cause observable O_1 and O_2 and 2) that these predicates instantiate the predicate variables in A_K. We can call this last claim 'K_P'. The point that I am making here is that K_P is obviously different to the Ramsey-sentence of K, R(K): $(\exists\Theta)(\exists\Sigma)\ (\forall x)\ [(\Theta x \supset \Sigma x)\ \&\ (O_1x \supset \neg O_2x)]$. One major difference is that the Ramsey sentence of K asserts the existence of *at least* two physical properties, whereas K_P asserts the existence of *just two* physical properties. Moreover, the latter states that the two properties are the causal antecedents of O_1 and O_2, something R(K) does not do. Another major difference is that the logical properties of R(K) and K_P, at least in this example, are different. That suffices to establish that the two methods, i.e. Ramseyfication and Russell's method, are not equivalent. No wonder then that even Maxwell remarks in passing that "the Ramsey sentence is *approximately* equivalent to Russell's contention that we do have knowledge of the structural properties of the unobservable" (1970b: 17) [my emphasis].

Worrall and Zahar

Worrall's and Zahar's variety of epistemic structural realism, initially also branded 'syntactic realism', is inspired by Poincaré's historical arguments, and in this respect differs from both Russell's version and Maxwell's version. The recent interest in structural realism was instigated by the publication of Worrall's 'Structural Realism: The Best of Both Worlds?' a decade and half ago. Worrall there argued that a sensible position in the scientific realism debate needs to take into consideration two warring arguments: the no-miracle argument and the pessimistic induction argument.[30] In

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[28] In a puzzling footnote, Maxwell notes that the account he offers in his (1968) is incomplete and incorrect in that "structure should not be identified with form; rather it is form plus causal connections with experience" (154). I do not know what to make of this, though my suspicion is that he might be attempting to fend off objections on how much the notion of abstract structure can tell us about the world.

[29] Worrall objects that this example is artificial, for K does not involve any intricate logical relations between the observational and theoretical terms. This, according to him, makes the theoretical part of the sentence content-free. I will address this issue in section three of chapter four.

[30] Worrall traces PI and NMA to both Poincaré and Duhem (see (1989: 140-2)).

short and as already sketched in chapter one, PI holds that since predictively successful scientific theories have eventually been discarded, we have inductive evidence that even our current theories, despite their great successes, will also be discarded one day. NMA holds that realism is the *only* view that does not make the predictive success of science a miracle. Worrall offers ESR as a position that underwrites both of these arguments and situates itself midway between constructive empiricism and traditional scientific realism. It underwrites the NMA because it argues that the success of science reflects the fact that we have got the structure of the world right. It underwrites PI because it concedes that non-structure gets abandoned.

Following Poincaré, Worrall takes the Fresnel-Maxwell case as historical evidence for ESR. He indicates that the structure of Fresnel's theory, as it is for example expressed through his equations for the relative intensities of reflected and refracted light at the boundary between two transparent media of differing optical densities, was carried over to Maxwell's theory unscathed. Thus, Worrall argues, if we look at theory change solely from the perspective of mathematical equations, the Fresnel-Maxwell case counts as evidence for the essentially cumulative development of science.[31] The underlying assumption is that it is reasonable to hold that what survives theory change is what has really latched on to the world. According to Worrall, Fresnel was completely wrong about the *nature* of light, viz. that light consists of vibrations that are transmitted through an all-pervading medium, the ether. Fresnel was probably right, however, about its *structure*, i.e. that optical effects depend on something or other that vibrates at right angles to the direction of propagation of light, just as required by the equations.

A question that naturally arises from the above exposition of Worrall's views is whether the mathematical continuity found in the above case is a widespread phenomenon within the history of science. Worrall grants that the Fresnel-Maxwell case is unique in that Fresnel's equations are entailed by Maxwell's theory without any modifications.[32] It is more often the case that equations of an older theory reappear only as limiting cases of equations in a newer theory. Indeed, the two great theories of the twentieth century, viz. the theory of relativity and quantum mechanics, depart from classical physics in ways that prima facie seem difficult – some people have argued impossible – to reconcile.

