# ***Representation and Realism:***
# ***On Being a Structuralist All the Way (Up and) Down***

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**Abstract**
Van Fraassen's *Scientific Representation: Paradoxes of Perspective* presents a structural empiricist approach to scientific representation. As he notes, in order to pin that representation down to an actual situation, we must supplement our 'God-like' reflections on the structure with some further specifying feature. In this essay I consider what that further feature might be, across a range of circumstances, from those having to do with the Semantic Approach in general, to the characterisation of structural realism and, finally, to the challenge set by van Fraassen in the form of the 'Appearances from Reality' criterion in the context of quantum mechanics. I agree with van Fraassen that having to introduce some such feature is no threat to the structuralist project in general, whether in realist or empiricist guise but would maintain that the realist also has the resources to satisfy the above criterion. The issue then is whether such further resources should be taken to be a constitutive part of the theory or not. Reflection on this reveals that underpinning this whole discussion is a certain view of theories as things that have well-defined identity conditions and in conclusion I suggest that dropping this demand will be a liberating move in all sorts of respects.

"Do you desire to construct a vast and lofty fabric? Think first about the foundations of humility. The higher your structure is to be, the deeper must be its foundation." (St. Augustine)

## Introduction: The Semantic Approach

It is a truism to say that yesterday's radical stance is today's establishment position and many have said this about the 'Semantic Approach' to theories. Echoing Suppe from over twenty years before (Suppe 1989), Halvorson wrote that, '[w]ithin a few short decades, the Semantic Approach has established itself as the new orthodoxy' (Halvorson, 2012; see also Frigg 2006, LeBihan 2012). The core claim of the Approach is taken to be that '… a theory *is* [my emphasis] a class of models' (Halvorson 2012 p. 190; see also p. 192). On the basis of this claim Halvorson then goes on to present examples of what he calls theories that cannot be regarded in terms of classes of models and also models that should not be regarded as theories. As a result, he concludes that, '… it is impossible to formulate good identity criteria for theories when they are considered as classes of models. ' (*ibid*. p. 190; see also p. 201; for a response see Glymour 2013) and hence the Semantic Approach founders.

The nature of the above claim that a theory is a class of models and the issue whether it should be taken as characterising the core of the Semantic Approach have of course been contested for many years. Thus, thirty years ago, van Fraassen wrote, '... if the theory as such, is to be identified with anything at all - if theories are to be reified - then a theory should be identified with its class of models.' (van Fraassen 1989, p. 222). But of course, that's a big 'if'! And one can, indeed some would say, *should*, resist this reification and instead take the Semantic Approach as just one such approach that can provide an array of devices – in this case set-theoretic models – that philosophers can deploy to capture certain aspects of scientific practice (see da Costa and French 2003; French and Saatsi 2006; French forthcomingb).

Furthermore, a crucial feature of that practice concerns the *representational* role of theories. As van Fraassen also notes, when a scientist presents a theory '… she provides a class of models for the representation of those phenomena' (van Fraassen 2014, p. 277). He continues, '… we properly speak of a model of combustion or of the San Francisco Bay in the way we speak of a painting of fire or of the Giaconda. ' (2014, p. 277). Thus, '[a] model is a mathematical structure [of the kind considered by Halvorson] in the same sense that the *Mona Lisa* is a painted piece of wood.' (*ibid*.). In other words, given that a scientific model is a representation, '…it does not follow that the identity of a theory can be defined in terms of the corresponding set of mathematical structures without reference to their representational function. ' (ibid., p. 278). As French and Saatsi noted, '[i]t seems to be a popular misconception of the semantic view that it says *nothing* but the following about theories: theories *are* (with 'is' of identity) just structures (models).' (French and Saatsi, 2006, p. 552).

Granted that this is a misconception, noting that there is more to a theory than the mathematical structure immediately raises the question: how are we to capture this representational function *for our purposes as philosophers of science*? Again we can draw on the resources of the Semantic Approach and characterise it formally in terms of (partial) isomorphisms holding between the relevant structures (van Fraassen and Stegman 1993; van Fraassen 2008). Such a move has been criticised on the grounds that such devices are neither necessary nor sufficient for representation (see Frigg 2006; Suarez 2010) but these concerns can be met (Bueno and French 2011). That they are not necessary is argued for via examples, typically from the world of art, where, it is claimed, we have representation but no isomorphisms or structural similarity more generally. Leaving aside the relevance of such purported counter-examples when it comes to representation in science, Chakravartty (2001*)* has pointed out that it cannot be the case that similarity *in general* is not necessary for scientific representation, since in the absence of any similarities at all, it is not clear how the usual practices of interpretation and inference could get off the ground to begin with.

