Structuralism about Scientific Representation*

Martin Thomson-Jones

Preprint

1 Introduction

I have two central aims in this paper, both relatively modest. The first is to present some ways of thinking about structuralism about scientific representation. After distinguishing two distinct structuralist theses about representation — "vehicle structuralism" and "content structuralism" — from one another and from various other structuralist theses about the sciences (§2), I will separate three different non-formal concepts of structure (§3.1), discuss their relationship to the familiar formal concepts (§3.2), and consider two different ways of explicating vehicle structuralism (§4). I will then go on (and this is the second aim) to present a line of argument for the conclusion that structural realists of a certain familiar sort should reject both vehicle structuralism and content structuralism, and, relatedly, the semantic view of theory structure (§§5 and 6). Appallingly, this conclusion may not be at odds with the commitments of any particular philosopher or group of philosophers, but I think it will be useful to spell out the connections explicitly nonetheless.

*Some of the points made in this paper were first presented as part of a talk given at PSA 2004, but did not make it into the paper which appeared in the proceedings (Thomson-Jones 2006). Thanks to Anjan Chakravartty, James Ladyman, and Bas van Fraassen for helpful correspondence and discussion.

Along the way, I will show that both content structuralism and (one version of) vehicle structuralism face a threat of triviality, and limn some of the difficulties which result from the more obvious ways of trying to evade that threat (§§4 and 5); and, building on a discussion of the relationship between vehicle structuralism and content structuralism, I will suggest a counter to Callendar and Cohen's (2006) scepticism about the idea that understanding scientific representation is a worthwhile philosophical pursuit in its own right (§5).

2 Structuralisms

We should begin by distinguishing a number of distinct structuralist theses about the sciences: two about scientific representation, two about scientific knowledge, and one about the metaphysics of the world we are investigating when we engage in scientific work.

First, vehicle structuralism, a thesis about the means we employ in scientific representation:

> (VS) All scientific representation is representation by means of structure

This is view is certainly in the air, and it may plausibly be claimed to be in the literature.[1] It is motivated in at least in part, and for some, by an attachment to one version or another of the semantic view of theory structure: if we focus on the role of theories in scientific representation, see theories as collections of

[1] It is at least suggested by passages in French and Ladyman (1999), Brading and Landry (2006), and van Fraassen (2006a) and (2006b), for example — which is not to say that all these authors would embrace the view, or that any of them would embrace it exactly as I have formulated it here. See also the last paragraph of this section for an important qualification.

models, and then take representation via models to be representation by means of structure, the view that scientific representation is representation by means of structure acquires a clear impetus.[2]

Second is content structuralism, a thesis concerning the content of our representations:

(CS) All scientific representation is representation of structure

(We will consider the relationship between vehicle and content structuralism in section 5.) Third comes limit structuralism, a thesis about the limits of scientific knowledge:

(LS) We can know only the structure of the world

Fourth, scope structuralism, a more positive epistemological thesis:

(SS) We can and do know much about the structure of the world

Fifth, and finally, metaphysical structuralism:

(MS) There is only structure in the world

The two varieties of contemporary structural realism distinguished by Ladyman (1998), epistemic and ontic, can then be characterised by saying that although they are both committed to (LS) and (SS), they differ over (MS): ontic structural realism affirms it, and epistemic structural realism denies it (or perhaps takes no stand on it).[3]

[2] I will address the question of how vehicle structuralism might be understood in some detail in section 4; and see the end of section 6 for more on the connection to the semantic view.

[3] These are only partial characterisations of the two varieties of structural realism; in particular, no claim has been made about the knowability of the structure of the unobservable world. Note also that there is a harmless redundancy involved in this characterisation of ontic structural realism: given (MS), a commitment to (LS) is unavoidable.

My focus is, first, on the two theses about scientific representation, and second, on the links between those theses and the epistemological theses.[4] One such link is straightforward: content structuralism entails limit structuralism. (That is, if all scientific representation is of structure, then scientific knowledge can only be knowledge of structure, as knowing that *P* involves representing the world as being such that *P*.) In section 6 we will encounter another, less direct link, but the point for now is just that the various theses can bear upon one another; and that, of course, adds to the interest of the theses about representation.

One last but very important point before we proceed: It might be objected that I have set up straw men by making vehicle and content structuralism claims about *all* scientific representation. If this is a concern, then we can insert a qualification into both theses throughout the following discussion: instead of making claims about all scientific representation, we can read them as making claims about all scientific representation via models and theories. They then become the claims that all scientific representation via models and theories is representation by means of structure, and that all scientific representation via models and theories is of structure, respectively.[5] Taken this way, there is much less room for complaints about straw men (or so it seems to me). In any case, it is worth noticing that the arguments given below go through whether they are read as concerning the stronger or the weaker versions of vehicle structuralism and content structuralism.[6] As the stronger formulations are simpler and more easily stated, I will employ them throughout; the reader can insert the relevant

[4] I will, for the most part, leave (MS) aside.

[5] Note that this way of putting things assumes nothing about the relationship between models and theories.

[6] See n. 23 for the one point at which it makes a difference.

qualifications if she so chooses.[7]

3 Structure

Arguments in favour of any of the structuralist theses we have just delineated need to include some elaboration of the notion or notions of structure which are in play. If the four negative theses — (VS), (CS), (LS), and (MS) — are to be interesting, furthermore, then the pressing issue is to ensure that the notions of structure being employed are thick enough to guarantee that something is ruled out. (Indeed, the philosophers who defend structuralist theses like these clearly take themselves not just to be ruling something out, but to be ruling out views actually held by other philosophers.) I will be not be arguing for any of the theses in question, and so I am spared the full burden of that task; but I do want to recommend a particular set of concepts of structure as especially helpful for the purposes of thinking about structuralism concerning scientific representation. These concepts are relatively intuitive, and they are not formal concepts. As I will explain, however, I think they have some advantages over the formal notions which tend to predominate in current discussions.

3.1 Three notions of structure

The first concept of structure I want to identify is the one at work in the architectural remark "There's a remarkable modernist structure on the corner of 57th and Parker." Here a structure is a particular object, an object which has parts

[7] Though I will not be presenting an overall assessment of (VS) or (CS) in this paper, I offer arguments against both in "Mathematical and Propositional Models" (in preparation). I do not, and would not argue that *no* scientific representation is representation by means of structure, however, nor (of course) that no scientific representation is of structure.

that have various properties and stand in various relations to one another. In this sense, the only objects which do not count as structures are mereological atoms, if such there be; but we only *call* something a structure in this sense when we want to call attention to... well, to its structure in one of the other two senses we are about to consider. Those other senses will be primary in what follows. To avoid confusion, I will say 'structured object' to capture this first notion; 'structure' will be used exclusively in the second and third ways.

In the second sense, a structure is an arrangement of properties and relations amongst the parts of an object. A structured object has, or instantiates, or exemplifies, a structure in this second sense (I will use the three verbs interchangeably). Structures of this sort are thus good candidates for being universals, whereas structured objects are particulars.[8]

We can characterise a given structure of this sort specifying the conditions under which an object, X, has it. So, for example, consider the concrete structure **S1**:

> X has **S1** iff there is a partition of X into five parts, a, b, c, d, and e, such that (i) a is above each of the other parts, but no other relations of aboveness obtain between the parts, and (ii) b, c, d, and e are all metallic, but a is not.