Redhead (2001a), himself an ESR sympathiser, cites two cases where the structural continuity between old and new is difficult to maintain. The first case involves the relationship between Minkowskian and Galilean space-times. Unlike Galilean space-time, Minkowskian space-time admits a non-singular metric. If, however, we let the speed of light tend to infinity, the metric becomes singular. This leads to the disappearance of the relativity of simultaneity, allowing for the recovery of Galilean space-time. The second case involves the relation between the Poisson and Moyal bracket formulations of classical and quantum mechanics respectively. The latter formulation generalises the former by introducing non-commutative multiplication for

[31] Heinrich Hertz's often quoted comment that 'Maxwell's theory is the system of Maxwell's equations' is congenial with Worrall and Poincaré's claim that the essence of the theory is the relations it postulates.

[32] That the Fresnel-Maxwell case is atypical has also been pointed out by, among others, Howson (2001), Redhead (2001a), and Kitcher (2001).

phase space functions. If we set Planck's constant to zero, commutativity is recovered and so is the Poisson formulation.

Redhead's two cases are meant to illustrate an abrupt qualitative discontinuity between the new and the old. Regardless of this discontinuity, Redhead notes an apparent affinity between old and new structures:

> Qualitatively new structures emerge, but there is a definite sense in which the new structures grow naturally, although discontinuously, out of the old structures. To the mathematician introducing a metric in geometry, or non-commutativity in algebra are very natural moves. So looked at from the right perspective, the new structures do seem to arise in a natural, if not inescapable way out of the old structures (19).[33]

In other words, if, like the mathematician, we see how natural the leap is from old to new structure, then we realise that the discontinuity is not debilitating. Seeing as this argument rests on a metaphor, it is no wonder that Redhead is reticent regarding its force. A major task for the structural realist then is to find a way to make concrete the correspondence relation between old and new structures.

Zahar has recently claimed that a proper defence of ESR requires a departure from standard semantics. By interpreting relations only through their relata, he maintains, standard semantics fails to give due priority to the relations, which are, after all, the focus of structural realism. Here is what Zahar says:

> …according to structural realism, we often have a good reason for supposing that 'R' [i.e. a specific relation] reflects a real connection between elements about whose intrinsic nature we know next to nothing. The conditions under which we are entitled to make such a realist claim obtain whenever we have a highly unified hypothesis H which both involves R and explains a whole host of seemingly disparate facts in a non-adhoc way (2001:38).

Implicit in this passage is an association between knowledge of the intrinsic nature of objects and classical semantics. In rejecting the former, Zahar believes that we must also reject the latter. The presumed association, however, is highly dubious since not knowing the intrinsic nature of objects does not force us to abandon the characterisation of relations in terms of individuals. We can simply stick with the less radical view that the individuals are known only up to isomorphism, expressing our knowledge of relations as higher order claims about sets of individuals. What is more, Zahar's support for the Ramsey-sentence approach does not seem to square with his call for a new semantics. Either, the Ramsey-sentence approach plus the associated classical semantics works, in which case there is no need for a new semantics, or it does not work and that is (potentially) why we must look for a new semantics.

Another interesting development has seen the reconciliation of structural realism with a position proclaimed by many (see, for example, Niiniluoto (1999)) as its main competitor in the realist camp, namely entity realism. In a noteworthy article, Chakravartty (1998) has sought to bring the two together under the banner of his own position, 'Semi-realism'. He argues that the properties we detect in experiments should be central to both accounts. Commitment to the existential claims of entity

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[33] See also his (2001b: 346-347).

realism, says Chakravartty, can be achieved only through relying on relations between detectable properties. Conversely, these relations, which are the focus of structural realists, contain substantive information about entities. Thus, he concludes, properly understood entity and structural realism "entail one another; they are, in fact, one and the same position: semirealism" (407).

6. Psillos' Objections

In a recent succession of articles ((1995), (2000a), (2001a), 2001b)) and a book (1999, ch. 7), Psillos has attacked various versions of structural realism, especially those of Russell, Maxwell and Worrall. Since a proper exposition of these criticisms would take rather long, I merely list them here and ask the reader to wait for a detailed treatment in the ensuing chapter. The seven most important objections that emerge from Psillos' attack, all of them directly challenging ESR, are:

(PS1) ESR commits us only to uninterpreted equations but these are not by themselves enough to produce predictions (1999: 153-4).