As for it not being sufficient, the argument is basically that representation is asymmetric – so Da Vinci's painting represents Lisa Ghirardini but not vice versa – whereas (partial) isomorphisms are not; again, responses can be sought, whether through appeals to inherent features of the formal relation or to 'external' factors such as the intentions of the user of the representation (Bueno and French 2011). Here my focus is on the latter move, situated in a broader context. Consider the further question: does an appeal to intentions in such cases fatally undermine the Semantic Approach or a structuralist account of representation more generally? One might think that it only does so if one insists that *all* aspects of the relationship between theories and the world have to be understood structurally. However, consider theory confirmation: to demand that a structuralist account be given of *that* seems to ask too much.

This is the issue that I want to consider here, understood in broader terms. What formal devices such as partial structures and partial isomorphisms and the like provide us with is the framework for a structuralist account of scientific representation. The question now is, are these structures enough in general? Many have argued that they are not, as I have already indicated. In a sense I shall agree but I want to insist that the introduction of some further element does not undermine this sort of structuralist approach overall.

## The Act of Self-Location

In his classic work on scientific representation van Fraassen adopted what has been called his 'haupsatz', namely that '[t[here is no representation except in the sense that some things are used, made or taken, to represent some things as thus or so' (2008, p. 23). Here we see such a non-structural element being introduced, namely the *user* of the representation. Is this fatal to the structuralist project of capturing, in the above terms, scientific theories and their representational function? One might balk at the claim that it does. After all, the structure, as presented above in terms of mathematical structures that are by their very nature abstract and general, must be effectively pinned down so that it can be said to apply to the particular situation under consideration. As van Fraassen himself puts it, '[t]he user must leave the God-like reflections on the structure … behind in order to apply the implications of those reflections to his or her actual situation' (2008, p. 71). This application, he suggest, must involve an essential act of self-location akin to the indicating element of a map that says 'You are here'.

This comparison with maps and models been made before, of course, and one must be careful not to make too much of it. It is (typically) not the case that a scientist is simply given a theory in the way in which an orienteer, for example, is handed a map and told to find her way to some location, which of course requires her to know from where she is starting. Leaving aside the Kuhnian point about the education of scientists, they don't approach theories as one does a map, as a tool via which one can orient oneself in an unfamiliar landscape. A theory is an element or feature of the relevant scientific practice – it is part of the environment in which the scientist lives. Asking her where she stands with regard to the theory will surely result in the same bemused expression as obtained when asking someone where they are within their home neighbourhood!

Of course, it might be pressed that this is just to push the argument back a stage and that at some point some representation has to be produced towards which the scientist must orient herself. This could lead us into deeper waters than we might be comfortable paddling in here so let us keep our attention on theoretical models, such as we find in Einstein's Special Relativity, for example. As van Fraassen points out, if we are to use this theory to predict what happens to an electrically charged body in motion, say, then some choice of coordinate system related to a physical frame of reference is required. LeavIng the God-like reflections on the structure of space-time behind in order to apply those reflections to the actual situation, or, in other words, for the representation to be *used*, something must be done that pins down the relevant structure to that situation. The connection between this choice of reference frame and the orientation of the scientist touched on above can be found in Weyl's famous characterisation of coordinate systems as 'the unavoidable residuum of the ego's annihilation' (quoted by van Fraassen in 2008, p. 71; for discussion of the phenomenological underpinnings of this phrase, see Ryckman 2005).

As van Fraassen goes on to note, such acts of self-location provide the conditions for relating theoretical models to specific empirical situations in general (2008, p. 87). And as we'll see, this becomes particularly pertinent in the case of that second great revolution in physics in the twentieth century, namely Quantum Mechanics and the infamous 'measurement problem'. Before we get there, however, let's consider measurement more generally.

## Measurement as Representation

Consider yet another question: what sorts of interactions in general count as *measurements*? Clearly the outcome of a measurement must represent the target in a certain fashion, in the sense of selectively resembling it at a certain level of abstraction, according to the theory. This constitutes the representation criterion and, again, as van Fraassen puts it, '[t]he outcome provides a representation *of* the measured item, but also represents it *as* thus or so.' (van Fraassen 2008, p. 180). An illustrative example (for my purposes at least) is provided by the images of collision events in particle detectors, such as those that yielded evidence for the existence of the Higgs boson at CERN, for example (see Garutti 2012). Here we might see a flash on the particle detector screen or computer generated lines whereby the particle under investigation is represented *as* an object and is granted, by virtue of being spatio-temporally located, at least for that instant, what Toraldo di Francia called a kind of 'pseudo-individuality' (Toraldo di Francia 1978).