My desk provides an example of an object which instantiates **S1**; the partition I have in mind is one on which a is the desktop (which is glass), and b, c, d, and e are the legs.

[8] It does not matter for present purposes whether structures of this second sort are in fact universals, or even whether there are any universals; I mention the issue only as a way of characterising the notion of structure I have in mind.

A structure in this second sense can be characterised by a sentence of the form:

> X has S iff there is a partition of X into n parts such that...

where the ellipses are filled in by some collection of statements about properties possessed by the parts, and relations holding amongst them.[9] (We can also allow, as a generalization of this schema, characterisations which refer to partitions into infinite collections of parts.)[10] I will call structures of this second sort *concrete structures*; the reason for this will become clearer when we meet the third notion of structure.

Note that there is no requirement of completeness built into the notion of a concrete structure — to say that object X has concrete structure S is not to say that S contains *all* the properties of and relations amongst the parts of X. (This point is entailed by the mere fact that **S1** is counted as a concrete structure instantiated by my desk, given that the parts of the desk have other properties and stand in other relations to one another than those included in **S1**.) Relatedly, an object can instantiate more than one concrete structure.[11] So, for example, my desk also instantiates **S2**:

[9] If we so wish, this schema can be treated as providing a reductive analysis of the 'X has S' locution when that locution is employed in the sense I am hereby specifying (so that the reductive analysis is correct by stipulation, so to speak). This means that we need not worry about the ontological status of structures as entities in themselves, or of such things as "arrangements of properties and relations"; talk of structures can be treated simply as indirect talk of parts, properties, and relations, and so as no more mysterious than talk of those things (however mysterious that may or may not be).

[10] We might also want to allow schemas of the form "X has S iff there is a partition of X into *at least* n parts such that..."; this would amount to allowing structures which are instantiated by an object purely in virtue of the properties and relations of just *some* of its parts.

[11] Whether one should think that there is, or might be, a structured object which instantiates only one concrete structure will depend on one's views about the metaphysics of properties, amongst other things. But even if there are such objects, they are clearly atypical.

> X has **S2** iff there is a partition of X into five parts, a, b, c, d, and e, such that a is above each of the other parts, but no other relations of aboveness obtain between the parts.

and **S3**:

> X has **S3** iff there is a partition of X into five parts, a, b, c, d, and e, such that b, c, d, and e are all metallic, but a is not.

relative to the partition on which a is the desktop and the other parts are the legs. And there are other partitions of my desk: into the electrons, protons, and neutrons it contains, for example, or (if one's ontology is sufficiently generous) into its left half and its right. The existence of these other partitions clearly multiplies further the range of concrete structures my desk instantiates.[12]

Note also that **S2** is a *relational concrete structure* (or *purely relational concrete structure*, for emphasis). That is, instantiating such a structure is purely a matter of having parts which stand in various relations to one another; no intrinsic properties are involved. Relational structures will become important in section 4.2.

Our third and final notion of structure is the notion of an *abstract structure*. As with concrete structures, we can characterise an abstract structure by specifying the conditions under which an object has it, using a sentence of the form:

> X has S iff there is a partition of X into n parts such that...

where, again, the ellipses are filled in by some collection of statements about properties possessed by the parts, and relations holding amongst them. The

[12] Incidentally, the present approach to thinking about structures can easily accommodate the notion of a substructure: we can simply say that S is a substructure of S' iff necessarily, for all X, if X has S', then X has S. (So **S2** and **S3** are both substructures of **S1**, for example.)

crucial difference is that when S is an abstract structure, the statements in question make no mention of any *specific* properties or relations.

As an example, suppose we start with the description of **S1**, and substitute for the specification of particular properties and relations the mere mention of some of the general characteristics of those properties and relations:

> X has **S4** iff there is a partition of X into five parts, a, b, c, d, and e, such that (i) there is an irreflexive, asymmetric, transitive two-place relation which a stands in to all and only the other parts, but which none of the other parts stands in to any part, and (ii) there is a property which b, c, d, and e all have, but which a does not.

S4 is another structure my desk instantiates, but one which it is natural to think of as abstract in a way that **S1**, **S2**, and **S3** are not.[13] Hence the labels: on the usage I am laying out here, **S1**, **S2**, and **S3** are all concrete structures, whereas **S4** is an abstract structure. The distinction rests on the question of whether there are specific properties or relations the parts of an object must possess in order for the object to have the structure in question.[14]

Note that various points made about concrete structures carry over in obvious ways to abstract structures: there is no requirement of completeness on an abstract structure; any given object will instantiate more than one abstract structure; many, perhaps all objects can be partitioned in more than one way,

[13] Note that I am not thinking of the relation in question as defined exhaustively by its extension on the set $\{a, b, c, d, e\}$; if it were, the mention of irreflexivity would be redundant.

[14] The examples I have given are ones in which either every mention of a property or relation is specific (**S1**, **S2**, and **S3**), or none are (**S4**). I will take it that those are the cases of interest, and leave aside the category of "mixed" cases.

Note also that I am using the labels 'abstract' and 'concrete' differently than Redhead (2001, pp. 74-75) and Votsis (2003, p. 881, and 2005, p. 1363); see §3.2 for more, and especially n. 17.

giving rise to even more abstract structures; and we can carve out, as a subclass of the abstract structures, the purely relational abstract structures.[15]

Finally, note that in picking out an abstract structure, we are indirectly picking out a *kind* of concrete structure. In picking out **S4**, for example, we are picking out that kind of concrete structure which involves: a partition of an object into five parts: an irreflexive, asymmetric, transitive two-place relation which one of the parts stands in to all and only the other parts, but which none of the other parts stands in to any part; and a property which is possessed by all and only those parts which do not stand in the aforementioned relation to any part.

In what follows, I will use the unmodified term 'structure' to cover both concrete and abstract structures, for much of what I want to say about the structuralist theses we are considering will apply whether those theses are understood as concerned with concrete or abstract structures.

3.2 Formal notions of structure

Proponents of structuralism tend to employ notions of structure which are more formal than the ones I have just laid out. One standard notion is what I will call the "tuple" notion of structure, on which a structure is an ordered tuple of the form $< U, P_i, R^n_j >$, where U is a set, the P_i are subsets of U, and the R^n_j are subsets of the n-fold Cartesian product of U with itself (for a range of values

[15] The substructure relation can be defined for abstract structures in just the same way as for concrete structures — see n. 12. We can also capture the idea that some abstract structures are more abstract than others, at least in part, by saying that if S and S' are both abstract structures, and S is a substructure of S', then S is more abstract than S'. (Suppose we elide the mentions of irreflexivity and transitivity from the characterisation of **S4**, for example.) It is important, however, not to confuse this notion of abstractness with the binary notion of abstractness laid out in the text. The binary notion will be the default notion when the terms 'abstract' an 'concrete' are applied to structures in what follows.

of n). The P_i are thought of as properties-in-extension (on U) possessed by the members of U, and the R^n_j are, similarly, relations-in-extension (on U) of various n-ary relations holding amongst the members of U.[16] A second formal notion is what I will call the "isoclass" notion, on which a structure is an isomorphism class of such tuples. I am drawing particularly on Votsis (2003, p. 881) here, but both of these formal notions, and others closely related to them, can be found throughout the literature.[17] The tuple notion, for example, plays a central role in the partial structures approach (e.g., French and Ladyman (1999), Da Costa and French (1990), and Bueno (1997)).[18]

What is the relationship between such formal notions of structure and the

[16]The 'P_i' is often absent. Sometimes this is because properties-in-extension are treated as unary relations-in-extension, so that the 'R^n_j' is read as covering them; and sometimes it is because the focus is exclusively on relations-in-extension, and so on a formal analogue of what I have called purely relational structures. I have nonetheless included the 'P_i' for greater ease of comparison to the informal notions laid out in the last subsection. The relevant adjustments are easily made when we want to focus on the special case of purely relational structures. Similarly, we might in some contexts want to consider tuples also containing distinguished members of U, or functions-in-extension, or both.