(PS2) Structural continuity through theory change can be explained better by traditional scientific realism than by ESR (1999: 147-8).

(PS3) Some non-structural theoretical content is retained in theory change, and this is better supported by current evidence and more likely to be true than non-structural theoretical content in the past (1999: 147-8).

(PS4) The structure vs. nature distinction that ESR appeals to cannot be sustained (1999: 157).

(PS5) ESR faces a dilemma: On the one hand, the H-W principle by itself can only establish a relation of embeddability between the external world and the 'world' of percepts, not a relation of isomorphism as required by ESR. Without a relation of isomorphism, the structural realists cannot establish inferential knowledge about the structure of the external world. On the other hand, H-W together with its converse, viz. different stimuli/physical objects imply different percepts, allow for the establishment of isomorphic relations but, in doing so, concede too much to idealism (2001a: S13-S16).

(PS6) The claim that the first-order properties and relations of unobservables are unknowable in principle cannot be justified (1999: 156; 2001a: S20-21).

(PS7) Knowing the abstract structure of the external world is not enough since it merely amounts to knowing formal properties such as transitivity, symmetry and reflexivity (2001a: S16-S17).

7. Ontic Structural Realists

An altogether different species of structuralism has been proposed by James Ladyman (1998). Ladyman argues that structural realism should be understood not just as an epistemological, but also as a metaphysical position. He claims that this much is suggested by Worrall's version of structural realism, which, according to Ladyman, is ambiguous between the two manifestations. Yet, neither Worrall nor any other ESR-ist adopts any substantive metaphysical positions but rather asserts the epistemic inaccessibility to physical objects beyond the level of isomorphism. Steven French (1998; 1999; 2003) has joined forces with Ladyman (see their (2003a) and (2003b)) in advocating what they call 'Ontic Structural Realism' or OSR for short. As I have already indicated, they claim to have traced the roots of OSR to Ernst Cassirer. But let us take things from the beginning.

Appealing to some of the aforementioned objections to structural realism, particularly Newman's objection and Psillos' objection that the distinction between structure and non-structure cannot be drawn, Ladyman hastily concludes that ESR is incapable of solving the problem of ontological discontinuity through theory change.[34] He ties this problem to a type of underdetermination that originates in the philosophy of physics, namely whether elementary particles are individuals. A solution to this latter problem requires drastic measures, according to Ladyman:

> What is required is a shift to a different ontological basis altogether, one for which questions of individuality simply do not arise… So we should seek to elaborate structural realism in such a way that it can defuse the problems of traditional realism, with respect to both theory change and underdetermination. This means taking the structure as primitive and ontologically subsistent (1998a: 420).

This is the crux of OSR. Crudely put, OSR prescribes that all that exists in the world is structure. Consequently, all that can ever be known about the world is structure.

The motivation for OSR comes from considerations about modern and, in particular quantum, physics.[35] In classical physics, elementary particles are taken to be indistinguishable individuals. More precisely, they are only distinguishable with respect to their spatio-temporal coordinates but not with respect to any other properties they posses. Their individuality is thought of as something over and above these latter properties. The quantum view of elementary particles, say French and Ladyman, underdetermines the metaphysics of elementary particles. That is, they can be viewed as either individuals or non-individuals.

To illuminate this point let us take French's example of two indistinguishable particles that are distributed over two states (see his (1998)). The scenario obviously offers four possibilities: (1) particles *a* and *b* in state *A*, (2) particles *a* and *b* in state *B*, (3) particle *a* in state *A* and particle *b* in state *B*, and (4) particle *a* in state *B* and particle *b* in state *A*. Under the orthodox view of quantum statistics, (3) and (4) are thought of as one and the same possibility with nothing distinguishing between them.[36] That is, according to the Bose-Einstein statistics implicit in the orthodox interpretation of quantum theory, these two possibilities are considered to be the very same thing. French takes this to mean that the particles must be thought of as non-individuals. He concedes, however, that there is another view within quantum statistics that, at least in principle, takes (3) and (4) as distinct. From this, he concludes that quantum physics underdetermines, i.e. is neutral, between the view of particles as individuals and that of particles as non-individuals.