Why 'pseudo-'? Well, when we try to project that particular representation beyond the measurement situation, as embodied in the particle detectors, we effectively bump up against quantum mechanics and must metaphysically accommodate, in particular, the implications of Fermi-Dirac and Bose-Einstein statistics (other kinds – the so-called parastatistics – are also theoretically possible and we'll come back to those shortly). As is well-known, the likes of Born and Heisenberg (and others) took these statistics and the way that permutations of the particles appeared to be treated within the formalism as implying that quantum particles must be regarded as *non-individuals* in some sense (for details, both historical and formal, see French and Krause 2006). Cassirer and Eddington then took this, in turn, to imply that the particles could not be treated as *objects* at all and should be regarded as mere 'nodes' in the relevant structure (Cassirer 1936; Eddington 1928). However, van Fraassen, Huggett, Redhead and French all argued that these quantum statistics are in fact also compatible with regarding the particles as individuals (by virtue of a different interpretation of particle permutations; see French and Redhead 1988; Huggett 1999; van Fraassen 1989). With Krause arguing that non-individuality can be formally characterised via quasi-set theory without abandoning the view of the particles as objects, that connection with structuralism was broken. In its place, Ladyman argued that it is the metaphysical *underdetermination* that results from these developments – between particles-as-individuals and particles-as-non-individuals – that represents a challenge for realism (see also van Fraassen 1989) and that this challenge could be met, and the underdetermination broken, by shifting from an object-oriented metaphysics to 'ontic structural realism' (Ladyman 1998; French 2014).

**Realism (of a Structural Kind)**

In his critique mentioned above, Halvorson claims that structural realism actually derives its plausibility from the Semantic Approach and suggests that, given his criticism of the latter, '… structural realism is no more plausible today than it was in the time of Carnap and Hempel. ' (2013, p. 476). However, although Ladyman (1998) did acknowledge that the Semantic Approach might be preferred by the structural realist because, in effect, it wears its structuralist colours on its sleeve, Worrall's so- called 'epistemic' form of structural realism was explicitly couched in terms of the alternative 'Syntactic Approach' that characterises theories in terms of sets of propositions, closed under some (typically classical) logic (Worrall 1989). Furthermore, Bain and Landry have argued that category theory is in fact a better framework for the structural realist to adopt (Bain 2013; Landry 2007; for criticisms see Lam and Wuthrich 2015) and French has acknowledged that the structuralist has a variety of meta-representational options to choose from (see French 2014 Ch. 5). Thus the ties with the Semantic Approach are looser than Halvorson suggests!

Furthermore, historically and currently, there were multiple motivations for structural realism, from which it can be said to derive its plausibility. For Worrall (1989) and Saunders (1993) the motivation was accommodating theory change and responding to the challenge set by Laudan, for example. For Cassirer and Eddington, the motivation for their neo-Kantian and 'subjective' structuralisms, respectively, had more to do with accommodating what theories of modern physics, such as General Relativity and Quantum Mechanics, appear to tell us. Similarly for French (2014) and Ladyman (1998), there is a significant emphasis on accommodating the role that certain symmetry principles play in today's particle physics, including, of course, the Permutation Symmetry that lies behind the Bose-Einstein and Fermi-Dirac statistics mentioned above. For them, the significance of this role tells us something important about the *world*, whereas for van Fraassen, of course, as a structural empiricist, it tells us something about *science*.

And what it tells us, I would maintain, is that the world, conceived *as* structure, should be understood, following Cassirer, as akin to a Parmenidean 'well-rounded' sphere in which symmetries, laws and, crucially, measurement outcomes are all interlocked (French 2014). The contents of those (possible) measurement outcomes constitute what van Fraassen calls the 'appearances' and here again we return to the overall theme of this essay: these outcomes function as what Wilson calls the 'existential witnesses' (Wilson 2017) that 'pin down' the structure of the world, as indicated above, to that which is applicable to our situation. So, consider quantum statistics yet again: Permutation Symmetry yields a range of possible statistical kinds, as again already indicated, including not just Bose-Einstein and Fermi-Dirac statistics but also an infinite variety of parastatistics (the application of these to particle physics played a crucial role in the development of quantum chromodynamics). However, we appear to occupy only the bosonic and fermionic sectors of Hilbert space and not any of the parastatistics ones, so the structure of the world is one that manifests bosonic and fermionic behaviour and in that sense is 'pinned down' to those sectors.

Recalling what was touched on above about indexicality and what van Fraassen calls the Act of Self-Location, it appears that here too we have the insertion of an apparently non-structural feature into our structuralist picture that effectively says 'we are *here*!' (in Hilbert space). Does that self-locating move undermine the structuralist enterprise? No – that aspect of the structure of the world that incorporates Permutation Symmetry allows for a range of possibilities and in order to talk about the structure of *this* world we need to specify which of those possibilities is actualised. As in the case of theory confirmation, the specification of the actual world from an array of possibilities should not itself be up for structuralist interpretation.

Acknowledging that we have more structural resources on hand than we need to represent the actual world also has obvious implications for discussions of modality in science. For the structural realist, the world, as structure, can be regarded as inherently modal, offering, perhaps, an alternative to the Humean and dispositionalist accounts of laws and symmetries (see Berenstain and Ladyman 2012; French 2014). For the empiricist, any modality is to be understood as 'in' the models; that is, as simply a reflection of the fact that, as just stated, the mathematical characterisation of Permutation Symmetry allows for a number of possibilities. In either case, acknowledging this feature allows us to further extend our explorations of the resources that are made available in the context of modern physics.