It is worth noting that a structure of this sort is also a structure in one established logical sense — namely, the sort of thing which provides an interpretation for a set of sentences in a first-order language. This is no coincidence: see n. 26.

[17]Votsis uses the labels "concrete" and "abstract" rather than "tuple" and "isoclass"; I have not followed his usage for obvious reasons.

Incidentally, in his (2005, pp. 1362-1363), Votsis seems to attribute both the tuple and the isoclass notions to Redhead (2001), but it is not clear to me that Redhead means to be employing either of them. Redhead gives as one example of what *he* calls a concrete structure "a pile of bricks, timbers and slates, which are then 'fitted together' to make a house" (2001, p. 74), and makes no mention of ordered tuples, so his notion of a concrete structure does not seem to be Votsis's (i.e., the tuple notion). Redhead then says that we can think of what he calls an abstract structure as *either* an isomorphism class of the sorts of things he calls concrete structures, *or* "in an ante rem Platonistic sense as the second-order Form which is shared by all the concrete relational structures in a given isomorphism class…" (ibid. p. 75). The second notion is clearly not equivalent to Votsis's notion of an abstract structure (which is the isoclass notion), and if I am right that Redhead's notion of a concrete structure is not the tuple notion, then the notion of an isomorphism class of (his) concrete structures is not Votsis's notion of an abstract structure, either.

[18]In that approach, the relations-in-extension are partial relations — relations-in-extension which may be defined only on a proper subset of U — but that difference will not bear on the present discussion.

informal notions laid out in the previous subsection? The first and simplest point is that neither formal notion can be equated with any of the informal notions. Set-theoretical tuples and isomorphism classes of such tuples are structured objects, certainly, but many structured objects are not set-theoretical tuples — my desk, for example. And structures in the informal sense, whether concrete or abstract, are the sorts of things which can be instantiated; neither a tuple nor a class of such tuples can be.

The second point is that, contrary to what we might initially be inclined to suppose, there are no simple one-to-one correspondences between the formal and informal notions. Consider, for example, the relationship between structures as tuples and concrete structures. First, a given $< U, P_i, R^n_j >$ will very often fail to single out a unique concrete structure, because specifying the P_i and the R^n_j will not, in general, single out a unique collection of properties and relations: two or more properties or relations can share an extension on a restricted domain.[19] For example, although it is true of the property of being metallic that it is a property which all the legs of my desk have but the desktop lacks, the same is true of the property of being cylindrical and the property of weighing 5lbs.[20] Secondly, it is obvious that there is no simple correspondence in the other direction: a given concrete structure does not typically single out a unique $< U, P_i, R^n_j >$, as many concrete structures are possessed by more than one object. Even choos-

[19] Of course, it may also be true that two or more properties or relations can share their extension *simpliciter* — perhaps even across an infinite set of concrete possible worlds — but the claim I need here is a much less controversial one.

[20] This example suggests that the "underdetermination" of concrete structure by structures-as-tuples will be a widespread phenomenon even if our ontology of properties is a sparse one, or (alternatively) we are restricting attention to a limited range of natural properties. On a more promiscuous ontology of properties, or given a less restricted field of attention, such underdetermination will be ubiquitous.

ing both a concrete structure and an object which has that structure will not always fix a unique $< U, P_i, R_j^n >$, as some objects instantiate some concrete structures relative to more than one partition. Thus there is no simple way of pairing up concrete structures with structures-as-tuples. And although there is not the space to go through every option here, this result generalises: there are no simple one-to-one correspondences between structures of either formal kind (tuples of the form $< U, P_i, R_j^n >$ or isomorphism classes of such tuples) on the one hand, and structures of either informal kind (concrete or abstract) on the other.[21]

The informal notions are thus not equivalent to the more standard formal notions. I would argue, however, that the informal notions have at least three advantages over their formal cousins. The first is their greater simplicity. The second is that the notion of a concrete structure does not tie the structure to a particular object or system which has it, unlike the tuple notion. If we are using the informal notion, we can point first at my desk and then at another desk of the same model, back at the IKEA store, and say "Look, same structure!"; with the formal notion, we cannot. In this respect it seems to me that the notion of a concrete structure captures something central to our intuitive notion of structure which the tuple notion does not.[22]

The third advantage of the informal notions is that they yield readings of ve-

[21] Or between structures of either formal kind and structured objects, for that matter.

[22] The isoclass notion *does* allow one to say "Same structure!" when pointing at the two desks, of course; but that notion does not enable us to capture the sense in which there is a structure shared by the two desks which is shared only by objects which have parts instantiating a certain pattern of relations of aboveness to one another. If, on the other hand, we are interested in focussing on a more abstract sort of structure the desks have, one which is *not* tied to the possession of any specific properties or relations, then the informal notion of abstract structure will serve our purposes just as well as the isoclass notion.

hicle structuralism and content structuralism on which those theses have greater *prima facie* plausibility. (a) Vehicle structuralism is the thesis that all scientific representation is representation by means of structure. If this is interpreted as the claim that all scientific representation employs set-theoretical tuples, or isomorphism classes of such tuples, say, it is less plausible than if it is interpreted as the claim that all scientific representation involves concrete structures, or even abstract structures: the claim that scientists are always singling out and employing arrangements of properties and relations, or kinds of such arrangements, when representing the world is surely easier to swallow than the claim that they are always employing formal structures of (say) a set-theoretical variety.[23,24] (b) Content structuralism is the thesis that all scientific representation is of structure. This, again, is clearly more plausible if it is read as the claim that all scientific representation is representation of arrangements of properties and relations, or kinds of arrangements of properties and relations, than if it is read as

[23] See the next section, when it will become clearer what I mean by talk of singling out arrangements of properties and relations and employing them in representation.

Incidentally, this is the one point at which the strength of my argument might be thought to depend on the fact that I have adopted an unqualified formulation of VS. It will seem to many less implausible that all scientific representation *by means of models and theories* involves the employment of formal structures than that *all* scientific representation does so, and not only because the former is a logically weaker thesis: the weaker claim may, in fact, have a fairly high degree of plausibility for adherents of at least some central varieties of the semantic view. Leaving aside the big question of whether the semantic view gets things right, however, we can say that even the qualified version of VS — the weaker claim — seems (pre-theoretically) more plausible when construed in terms of the informal notions of structure than the formal, even if the plausibility gap is smaller than the gap between the informal and formal construals of the unrestricted version of VS. I would thus maintain that this argument for using the informal notions goes through either way.