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[34] It is puzzling how Ladyman comes to think that these problems have anything to do with the problem of theory change.

[35] Paradoxically, French (1998) argues that we cannot read metaphysics off current physics.

[36] In classical statistical mechanics, (3) and (4) are thought of as distinct.

Astonishingly, French and Ladyman claim that this underdetermination supports OSR. Yet, at most, the underdetermination seems to raise doubts about the individuality of particles.[37] A defence of the view that we should throw away an individual-based ontology and reconceptualise the role of individuals in terms of structures, as French and Ladyman suggest, would at least require demonstrating that elementary particles are non-individuals. Their own insistence on underdetermination between the two possibilities defeats any such approach. If anything, the underdetermination counsels agnosticism between the two views of particles and, by extension, agnosticism about OSR.[38]

It is worth noting that in his original article, Ladyman offers the model-theoretic (a.k.a. semantic) approach to theories, according to which theories are conceived of as sets of models, as a general framework for the treatment of theories. Together with French, they have since then extended this framework with the so-called 'partial structures approach', developed first by Newton Da Costa (see, for example, Da Costa and French (1990)). Among other benefits, this approach allegedly provides a better representation of continuity through theory change, especially those cases where continuity is only approximate. As French and Ladyman have admitted, however, the radical shift in ontology requires a new semantics to go with it. What remains wanting, is the fleshing out of this much-advertised new semantics. Many have questioned the very possibility of conceiving of objects as structures. Moreover, even if the vaunted reconceptualisation were possible it is doubtful that this would be a good reason to abandon an object-based ontology.

In view of the fact that my dissertation deals solely with the epistemological dimension of the scientific realist debate, OSR will not be investigated further. It is mentioned here only in order to cover all major developments in structuralism of the natural sciences. Notwithstanding the perhaps insurmountable difficulties it faces, OSR is at the cutting edge of metaphysics, its proposal as radical as they get.

8. Empiricist Structuralism

Van Fraassen (1997; 1999) has vehemently attacked structural realism, both its epistemic and ontic forms, arguing instead for an empiricist version of structuralism, which he aptly calls 'empiricist structuralism'. He agrees with Worrall that there is a preservation of structure through theory change, but argues that the type of structure involved is the structure of the phenomena, not the structure of the unobservables (1999: 30-1).[39] In van Fraassen's eyes there are two realms of scientific investigation: 1) the phenomena and 2) the mathematical structures. We represent the structure of the phenomena with the help of mathematical structures.

Van Fraassen claims that the empiricist can explain how and why earlier theories were successful. Instead of the realist explanation that requires old theories to have latched on to the structure of the unobservables, his alleged explanation requires that

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[37] This objection, as well as many others, has also been raised by Tian Yu Cao (2003a; 2003b), Anjan Chakravarrty (2003) and Matteo Morganti (forthcoming).

[38] Ladyman seems to have had a change of heart. When I raised this point at a BSPS lecture given by French and entitled "*From Poincaré's Crutch to Melia's Weasel: Having One's Ontological Cake and Eating it too*" Ladyman agreed that what the underdetermination argument warrants is agnosticism.

[39] As van Fraassen notes: "There was something they [i.e. the theories] got right: the structure, at some level of approximation, of those phenomena" (31).

the new theories imply "approximately the same predictions for the circumstances in which the older theories were confirmed and found adequately applicable" (25). This, according to van Fraassen, doubles up as a criterion for theory acceptance. That is, a new theory must at least be able to make approximately the same confirmed predictions as the old one. It also satisfies the no miracles intuition, continues van Fraassen, without making the success of science a miracle, "because in any theoretical change both the past empirical success retained and new empirical successes *were needed as credentials* for acceptance" (25) [original emphasis].