Nevertheless, structural realism faces a further serious challenge, which again illuminates the theme of how we 'pin down' our structural commitments and is presented by van Fraassen as follows.

## Challenge: The Appearance from Reality Criterion

According to van Fraassen, the realist must be committed to the claim that the scientific representation of nature should include the appearances by showing how they are 'produced as a proper part of the depicted reality' (van Fraassen 2008 p. 281). Here he quotes Leplin: 'A theory is not simply an empirical law or generalization to the effect that certain observable phenomena occur, but an explanation of their occurrence that provides some mechanism to produce them, or some deeper principles to which their production is reducible.' (Leplin 1997). Thus what is required is an *explanation* that takes us from the relevant feature of the theory, as *explanans*, to the appearances, as *explanandum*, that allows us to grasp how the latter is 'produced' by the former; or as van Fraassen puts it, '[t]he appearances are to be explained as *produced* in the world depicted by fundamental physics.' (2008, p. 282). Here, then, is the challenge for the structural realist: can the relevant symmetries, such as Permutation Symmetry, act as these 'deeper principles' and function as the *explanans* in an explanation of the relevant appearances?

I think the answer to that question is 'yes' and so the challenge can be met. Consider the following phenomenon: white dwarf stars are the final evolutionary stage of stars that are not sufficiently massive to form neutron stars and that stage is reached when the gravitational collapse of the star is halted by electron degeneracy 'pressure'. The explanation for that 'halting' of the collapse appeals to the Pauli Exclusion Principle which prevents electrons from occupying the same state (where their state encompasses not only their energy but also their spin). How the Exclusion Principle, viewed as a constraint on electron occupancy, can act as an *explanans* in this case has been a matter of some dispute (Lewis 1986; Skow 2014). However, French and Saatsi (2018) have argued that we can accommodate this case within Woodward's 'counterfactual-dependence' account of explanation, in which the core idea is that symmetries play a role in explanatory arguments that is comparable to that of a contingent initial or boundary condition in causal explanations. Thus, a symmetry fact together with an appropriate connection between that fact and the *explanandum* can provide 'what-if-things-had-been-different' information, thereby showing how an explanandum *depends on* the symmetry. Although this counterfactual-dependence view of explanation has been largely developed in the context of causal dependence, in recent years it has been extended to various kinds of non-causal dependencies (see, for example, Jansson and Saatsi 2019; Saatsi 2018) and many symmetry explanations are likewise naturally construed as being non-causal.

Of course, there remains the issue of the kind of dependence involved if it is non-causal and this bears on van Fraassen's insistence that the appearances must be explained as *produced* in the world – clearly when it comes to symmetries the mode of production must go beyond the causal or 'mechanistic' in Leplin's terms. Here we must step carefully so as to not beg any questions, particularly against the structural realist! First of all, we must appropriately characterise the relationship between Permutation Symmetry and Fermi-Dirac statistics, the nature of which is captured by the Pauli Exclusion Principle that features in the above explanation of the halting of white dwarf collapse. There is a range of devices in the metaphysicians' 'toolbox' (French and McKenzie 2012) that we might utilise to capture the nature of this relationship but some can be shown to be unfit for purpose in this particular case (McKenzie forthcoming; Wolff 2012). As an alternative, we might deploy the determinable-determinate relationship (Wilson 2017), with Fermi-Dirac statistics understood as the determinate of Permutation Symmetry, construed as the relevant determinable (French 2014). We can even formalise this relationship in such a way as to capture the idea of the determinate 'belonging' to the determinable (Denby 2001).

This then captures the sense in which the relevant symmetry plays the role of a boundary condition as mentioned above – we exist in a world bounded by the Bose-Einstein and Fermi-Dirac sectors of Hilbert space. However, this still leaves the further question: how does the fact that electrons are fermions and subject to the Exclusion Principle *explain* the halting of the star's collapse? Skow, for example, takes the phrase 'degeneracy pressure' seriously, arguing that we can extend the meaning of 'pressure' from that of the impact of gas atoms on some container, to that of the resistance that results from electrons occupying the relevant quantum states (Skow 2014). However, given that the 'action' of the Exclusion Principle cannot be accounted for in terms of any of the known fundamental forces, it is clear that such an extension effectively releases the meaning of the term from its causal moorings (French and Saatsi 2018., p. 192). Strevens, on the other hand, suggests that the relationship between the Exclusion Principle and the halting should be understood as some kind of metaphysical dependence, as in the case of Permutation Symmetry above (Strevens 2008, p. 178). However, in this case we do have the kind of asymmetry we associate with dependence, unlike the relationship between Permutation Symmetry and Fermi-Dirac statistics, in that the halting of the collapse of the white dwarf star is dependent on the action of the Exclusion Principle and not vice versa. Of course, you might find this too 'thin' a characterisation, as compared to a causal relationship but here a structural realist might suggest that this thinness is a result of the metaphysical proximity of the two relata: for her, the observed halting and the Exclusion Principle are both features of the structure of the world, conceived à la Cassirer as indicated above.