[24] This is quite compatible with the claim that it might be helpful, for certain purposes, to use formal structures in the philosophical representation of the workings of scientific representation. French and Ladyman (1999, p. 107) and French (forthcoming) emphasise that various of their claims are to be taken in this latter spirit. It seems to me, nonetheless, that if we want to understand how scientific representation works, then sooner or later we will need to know what sorts of thing scientists in fact employ when representing the world.

the claim that all scientific representation is representation of set-theoretical tuples, or isomorphism classes of tuples (for example). We do not normally think of the physical world around us as containing such formal structures, but we surely do normally think of the world as containing arrangements of properties and relations (and so, kinds of arrangements of properties and relations).[25]

I want to recommend the informal notions of structure as useful conceptual tools, then, when it comes to the understanding and examination of various elements of the structuralist approach to science. This is not to say that we should eschew the formal notions entirely, of course, nor that they may not be better tools for certain purposes. Clearly the formal notions do have features which may be advantageous in some contexts. The set-theoretical formal notions described above, for example, allow us to bring model theory to bear, and certainly some would maintain that doing so makes philosophical progress possible on certain fronts. Nonetheless, I want to claim that the informal notions are clear and precise enough for many purposes, and better-suited than the formal notions to some tasks. I also think that my arguments in the remainder of this discussion would carry over to construals in more formal terms of the various structuralist theses we are considering.[26]

[25] Especially given the points made in n. 9.

[26] Attachment to the $< U, P_i, R^n_j >$ notion of structure may come from a commitment to a certain programme in the semantics of natural language (or at least the language of science), or, relatedly, from linking a notion of model appropriate to the philosophy of science to the notion of model found in the standard Tarskian semantics of first-order languages. I do not wish to presuppose the former commitment, however, and have argued that the latter tendency is ill-advised (Thomson-Jones (2006)). Note, too, that although my emphasis here is on making room for non-formal notions of structure, we can also challenge the assumption that a formal approach should rely primarily on set-theoretic tools; see Thomson-Jones (2006, esp. p. 534) and Landry (2007).

4 Explicating vehicle structuralism

We can now turn to the task of spelling out the content of vehicle structuralism, the thesis that all scientific representation is representation by means of structure. I will lay out two readings of this claim.

4.1 Representation via structured objects

In order to represent by means of structure, we need to single out the structure by means of which we aim to represent. One way of doing this is to draw attention to a structured object which has the structure in question. Of course, given that any structured object instantiates numerous structures, one cannot single out a particular structure simply by drawing attention to a structured object which has it; what one can do, however, is draw attention to a structured object and make one of the structures it instantiates salient, somehow or other. On the first understanding of (VS) I have in mind, all scientific representation involves picking out a structure in this way — via a structured object which has it — and then using the structure in question to represent whatever it is we are representing as being whatever we way we are representing it to be. On this view, then, the tools we use to represent the world, the vehicles of representation, are structures. As the structures we use are (on this view) always introduced by way of structured objects, however, it is also follows that all scientific representation is representation by means of structured objects.

To put this a little more precisely: Say that we are *displaying* a structure when we pick out a structure by (i) drawing attention to a structured object which has that structure and (ii) singling out the structure in question from amongst the

many structures the object instantiates. Then count an act of representation as an act of representation by means of structure if and only if (a) it involves displaying a structure which plays a central role in the representing, and (b) the displayed structure then carries all the content conveyed by the representational act.[27] Vehicle structuralism, on this first explication, is the thesis that all scientific representation works that way. I will call the view encapsulated in this thesis *display vehicle structuralism*, or *DVS*.

This explication of vehicle structuralism employs the notion of the content conveyed by an act of representation, and the notion of *x*'s carrying all the content conveyed by a given representational act. I will not attempt precise accounts of either notion; the hope is that the discussion in the rest of this subsection will make them clear enough.

When we ask whether some structure which plays a role in a representational act carries all the content conveyed by that act, we are asking: Is everything that is being said about the target system being said via the structure in question? Would any content still be conveyed if we took that structure out of the picture? It is not difficult to construct a definite counter-case: a case in which, although a structure plays an important role in a representational act, it clearly does not carry all the content conveyed. Suppose, for example, that I construct a scale model of the Golden Gate Bridge out of (unpainted) balsa wood. I then hold the model up in front of you, point at it, and say "The Golden Gate Bridge has this sort of spatial structure; oh, and it's red."[28] Part of the content I

[27] Note that no claim is made here about when an act counts as an act of representation.

[28] I am not assuming here that the act in question counts as an act of *scientific* representation; the point here is only to get some purchase on the notion of *x*'s carrying all the content conveyed by an act of representation, whatever the domain.

The problem of saying what it is for a representational act to count as an act of scientific rep-

have conveyed is that the target system is red, but clearly the structure displayed (namely, a certain spatial structure possessed by the model) does not carry that content. To put it another way, if we imagine the events described taking place *sans* the displayed structure — suppose there is nothing in my hands when I point and utter the words in question — I would still succeed in conveying the content that the bridge is red.

It is less easy to find cases of representation in actual scientific practice which unquestionably fit the picture at the heart of DVS.[29] Here, though, are two examples which *might* fit, and which should at least help to make the idea underlying DVS more vivid. The first example, though not typical of most scientific representation, is relatively simple, and so heuristically useful; the second is more typical, and points towards one connection between vehicle structuralism and the semantic view.

First, then, consider the famous model of DNA which Francis Crick and James Watson constructed in the early 1950s using copper wire, carefully crafted tin plates, and (in occasional moments of desperation) pieces of cardboard.[30] One thing Crick and Watson did with this physical model — the main thing — was to represent the DNA molecule as made up of parts of various kinds standing in certain spatial relations. Suppose, more precisely, that at least on some occasions, Crick and Watson used the tin-plate model to convey *just* the idea that

---

resentation is one I have purposefully left aside. Any reader who is troubled by this can take the temporary measure of inserting the qualified forms of VS and CS into the discussion throughout: presumably all ordinary cases of representation by means of (scientific) models and theories count as cases of scientific representation, whether or not there are other kinds, and whether or not it is possible (or useful) to put a line around the scientific cases.

[29] It is easier to construct artificial cases which fit the picture, especially if we are not concerned with limiting ourselves to scientific representation: see the "British are coming" case discussed at the beginning of §5, below.

[30] See Watson (1969), pp. 45, 67, 97, 108, and 113.

DNA is made up parts of four different kinds standing in such-and-such spatial relations to one another.[31] That is, suppose they conveyed specific ideas about the geometry of the molecule on such occasions, and told their audience that the parts in locations X and Y are of kinds 3 and 4, respectively, but conveyed nothing about what kinds 3 and 4 are (e.g., that they are the kinds *cytosine base* and *guanine base*). Such representational acts would seem to fit the DVS picture in a particularly simple way: they are acts in which the agents first display a structure (in this case, one which consists in having parts of four different kinds standing in such-and-such spatial relations) by holding up a structured object which has it (the tin-plate model), and then simply attribute *that very structure* to the target system. Given that understanding of what was going on in the representational acts we are considering, it seems entirely plausible to claim that all the content conveyed was carried by the displayed structure: if the tin-plate model had somehow been removed from the representational acts in question, Crick and Watson would have failed to pick out the structure which their representational acts were intended to attribute to DNA; and there was no other content conveyed by those acts.[32]

A second example which seems to fit the DVS picture is provided by the use of the real line to represent time. Or rather: the use of the real line to represent time seems to fit the DVS picture if we are willing to adopt a Platonist un-

[31] I am leaving aside the sugar and phosphate molecules.