The motivation for van Fraassen's structuralism is different from any of the ones we have seen so far. It is worth quoting him in full:

> According to the semantic approach, to present a scientific theory is, in the first instance, to present a family of models - that is, mathematical structures offered for the representation of the theory's subject matter. Within mathematics, isomorphic objects are not relevantly different; so it is especially appropriate to refer to mathematical objects as "structures". Given that the models used in science are mathematical objects, therefore, scientific theoretical descriptions are structural; they do not "cut through" isomorphism. So the semantic approach implies a structuralist position: science's description of its subject matter is solely of structure (1997: 522).[40]

Given that mathematical objects can only be described up to isomorphism, van Fraassen says, our use of mathematical structures to describe the phenomenal world makes us structuralists. The motivation is thus primarily linguistic, in that he is arguing that language, in particular mathematics, gives rise to, and perhaps even necessitates, structuralism.[41] This linguistic motivation is reminiscent of the view, held by Poincaré and Russell, that nothing other than structure is transmissible. It is worth noting that, despite the jargon used by semantic theorists, the semantic approach is superfluous in the above argument since one need not be a semantic theorist to hold the two premises, i.e. that mathematical objects are describable up to isomorphism and that we use mathematical objects to represent the world.

Following in van Fraassen's footsteps, Otávio Bueno (1997; 1999; 2000) argues for a position that he calls 'structural empiricism'. His position inherits some of the main features of constructive empiricism, such as the notion of empirical adequacy, but also van Fraassen's recent emphasis on structures. His notion of structure, however, is a bit more idiosyncratic. Like French and Ladyman, Bueno relies on a partial structures approach to scientific theories. Within this framework, he introduces variant notions of empirical adequacy, such as the notion of degrees of empirical adequacy, characterised in terms of the notion of partial isomorphism (see his (1999: section 3)). Indeed, Bueno takes himself as extending van Fraassen's account by fleshing out a more flexible relation between structures, provided by the partial structures approach. This has been a move already suggested by van Fraassen (see his (1997: 524)), and Bueno acknowledges as much.

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[40] See also his (1999: 31-2).

[41] Though van Fraassen does not elaborate on this point, I presume that his claim is not restricted to the language of mathematics but any language that has the tools to describe the world.

9. The Main Structural Realist Obstacles

Given the above elaboration of the historical development of structuralism and in particular structural realism, we can identify four main obstacles that structural realists need to somehow account for:

(SRP1) The Newman objection: The ESR claim that all that we can know about the world is that it has a certain abstract structure is either trivial or else false. It is trivial because, modulo cardinality constraints, such claims can be shown to be true a-priori by appeal to the theorems of set theory. It becomes false when, in order to avoid the triviality accusation, appeal must be made to non-structural considerations, thereby abandoning pure ESR.

(SRP2) The structural discontinuity objection: There is insufficient historical evidence for structural continuity through theory change. The Fresnel-Maxwell case is atypical. Most current theories' immediate predecessors are, at the level of structure, discontinuous with their successors.

(SRP3) Psillos' medley of objections: PS1-PS7.

(SRP4) The Empiricist Structuralist Challenge: There is continuity of structure through theory change, but it is continuity of the structure of phenomena not of the structure of unobservables.

These are added to the obstacles faced by scientific realism outlined in chapter one. The only exception is SRP2, which, naturally, overlaps with RP2 to a certain extent.

10. Conclusion

The history of structuralism in the natural sciences is rich and varied. Among the many structuralist positions, ESR, especially Worrall's version, has been hailed by many as a refreshing new hope for realism. As we have seen, it has also been heavily criticised. The rest of this dissertation will be an evaluation of ESR in light of the objections raised against it and, more broadly, the objections raised against all versions of realism. First in line is chapter three where I address Psillos' objections PS1- PS7, who spearheads the critique of structural realism. In addressing these objections I will try to clarify and make precise the notions and principles on which structural realism depends. Chapter four is devoted to the Newman objection, SRP1, hailed by many as *the* fatal blow to structural realism. In chapter five I pursue a historical case study in an effort to address the historical objections SRP2, and RP2. Following that is a chapter on underdetermination where RP1 and, for reasons that will become clear later, SRP4 are tackled. Finally, the seventh chapter offers a glimpse into the future directions the research of this dissertation can be taken.

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