There is more to say, of course but I would maintain that Permutation Symmetry can be said to 'produce' the appearances associated with the halting of the collapse of white dwarf stars in a way that meets van Fraassen's challenge. However, van Fraassen then sharpens the problem for the realist by posing the challenge in the context of quantum mechanics, where it appears in the form of the infamous 'measurement problem'.

## The Measurement Problem

Thus he suggests that, '… the Copenhagen development of quantum theory exemplifies a clear rejection of the [Appearances from Reality] criterion.' (2008, p. 291). And given the tremendous success of the theory, under that interpretation, we should then be wary of imposing this criterion in general. If the realist nevertheless insists on accepting it, then she must deal with the measurement problem, which van Fraassen characterises as follows:

Measurement Problem: the quantum theoretical description of the interaction between system and measurement apparatus provides no place for specific outcomes

Putting things quite bluntly, quantum mechanics offers an inherently probabilistic description (think of Schrödinger's Cat) and in order to account for a specific measurement outcome (such as 'the cat is alive'!) something further must be added to the theory, where by virtue of being extraneous to the theory, that 'something further' goes beyond what can be supported by the physics and hence can be contested. I'll come back to that shortly but as van Fraassen notes, the measurement problem is not an issue for empiricists, since the empirical adequacy of the theory can be cashed out in terms of the '… surface models of phenomena fit[ting] properly with or into the theoretical models.' (2008, p. 305); that is, we have matching between two families of probability functions. From this perspective, he goes on, the measurement problem represents a 'methodological rejection' of the Appearance from Reality criterion in the new theoretical context of quantum physics.

As he also emphasises, it is likewise no problem for physicists who (more or less) happily continue with their theoretical and experimental practices without (for the most part) worrying about the problem. As Cordero has argued, they have decoherence to thank for that, which introduces an '…effectively irreducible "experimental astigmatism" ' (Cordero 2001). 'Decoherence' is a term that, very broadly speaking, describes the 'loss' of quantum behaviour when a system interacts with the environment As a result, '[a]spects as profound as those regarding the group-theoretic symmetries are untouched by the debate at the stochastic level. That is, above a certain descriptive depth all the models yielded by the … [various interpretational] approaches converge both structurally and semantically in terms of effective partial isomorphisms that reach deeply into the respective theoretical fabrics …'(ibid., p. 308). In effect, then, different interpretations of the theory – such as the Bohm, Everett and GRW interpretations, to pick the more well-known – share a thick body of modeling and relevant prior knowledge in terms of which the outcomes produced by the sorts of particle detectors mentioned above, say, can be understood. Cordero argues that this yields a series of 'local meanings' of the theory that can be captured via partial representations involving restricted domains that in turn incorporate limited levels of theoretical and experimental precision. What this then supports is, at best, a 'restricted' form of structural realism that resonates with recent moves to 'local' forms of realism (Saatsi 2017; Vickers 2013). These in turn urge us to limit our realist commitments to those that are specific to the relevant theoretical situation under consideration

Such 'localised' realism is not necessarily at odds with the structuralist tendency in general, especially if we recall the core motivation, running from Cassirer and Eddington to Ladyman and current accounts, of accommodating certain specific features of twentieth century physics. Alternatively, however, we might still prefer a more global account and consider, in a little more detail, the nature of that 'further element' that should be added to the quantum mechanical description in order to satisfy van Fraassen's 'Appearances from Reality' criterion. The hope then is that this will then bridge the gap between the probabilistic description offered by the theory and the specific measurement outcomes, in some way or other. As we'll see, this can be done but only at some cost.

Let us begin with the Copenhagen development of the theory, as mentioned above. As is now well-known the label was actually applied in the 1950s (Beller 1999) as a way of characterising what was deemed to be the 'orthodoxy'; indeed, the labelling may be said to have contributed to the cementing into place of that orthodoxy. And that has since been presented in broadly instrumentalist terms that are amenable both to physics practice and empiricist philosophy. However, prior to that labelling moment, one can discern distinct strands within the groups of physicists most commonly associated with the so-called 'Copenhagen Interpretation', offering two types of solution to the measurement problem and thus two ways of bridging the above gap: the first is associated with Bohr and appeals to the 'classical' nature of the measurement environment. Again putting things simply, the core idea here is that we are compelled to describe measurement outcomes in classical terms and hence the 'gap' between what the theory says and specific outcomes isn't bridged so much as entrenched in a fundamental shift from one kind of description to another. All we need to do, then, is make sure we use the right description in the right context. As is well-known, this solution came under intense criticism, not least on the grounds that as it continued to be developed, quantum mechanics was actually applied to broadly 'macroscopic' situations for which 'classical' physics was supposed to be appropriate, thus undermining the force of the 'compulsion' to use classical language in such situations. A striking and, at the time, forceful example of this is the development, from the mid-1930s onwards, of quantum models of superconductivity and superfluidity, led by the London brothers (another, presented in the form of a thought experiment, is Schrödinger's Cat, as touched on earlier).