[32] I will not attempt to settle here the question of whether a representational act which centres on the tin-plate model but specifies the four kinds can be fitted to the DVS picture. There are at least some complications there, however. In particular, no such representational act could be taken to be of the especially simple sort just described, in which it is a straightforward matter of attributing the displayed structure to the target system, because the tin-plate model does not instantiate any structure which involves the property of being, say, a guanine base (which is just to say that no part of the tin-plate model is a guanine base).

derstanding of our mathematical discourse.[33] Then we can say that in talking about the real line we are drawing attention to a certain structured object, one which has real numbers as parts (where real numbers are taken to be objects in their own right). And a certain abstract structure the real line instantiates — a structure which is (say) a matter of having a non-denumerable collection of parts standing in a transitive, irreflexive, antisymmetric, connected relation — can be made salient, so that that structure has been displayed. The structure in question then carries the content we convey when, using the real line, we represent time as having just the structure in question. Such acts of representation are thus acts of representation by means of structure.[34]

It is worth addressing a misunderstanding which might arise around the talk of a structure's "carrying all the content" conveyed by a given act of representation. Such talk is not meant to suggest that no factor other than the relevant structure plays a role in bringing it about that representation takes place, or that the content conveyed is such-and-such. Indeed, it is an explicit feature of this explication of the notion of representation by means of structure (and of the examples given) that agents are involved. The intentions of those agents can play a role, as can background sets of rules, conventions, beliefs, and the like, many of which will play a role in virtue of being shared by the agent and her audience. Linguistic acts may be central, too: it might be an important part of the process for the agent to say "Now, look at this tin-plate construction, and see the

[33] We will consider the consequences of taking a different view of mathematics — the structuralist view — in a few moments.

[34] Note that here I have considered a representational act in which we do no more than represent time as having a certain abstract structure. If more is being said when we say that the parts are times, or moments, and that the relation is (say) the earlier-than relation, then there will be complications involved in fitting a representational act which conveys that additional content to the DVS picture, complications of the same sort as the ones discussed in n. 32.

way it forms a sort of double helix," or "Consider the real line…." Even physical gestures might be crucial — acts of pointing, say. These allowances are all consistent with an insistence that the displayed structure carries all the content conveyed by the act of representation, as that phrase is intended. The intuitive picture is that a sort of "funnelling" takes place in an act of representation understood this way: various factors play a role in making representation happen, and in fixing the content conveyed, but there is a *stage* in the process by which content "moves" from representer to audience at which all the content involved is conveyed via some structure.[35]

To round out the discussion of the first explication of vehicle structuralism, and segue into the second, consider again the use of the real line to represent time. Suppose that in place of Platonism, we adopt a structuralist view of mathematical discourse. Then it is still true that we are singling out a structure when we say "Consider the real line…"; but on the mathematical structuralist's view, that is all we are doing. We are not picking out a structured object which has the structure in question, for there is no realm of *sui generis* mathematical objects; in particular, there are no such objects as the real numbers, and so no structured object, the real line, made up of them.[36] On the assumption that the use of the real line to represent time is a paradigmatic example of at least one type of scientific representation (albeit a very simple example), it follows that if structuralism

[35]Bear in mind that the point here is not to decide whether it is accurate, in the final analysis, to claim that any or all scientific representation works this way; I am merely trying fill out the structuralist picture of scientific representation.

Incidentally, the points made in this paragraph apply in equal measure to the second explication of VS, to which we are about to turn.

[36]Or at least, even if it so happens that there is a realm of objects which have the features the Platonist looks for in a mathematical object, we are not referring to objects in that realm when we speak mathematically.

is the correct philosophy of mathematics, then display vehicle structuralism is false. This is because that thesis insists that all scientific representation involves the displaying of a structure, and so involves the use of a structured object. Here, then, we have one quick way of arguing against display vehicle structuralism. It is a significant disadvantage of this argument, however, that it relies on a particular philosophy of mathematics.[37]

4.2 Structure without a structured object

The mathematical structuralist's take on the use of the real line to represent time reminds us that displaying a structure is not the only way of picking one out, and that we can single out a structure without employing any object which has that structure. For example, we might simply say "Consider the structure which involves being partitioned into five parts, a, b, c, d, and e, such that…," and thus pick out a structure my desk instantiates without involving the desk or any other structured object.[38] We might speak of singling out a structure *directly* when it is picked out this way.

On the second explication I want to consider, vehicle structuralism is the thesis that all scientific representation involves singling out a structure which then carries all the content conveyed by the act of representation. *Simple vehicle structuralism* (*SVS*), as I will call this thesis, thus differs from display vehicle structuralism only in that it contains no insistence that we single out structures

[37] The arguments I lay out against display vehicle structuralism in "Mathematical and Propositional Models" (in preparation) do not rely on such a heavy independent philosophical commitment.

[38] I am using 'single out' and 'pick out' interchangeably; unmodified, both phrases are intended to leave open the means, so to speak, and that is how I have been using them thus far.

in any particular way.[39] It is thus a weaker thesis than display vehicle structuralism. Indeed, there is a significant danger that simple vehicle structuralism weakens vehicle structuralism to the point of triviality, given the notions of structure in play.[40]

Here's why: It is plausible that all (or virtually all, or most) scientific representation involves presenting some target system or type of system, real or imaginary, either as having various parts which have various properties and stand in various relations to one another, or at least as having various parts which instantiate some *kind* of arrangement of properties and relations.[41] On the notions of structure I introduced earlier, this is just to represent the target system as having a certain structure (concrete or abstract). But representing target system X as having structure S can always be thought of as singling out S, and then using it to represent X as being a certain way (namely, as having S). Given that on this way of looking at it, the representational act consists entirely of attributing S to X, it also seems clear that S carries all the content conveyed by that act. It thus looks as though any act of scientific representation (or virtually all, or most) will fit the account offered by simple vehicle structuralism for very general reasons. Simple vehicle structuralism is thus in danger of seeming trivial (or nearly so) on this second explication.[42] (Note, on the other hand, that there is no argument

[39] Accordingly, simple vehicle structuralism has no difficulty in accommodating the mathematical structuralist's understanding of the real line/time case — or the Platonist's.

[40] By saying that simple vehicle structuralism is in danger of seeming trivial, I do not mean that it begins to look like an analytic or logical truth. I mean rather that it begins to look too weak and uncontroversial to be staking out a specifically "structuralist" approach to scientific representation.

[41] This is especially if plausible if we include the trivial partitioning of a thing into its sole improper part.

[42] If the parenthetical 'virtually all, or most' is needed in this argument, then although simple vehicle structuralism might still be true, it will only apply for the very general reasons just presented in virtually all or most cases, and thus will only be *nearly* trivial.

here for the triviality of display vehicle structuralism, as that thesis insists that *S* is always singled out by being displayed, and that, I take it, is not trivial.)

Given the background of recent discussion, two ways of avoiding this sort of triviality suggest themselves. Both involve modifying simple vehicle structuralism by restricting attention to certain special sorts of structure: abstract structures in the first case, and purely relational structures in the second.[43] That is, the vehicle structuralist can announce that the thesis she means to defend — and, perhaps, intended all along — is either

> (SVSa) All scientific representation is representation by means of abstract structure

or

> (SVSr) All scientific representation is representation by means of purely relational structure

where we are representing "by means of a structure" when our representational act involves singling out a structure which then carries all the content conveyed that act.[44]

I will not attempt to assess either of these theses here, but it is worth noting certain aspects of what is involved in defending them. Consider, for example, a representational act which represents the hydrogen atom as being the way the

[43] We have already seen (in §3.2) that there is a formal notion of abstract structure in the literature, and it is often traced back to Russell (e.g., Votsis (2003), p. 881); and those who employ the tuple notion of structure often focus exclusively on relations. A third option, of course, is to impose both constraints, but the points I am about to make will extend to that option automatically.

[44] An exclusive focus on abstract structures might be taken to yield the purest form of structuralism. If so, it seems that structuralists differ in their degree of purity: see Ladyman (2007), §3.

Bohr model of hydrogen says it is — call this a 'Bohr act' for short. We can, of course, see a Bohr act as attributing a certain structure to the hydrogen atom; and the defender of either (SVSa) or (SVSr) is committed to the claim that such an act involves singling out a structure (abstract or purely relational, respectively) which then carries all the content conveyed by the act. There are thus two options for the defender of either (SVSa) or (SVSr): either the structure employed in the Bohr act (the one which carries all the content) *is* the structure attributed to the hydrogen atom by that act, or there are two distinct structures.

The first option is attractive in that it tells a relatively simple story: the agents who are doing the representing do it by singling out a certain structure, and then attributing that very structure to the hydrogen atom. But there are difficulties here nonetheless. The defender of (SVSa) is committed to claiming that the structure singled out and employed for the purposes of representation is an abstract structure, and so the identification of the structure employed with the structure attributed yields the claim that Bohr acts attribute only a certain abstract structure to the hydrogen atom. The defender of (SVSa) will thus have square such purported abstractness with the fact that it seems as though we attribute specific properties to the hydrogen atom in the course of Bohr acts — we attribute a charge of $+1.6 \times 10^{-19} C$ to one part of it, for example. Similarly, the defender of (SVSr) who takes the first option is committed to claiming that we attribute no intrinsic properties to any part of the hydrogen atom in performing a Bohr act, which is not a trivial commitment.

The defenders of (SVSa) and (SVSr) can avoid these difficulties by taking the second option, but the cost will be a more complex story about how representation works in such cases. The defender of (SVSa) who allows that the structure

attributed to the hydrogen atom in Bohr acts is not abstract, and who thus pictures those acts as involving two distinct structures, the structure employed and the structure attributed, will need to provide a more detailed account of how an abstract structure, involving no specific properties or relations, is used (in a representational act in which it carries all the content conveyed) to attribute certain specific properties and relations to the hydrogen atom. Similarly, the defender of (SVSr) who is not comfortable insisting that the structure attributed to the hydrogen atom in Bohr acts is purely relational, and who thus has a "two-structure" picture of such acts, will need to say more about how purely relational structures are used to attribute intrinsic properties (amongst other things) to the parts of the hydrogen atom.[45]

The upshot is that if the simple vehicle structuralist attempts to avoid the triviality charge outlined above by strengthening her central thesis in either of the ways we have just considered — that is, by claiming that all scientific representation is by means of either abstract or purely relational structures — she will have more work to do to make her account seem plausible.

5 Vehicle structuralism and content structuralism

In section 6 we will consider some connections between structuralism about scientific representation, structural realism, and the semantic view. First, in this section, we will examine the relationship between the two basic structuralist

[45] I do not mean to insinuate that it will not be possible to provide such accounts; my point is just that there are questions that need to be answered on this sort of approach, and that it is not *obvious* how those questions are to be answered.

theses about representation, vehicle structuralism and content structuralism.

It might seem for a moment as though there is no logical room for manoeuvre between vehicle and content structuralism. If all scientific representation involves displaying a structure, or at least singling one out, and then using it to represent some part of the world in such a way that the entire content of the representation is carried by the structure in question, then, we might think, it must follow that all scientific representation is representation of structure. Once we say this out loud, however, it becomes clear that there is a logical gap between the two theses after all. Certainly one particularly straightforward way of using a structure S to represent some part of the world is by singling S out and saying "Look: *this* part of the world (object, system...) has *that* structure"; and if that is all we do, then our representation will have been entirely of structure. But there are other ways we might choose to employ a structure for the purposes of representation. For example, suppose I set in place a background rule which says: *whenever I bring structure S to your attention, that will be my signal that the British are coming*. Then clearly I can employ S to represent the British as being on their way (or the arrival of the British as imminent, or the world as containing approaching British forces/Britpop bands). Thus it is possible to represent, by means of structure, something other than structure. And so unless we are willing to insist that restricting our attention to *scientific* representation makes the right sort of logical difference here, it seems we should take it to be logically possible that scientific representation is always by means of structure, but not always of structure. That is, it seems we should conclude that VS does not entail CS.

One objection to this line of argument would involve claiming that representing the British as being on their way *is* representation of structure (and of

nothing else). Given the notions of structure I delineated in §3.1, this claim seems entirely plausible, and so the objection seems reasonable at first sight. But this simply draws attention to the fact that CS, as it stands, is vulnerable to just the sort of triviality charge SVS faced. Indeed, the charge arises in a very similar way: It is plausible that the content of all (or virtually all, or most) acts of scientific representation is that some target system or type of system, real or imaginary, either has various parts which have various properties and stand in various relations to one another, or at least has various parts which instantiate some *kind* of arrangement of properties and relations. And this is just to say that the content of all (or virtually all, or most) acts of scientific representation is that some target system or type of system has a certain structure (concrete or abstract); which, in turn, is just to say that all scientific representation is of structure. Thus CS, as stated, looks plausible for reasons which are so general that it is hard to see it as a peculiarly "structuralist" thesis. Presumably, then, the structuralist will want to strengthen CS — perhaps by restricting attention to either abstract or purely relational structures, as before — so that some sort of representational content would count as being of something other than structure in the appropriately restricted sense. But then we can simply substitute some content of that sort for the content of 'The British are coming' in the argument given above, and so establish that the strengthened form of CS is not entailed by VS either.[46]

Another objection might be that in the envisioned case, the structure em-

[46] Note also that a defender of CS who responds to this triviality problem by restricting attention to abstract structures will have to claim that Bohr acts attribute no specific properties or relations to parts of the hydrogen atom, whereas one who responds by restricting attention to purely relational structures will have to claim that Bohr acts attribute no intrinsic properties.

ployed is not carrying all the content conveyed by the representational act. The obvious thought here would be that the stage-setting (in which I tell you the rule about what you should take me to mean if I draw *S* to your attention) is doing some central work. The response to this objection is that although it is indeed true that the stage-setting is crucial, that fact does not distinguish this case from the cases we have been taking to paradigmatic of representation by means of structure (namely, the Crick and Watson case and the case of the real line). As we noted earlier, factors other than the mere singling out of a structure are essential to bringing it about that an act of representation occurs in those cases, too; and indeed, such additional factors play a role in determining the content which is conveyed in those cases, just as the relevant bit of stage-setting does in the "British are coming" case. Simply displaying a structure possessed by the tin-plate model is not enough to bring it about that we are representing; nor is it enough to bring it about that we are representing the parts of DNA molecule as standing in various spatial relations to one another. In addition to singling out the structure in question, we also need to identify a representational target, and make it clear what we mean to convey about that target by singling out the structure in question. Certainly the simple option in the latter respect is that we mean to convey that the target just has the structure in question; but even that needs to be fixed somehow, and fixing it is part of the stage-setting. Thus if representation is not by means of structure in the "British are coming" case for the sort of reason given, neither is it by means of structure in our paradigmatic cases. Furthermore, as an additional reason for rejecting this objection, note that the "British are coming" case passes the counterfactual test I proposed to help fix the sense of the idea that some structure involved in an act of rep-

resentation carries all the content conveyed: if we imagine my going through the same motions but without displaying the structure in question to you at the crucial moment, it seems clear that I would fail to convey anything to you.