The second strand is typically associated with von Neumann and is generally understood as resolving the measurement problem by appealing to consciousness as the 'extra factor'. This bridges the gap by 'collapsing' the quantum wave function, reducing the range of possible outcomes to just one. Well-known and obvious concerns were raised about this proposal, not least having to do with how the intervention of consciousness could 'cause' the wave function to collapse or more generally close the gap between the quantum description and the specific measurement outcomes. However, von Neumann himself actually wrote very little on the role of consciousness and many of those concerns were expressed in response to what was taken to be a summary of his view, written by London and Bauer (1939). As it turns out, this was no mere summary but presented an entirely different approach that drew on London's background in Husserl's phenomenology (and here we recall Ryckman's contextualisation of Weyl's point, acknowledged by van Fraassen, about coordinate systems in the relativistic context). Instead of seeing consciousness as some extraneous element that mysteriously collapses the wave function and thereby accounts for specific measurement outcomes, it is here presented within an understanding of quantum mechanics as a 'theory of knowledge' in general. Within that framework, the wave function is taken to describe *everything*, contra Bohr, and it is the separation of both consciousness and the system under consideration from the superposition through a phenomenological act that yields a definite measurement result. Hence what we have is not so much a further or extraneous element imposed from outwith the theory, as it were, but a phenomenologically grounded expression of the very conditions for doing science, indeed for acquiring knowledge, in the first place. Within this framework, the measurement problem is seen as no 'problem' at all, but rather as an acute manifestation of the nature of our engagement with 'the world' that can only be properly grasped in phenomenological terms (see French forthcominga). It was, in fact, Wigner who effectively appropriated this account and presented it in terms of consciousness mysteriously producing the collapse of the wave function, thereby generating all the concerns that ultimately led to the approach in general being widely discarded.

So, when it comes to the Copenhagen development of quantum theory it appears we have (at least) three variants: Bohr's version, with a classicality condition; von Neumann/Wigner's with consciousness as the cause of collapse; and London's with the theory understood from a phenomenological perspective. Only in the second case do we have a specific extraneous element that is introduced; in the other two we have, rather, the articulation of conditions for applying the theory or acquiring knowledge more generally. In whatever case, where do we stand with the Appearance from Reality criterion? Recall that the requirement is that the appearances should be explained as *produced* in the world depicted by the physics. Now, if the mode of production is taken to be mechanistic, then only in the case of the von Neumann/Wigner variant could we say that the requirement is met and then only contentiously and with a broad understanding of 'mechanistic'. With that meaning of 'produce' on the table, it would indeed seem that when it comes to the cases of the Bohr and London variants, the Appearance from Reality criterion has been set aside. However, to leave it at that would be to ignore the role of the further conditions which are introduced in each case – a classical/quantum division in that of Bohr and a fundamentally phenomenological framework in the case of London. It is certainly not the case that 'the theory', however that is to be understood (and we'll come back to this issue shortly), yields the appearances on its own. In either case, some further move has to be made and although we obviously can't give this a mechanistic construal, perhaps we can take some liberties and acknowledge such a move as a form of production, in broadly van Fraassen's sense. If so, then it would seem that the criterion can be met, and in an interestingly different way in each case. However, if we acknowledge this, there is the further question to be answered, as just touched upon: what, then, *is* the theory of quantum mechanics?

Recalling Halvorson's critique of the Semantic Approach that we began with, if we were to move away from the toy examples that he focuses on and characterise an actual theory in terms of families of models, such as quantum mechanics, what would we start with? Do we include the above 'further elements' and conditions? In Bohr's case, presumably not, since his classicality condition can be understood as delineating the domain of applicability of 'the' theory but in the London case, there is no such need for delineation; rather, it is only when we see 'the' theory from the phenomenological perspective that we can account for the appearances. But then, what do we take 'the' theory to be?

Everett, at least, was clear in his response to what was perceived to be the Copenhagen orthodoxy. Under the influence of Frank's 'empirical pragmatism' (Barrett and Byrne 2012, p. 258) he maintained that a theory, in general, is a mathematical model with a homomorphism holding between the model and 'the world', where the latter could either be taken to be 'the world of experience' (i.e. the sense perceptions of the individual), or the 'real world', '… depending upon one's choice of epistemology ...' (Everett, in Barrett and Byrne 2012, p. 169). Here we have a characterisation that obviously meshes with the Semantic Approach, but with homomorphism selected as the appropriate formal relation rather than isomorphism because Everett felt that not only was the theory not required to explain *all* of our experience but there may be parts of the model that are not interpreted *as* our experience (ibid. p. 169, fn cq). Crucially for the interpretation of quantum mechanics that he proposed, what he meant by 'experience' here were memory sequences and more particularly, those that were 'typical' (in a sense that when technically defined gave the standard quantum statistics; see Barrett 2018).