So CS is not a logical consequence of VS. This claim, we might note, is in line with a Goodmanian insistence that relations of representation are fundamentally arbitrary, and that anything can be used to represent anything else.[47] Nonetheless, there is a connection between VS and CS worth spelling out: even given the relevant Goodmanian points, and the lack of a straightforward entailment, VS gives us reason to believe CS.

The simple but crucial observation is that it is one thing to say that anything *can* represent anything, and quite another thing to say that there are no general patterns in the ways we in fact represent. Once we consider our actual representational practices, it is obvious that practical considerations come into play, for one thing.[48,49] So, for example, there are two obvious practical disadvantages to representing the British as being on their way by employing the structure S in the way described above: first, the representational act required its own special bit of stage-setting; second, it would be easy for my audience to forget what it is I mean to convey by displaying S. (To make the second point vivid, imagine that there is a large range of things I might want to be able to convey, and that for each of them we set up a similarly arbitrary link to some structure or

[47] See Goodman (1976). On p. 5, for example, Goodman makes the slightly qualified claim that "almost anything may stand for almost anything else," and follows up with the claim that a particular sort of standing-for, denotation, is "the core of representation." (Of course, even the correspondingly qualified claim that that almost anything can represent almost anything else does not follow from these two claims, but Goodman has been taken to assert that, too.)

[48] We could also call them "pragmatic" considerations, provided we do not allow the term to trigger unwanted associations.

[49] I do not mean to suggest that Goodman failed to take account of these points — he clearly did not.

other.) No special stage-setting is required, in contrast, if I represent the British as being on their way by declaiming the words 'The British are coming,' and my audience is unlikely to forget what I mean to convey by uttering those words.[50] Similarly, consider a case in which I use S to represent something as having that very structure — by identifying X as the target and saying "X has S," for example. Here again there is no need for special acts of stage-setting peculiar to the representational task, and no danger that my audience will forget something crucial to the success of my attempt to convey to them what it is I am attempting to convey. In other words, there are practical reasons for using structures just to represent the structure of things; and this makes it plausible that when it comes to representation, that is in fact what we use structures for. Thus if all scientific representation is representation by means of structure, then it is plausible enough that, *de facto*, all scientific representation is of structure: VS gives us reason to believe CS. Correspondingly, the rejection of CS would give us some reason to reject VS; and that point will be important in the next section.

Of course, the argument of the last paragraph assumes that the members of my audience are competent English-speakers, and becoming a competent speaker of English requires a great deal of "stage-setting" in itself. Thus it is not as though we have dispensed with the need for an appropriately prepared audience when I convey the relevant content simply (!) by uttering the words 'The British are coming.' Very little representation, if any, comes out of the blue. What is more, language might have been set up to work very differently than it does. The claims made in the argument of the last paragraph are thus quite compatible with a Goodmanian insistence on the ultimate arbitrariness of representa-

[50] The emphasis here is on the word 'special' — see the next paragraph.

tion, and on the role of convention. But when we are interested in scientific representation as it actually is, it is perfectly appropriate to take into account the fact that acts of scientific representation are performed by creatures who, in fact, are already speakers of various natural languages, have already learned a set of conventions governing the activity of (literal) pointing, and so on.

Herein, incidentally, lies the beginnings of a response to Callendar and Cohen (2006). It may be that certain fundamental questions about how representation works fail to take on a different cast in the scientific case than in other contexts, but it is nonetheless entirely possible that given the sorts of representational task we are attempting in the sciences, and given the various practical constraints at work, there are some particular ways of representing that *de facto* predominate in the sciences — some characteristic kinds of representational vehicle which are employed, for example. So there can be a special question about how representation works in the sciences. That question may well be worth asking, and answering, furthermore, for it may be that articulating an account of the specific ways of representing which predominate in the sciences will aid us in our attempts to understand scientific explanation, theory testing, modelling, and the various other aspects of scientific practice which concern us in the philosophy of science.

6 Structural realism, and the semantic view

My last piece of business is to draw out certain connections between structuralism about scientific representation, structural realism, and the semantic view of theory structure. In particular, I want to trace out a line of reasoning which

takes us from one standard defence of structural realism to the rejection of content structuralism, vehicle structuralism, and the semantic view. As I mentioned in the introduction, it may be that no actual philosopher holds a combination of views in tension with the conclusions I will draw out here; nonetheless, I think it is worth bringing the connections out into clear sight.

As a starting point, let us see why a certain sort of structural realist does well to reject content structuralism. Here, and throughout the remainder of the discussion, I have in mind a modified content structuralism which manages to avoid the charge of triviality discussed in the last section. This modified content structuralism might be the thesis that all scientific representation is of abstract structure, perhaps, or the thesis that all scientific representation is of purely relational structure — the details will make no difference. In fact, the arguments of this section will largely swing free of our choice of notion of structure, and so they are independent of the ideas in section 3, above. All that matters is that the term 'structure' is used in the same way throughout (including in the statements of vehicle structuralism, content structuralism, and the tenets of structural realism), so that we are not trading on ambiguities.

So: Consider the epistemic structural realist, or 'ESRist,' who, in the terms of section 2, accepts LS and SS, which is to say that she believes that although we can know only the structure of the world, we can and do know a good deal about that. There is, of course, no contradiction between this view and content structuralism, the claim that scientific representation only ever tells us about the structure of the world (i.e., between LS, SS, and CS).[51] But consider the main

[51] At worst, there is some redundancy involved in declaring a commitment to CS, LS, and SS: if our representations tell us only about structure (CS), there is little point in saying that we have good reason to believe only they what they tell us about structure (LS). Note, however — and

argument for ESR: that it is the only position which both does justice to the intuitions underlying the miracle argument, and escapes the jaws of the pessimistic induction. The crucial part of this argument for the present point is the second. In responding to the pessimistic induction, the ESRist grants that there are radical discontinuities between successive theories in the history of even the mature sciences, but insists (and this is the definitive manoeuvre) that these are discontinuities only with regard to what theories say about the *nature* of things; at the level of postulated *structure*, there is enough continuity to make realism plausible. The alleged evasion of the pessimistic induction thus relies on the idea that theories tell us both about the structure of the world, *and* about the nature of the things in it.

Exactly how we should understand the distinction between structure and nature need not detain us here: all that matters is that the proposed response to the pessimistic induction presupposes that theories tell us both about the structure of the world and about something else. It follows straightforwardly from that fact that CS undercuts this argument for ESR. If content structuralism is correct, so that everything scientific theories say is about structure, the diagnosis of discontinuity offered in the course of the argument is no longer an option. The radical differences of content that obtain between Fresnel's aether theory of light and Maxwell's electromagnetic theory (to use Worrall's (1989) example) will have to be differences of postulated structure, and the pessimistic induction will rise again at the level of structure. If she wished both to embrace content structuralism and to retain some version of this central argument for her posi-

this is to anticipate the point that the ESRist should reject CS — that this combination of views is clearly not what the ESRist has in mind, as she clearly means to be describing a *restriction* on what we should believe.

tion, the ESRist would thus have to provide us with a distinction between kinds of postulated structure — the kind we should believe in, and the kind we should not. Insofar as this would be a new problem with no obvious solution, the ESRist would do better simply to reject content structuralism.[52]

The next step is a simple one: it follows from the arguments in section 5 that vehicle structuralism and the denial of content structuralism make for uneasy bedfellows, and so the ESRist has some reason to reject vehicle structuralism, too. Despite the initial appearance of a natural affinity between structuralism about scientific representation and structural realism, then, these positions do not play happily together. More carefully, and so less colourfully: structuralism about scientific representation does not combine well with the best-known argument for one central form of structural realism.

Finally, there is a connection here to the semantic view. As I mentioned in section 2, the semantic view of theory structure provides one central source of support for vehicle structuralism. Invoking the standard first approximation, we can say that the semantic view is the view that theories are collections of models, or are usefully viewed as such. On several versions of the semantic view, moreover, the models in question are mathematical structures of one sort or another (e.g., Suppes (1957), (1960), (1967); van Fraassen (1970), (1972), (1980), (1987); French and Ladyman (1999)).[53] Or at least, that is how it is often put. With the

[52] Of course, this point, and the points which follow, extend to any ontic structural realist who might wish to draw support for his position from the argument we have been considering.

[53] For my own view about the best way of understanding the seminal variants due to Patrick Suppes and Bas van Fraassen, see Thomson-Jones (2006). Despite the fact that the work of Ronald Giere and Frederick Suppe is often mentioned in the same breath as that of Suppes and van Fraassen, their accounts of theory structure diverge in a number of significant (and different) ways from the Suppes-van Fraassen approach. (See, e.g., Giere (1988) and Suppe (1989)). Particularly relevant here is the fact that models, on Giere's account, are not mathematical structures; see Thomson-Jones (forthcoming).

stipulations of section 3 and the discussion in section 4 in mind, we should more carefully say this: On several versions of the semantic view, the models which make up theories are either structured mathematical objects, or structures of a mathematical sort, depending on one's philosophy of mathematics. In either case, however, it seems a small step to say that theories represent by means of structure, or that we do so in using theories to represent. The semantic view thus lends credence to vehicle structuralism.

Building on this connection, we can see that the ESRist should feel some pressure to reject the semantic view as long as she supports her position by appealing to the usual argument. That argument requires the ESRist to reject content structuralism for theories (and so to reject it *simpliciter*), as we have seen; she then has reason to reject vehicle structuralism for theories, given the arguments of the last section (and so to reject VS *simpliciter*). As the semantic view leads naturally to vehicle structuralism for theories, this means that the ESRist should be inclined to reject that view of theory structure. Unsurprisingly at this point, perhaps, the view of theory structure which most naturally accompanies structuralism about scientific representation looks to be at odds with the central argument for structural realism, too.

References

Brading, K. and Landry, E. (2006), "Scientific Structuralism: Presentation and Representation," *Philosophy of Science* 73: 571-581.

Bueno, O. (1997), "Empirical Adequacy: A Partial Structures Approach," *Studies in History and Philosophy of Science* 28: 585-610.

Callendar, C. and Cohen, J. (2006), "There Is No Special Problem About Sci-

entific Representation," *Theoria* 55: 67-85.

Da Costa, N. C. A. and French, S. (1990), "The Model-Theoretic Approach in the Philosophy of Science," *Philosophy of Science* 57: 248-265.

French, S. and Ladyman, J. (1999), "Reinflating the Semantic Approach," *International Studies in the Philosophy of Science* 13: 103-121.

French, S. (forthcoming), "Keeping Quiet on the Ontology of Models," *Synthese*.

Giere, R. N. (1988), *Explaining Science: A Cognitive Approach*. Chicago: The University of Chicago Press.

Goodman, N. (1976), *Languages of Art: An Approach to a Theory of Symbols*. Indianapolis: Hackett Publishing Company, Inc.

Ladyman, J. (1998), "What is Structural Realism?", *Studies in History and Philosophy of Science* 29: 409-424.

Ladyman, J. (2007), "Structural Realism," in E. N. Zalta, ed.,*The Stanford Encyclopedia of Philosophy (Summer 2008 Edition)*. URL = <http://plato.stanford.edu/archives/sum2008/entries/structural-realism/>.

Landry, E. (2007), "Shared Structure Need Not be Shared Set-Structure," *Synthese* 158: 1-17.

Redhead, M. (2001), "The Intelligibility of the Universe," in A. O'Hear, ed., *Philosophy at the New Millennium*. Cambridge: Cambridge University Press, pp. 73-90.

Suppe, F. (1989), *The Semantic Conception of Theories and Scientific Realism*. Urbana: University of Illinois Press.

Suppes, P. (1957), *Introduction to Logic*. Princeton: Van Nostrand.

Suppes, P. (1960), "A Comparison of the Meaning and Uses of Models in Mathematics and the Empirical Sciences," *Synthese* 12: 287-301.

Suppes, P. (1967), “What is a Scientific Theory?”, in S. Morgenbesser, ed., *Philosophy of Science Today*. New York: Basic Books, pp. 55-67.

Thomson-Jones (2006), “Models and the Semantic View,” *Philosophy of Science* 73: 524-535.

Thomson-Jones (forthcoming), “Missing Systems and the Face Value Practice,” *Synthese*.

Thomson-Jones (in preparation), “Mathematical and Propositional Models.”

van Fraassen, B. C. (1970), "On the Extension of Beth’s Semantics of Physical Theories," *Philosophy of Science* 37: 325-339.

van Fraassen, B. C. (1972), “A Formal Approach to the Philosophy of Science,” in R. Colodny, ed., *Paradigms and Paradoxes*. Pittsburgh: University of Pittsburgh Press, pp. 303-366.

van Fraassen, B. C. (1980), *The Scientific Image*. Oxford: Clarendon Press.

van Fraassen, B. C. (1987), “The Semantic Approach to Scientific Theories,” in N. J. Nersessian, ed., *The Process of Science*. Dordrecht: Martinus Nijhoff, pp. 105-124.

van Fraassen (2006a), “Structure: Its Shadow and Substance," *The British Journal for the Philosophy of Science* 57: 275-307.

van Fraassen, B. C. (2006b), “Representation: The Problem for Structuralism," *Philosophy of Science* 73: 536-547.

Watson, J. D. (1969) *The Double Helix: A Personal Account of the Discovery of the Structure of DNA*. London: Readers Union.

Worrall, J. (1989), “Structural Realism: The Best of Both Worlds?”, *Dialectica* 43: 99-124.

Votsis, I. (2003), “Is Structure Not Enough?”, *Philosophy of Science* 70: 879-890.

Votsis, I. (2005), "The Upward Path to Structural Realism," *Philosophy of Science* 72: 1361-1372.