As a result, Everett insisted, despite the kinds of concerns that underlie the challenge represented by the 'Appearance from Reality' condition, '[t]he theory *is* isomorphic with experience when one takes the trouble to see what the theory itself says our experience will be.' (Everett to DeWitt, in Barrett and Byrne 2012, p. 255). Thus, he maintained, what he called 'pure wave mechanics', with its superpositions of states, is in fact 'empirically faithful' as long as one understood that there has to be a 'renegotiation' of empirical adequacy in the context of theory selection. Now of course, this notion of faithfulness offers only a weak empirical standard as Barrett has noted and there is no explanation of why a particular sequence of records should be regarded as 'typical' (Barrett 2018). Nevertheless, Everett's account does show how the appearances might be obtained from the fundamental physics. It also, crucially, highlights how the satisfaction of the Appearances from Reality criterion assumes implicit prior consideration of both what we take to be 'the' theory and how we conceive of its relationship to experience.

Pressing on in our search for a global realist response to van Fraassen's challenge, we can re-frame this account in broadly structuralist terms. The central premise of (ontic) structural realism aligns with Everett's overall stance, namely to take quantum mechanics seriously as presenting 'the structure of the world'. For the Everettian this structure has to be understood in terms of 'branches' within the framework of the relative state formulation but in a sense it offers too much structure. Again, some further feature or device has to be introduced to pin down the relevant aspects of that structure to yield our experiences. In Everett's case this feature is the relevant memory sequences, with measurement outcomes 'typically' distributed according to the standard quantum probabilities. Thus this amounts to 'what the theory itself says our experience will be.' (Everett to DeWitt, Barrett and Byrne 2012, p. 255). As noted above, the associated empirical faithfulness may seem too modest, explanatorily speaking. In that case, one might prefer the so-called Deutsch-Saunders-Wallace approach which introduces decision theory as the further element, yielding the relevant probabilities via reflection on the choices of an ideal agent (Wallace 2012).

Again, we can usefully compare such 'further elements' to those indicated above when it comes to the different variants of the Copenhagen Interpretation. The lesson to be drawn is that given the nature of what Everett called the 'mathematical model' sitting at the heart of 'the' theory, something further has to be added to the mix, whether that's consciousness, or typicality or, thinking of the Bohmian case, some privileged 'hidden variable' such as position or some kind of probability 'field' as with GRW, or a reconceptualisation of quantum mechanics as itself a theory of knowledge, as London and Bauer maintained. All of these features or moves can be understood as enabling the 'production', perhaps understood broadly, of the appearances from the physics. And crucially, then, the challenge underlying the 'Appearance from Reality' criterion hinges on a prior decision as to what we are going to take 'the' theory to be. That decision in turn hinges on '… what explanatory assumptions one has an obligation to include in one's specification of a theory.' (Barrett preprint, p. 16). In particular, if one feels that one is not obliged to include any of the above elements, moves or frameworks in one's specification of quantum theory then 'the' theory by itself, as it were, cannot meet van Fraassen's requirement. If, on the other hand, one takes these features precisely to be the kinds of explanatory assumptions that should be part of the specification, then the challenge can be met, but with obvious costs, not only for each case but also globally, with the blossoming of a multiplicity of different quantum 'theories'. And lest you think that this is just underdetermination redux, compare and contrast Everett's 'pure wave mechanics' plus typicality with London's phenomenologically based conception of quantum mechanics as a theory of knowledge – can these usefully be regarded as merely different interpretations?

It seems, then, that we have something of a dilemma: either we exclude such explanatory assumptions from our specification of 'the' theory, and then bite the empiricist bullet when it comes to obtaining the appearances from reality, or we introduce some such assumption and accept both the local and global costs. In seeking a way forward, let us return to Halvorson's critique of the Semantic Approach. We recall that van Fraassen's response was to emphasise the significance of the representational function of theories. Here the example of the Mona Lisa was invoked and, as we noted above, scientific theories are typically compared with paintings in discussions about representation, not always appositely. And indeed, more generally, theories are not like paintings in certain, obvious, ways – they are not physical objects, for example. This is clearly fundamental when it comes to the evaluation of the faithfulness of the representation in each case. Furthermore, it is not just that a theory cannot be identified with a particular presentation of it, in a particular 'mode' or language, say. We would not want to say that Newtonian mechanics expressed in French is a different theory from that expressed in English. Likewise, many would be reluctant to claim that the Special Theory of Relativity as expressed in Einstein's 1905 paper in terms of clocks and rods is a different theory from the formulation presented in terms of Minkowski space-time, although that might be more contentious that the Newtonian case. Indeed, it is these kinds of 'intuitions' that motivate, in part, the Semantic approach – *if* theories are to be identified with anything at all (and again, that's a big 'if'), they should be identified with something that transcends language.

Alternatively, theories have been compared with other forms of art, such as works of music. Popper, famously, placed both theories and musical works in his 'World Three', the world of 'intelligibles'; that is, the products of the human mind (whereas World One is the world of physical states and World Two is that of mental states). This encourages the view that they are in some sense abstract entities, or, perhaps, abstract *artefacts* as Thomasson has suggested, created and sustained by certain intentions (Thomasson 2006). The worry here is not only do such views offer an inflated ontology but they face a number of challenges in terms of accommodating the kinds of heuristic moves that can be identified and traced in scientific practice (see French forthcomingb).

There is a further alternative to all these sorts of accounts that avoids having to introduce new worlds, or abstract artefacts or, indeed, any further ontological commitments at all. It also allows us to escape the above dilemma and effectively sidesteps the need to proscribe identity conditions for theories that the likes of Halvorson demand. We simply deny that theories are the sorts of 'things' that have identity conditions at all, whether abstract artefacts, denizens of World Three or whatever. Here we also recall van Fraassen's quote from before: '... if theories are to be reified … then a theory should be identified with its class of models.' (van Fraassen 1989, p. 222). As I've said, that's a big 'if' and what is being suggested here is that we bluntly decline to affirm the antecedent. One way of making good on this is simply to *deny* that there 'are', in whatever sense, theories at all (French and Vickers 2011). Of course we may say things that are apparently *about* theories, such as 'quantum mechanics is our most empirically successful theory' or 'quantum mechanics is elegant' but that should not be taken to imply that what makes these statements true is some *thing*, 'the' theory of quantum mechanics. We can adopt the eliminativist strategy of taking something else as the truthmakers of such statements, such as the various practices engaged in by physicists (and philosophers, as we'll see; French and Vickers ibid; French forthcomingb).

So what makes the statement 'quantum mechanics is our most empirically successful theory' true are a range of practices associated with experimental work, as well as with modelling and theoretical manipulation. Of course, in articulating that sense of empirical success we will have to address the kinds of issues that Everett tried to tackle and that underpin the Appearance from Reality criterion. So we should include among those practices the broadly reflective practices of the likes of Everett, as well as London, von Neumann and others, that involve thinking about selecting 'typical' memory sequences, or the insertion of consciousness into our framework or even taking 'the' theory to be a theory of knowledge under the phenomenological understanding. As for 'quantum mechanics is elegant', we can cash this out in terms of some combination of parsimony and power and take the statement to be made true by the relevant practices, involving, for example, the ease of deduction of certain statements from the axioms or fundamental claims of the theory, the way in which a wide variety of claims (both theoretical and empirical) can be obtained from these axioms and so on (French forthcomingb).

This eliminativist stance avoids a bloated ontology but potentially at the cost of rendering problematic our understanding of theories as *representations*. Now we face yet another question: how can something that is not a *thing* represent something else?! The answer is to acknowledge that when we, whether scientists or philosophers of science, make claims about theories fulfilling a representational role we have a certain construct in mind. We may then present that construct to one another, via symbols scribbled on paper or the whiteboard, or, particularly if we are philosophers, via some framework such as that offered by the Semantic Approach. However the models of the latter are neither to be identified with the theory nor to be taken as representing that theory as an entity, whether abstract or not; rather, they should be seen as devices that we, philosophers of science, can deploy to (meta-)represent those aspects of scientific practice we are interested in. At that (meta-)level we can then introduce partial isomorphisms and the like to capture the relevant representational function holding between 'the theory' (meta-characterised in terms of a family of models) and the given system (also meta-characterised in terms that allow for such a relation to be taken to hold; see French forthcomingb).

Expressing it in those terms raises an obvious worry for the realist, but I want to emphasise that to deny the existence of theories as things is not to deny the existence of things apparently referred to by those theories. We should not allow our eliminativism to bleed across from our stance on theories to our stance towards the world. Nevertheless, we might well have good reason to be a certain kind of eliminativist in the latter case also. Consider: certain scientific practices running throughout twentieth century physics emphasise and illuminate the role of symmetries and, as indicated above, this has been one of the prime motivating forces behind structuralism, from Cassirer and Eddington to Ladyman. Viewed, realistically, as saying something about the world, we can take structuralism and, in particular, the fundamental role granted to symmetries, as implying the elimination of elementary particles *as things*, with statements apparently about them made true by features of the structure of the world (French 2014).

However, that's a whole other set of issues and one can (and should) be an eliminativist about theories while adopting any of a range of stances and positions within those stances towards the ontology of the world. Having said that, it should now be apparent that there is a certain parallel between the issue of 'pinning down' the structure of the actual world and that of satisfying the Appearance from Reality criterion. With regard to the former, we noted that the mathematical description of these symmetries yields surplus structure that goes beyond what we need in practice. So, again, the group-theoretic description of Permutation Symmetry yields forms of quantum statistics that do not seem to be relevant to our world. Thus we need to pin down that structure to the actuality and understand Bose-Einstein and Fermi-Dirac statistics as 'existential witnesses', in Wilson's sense. Likewise, as we've just considered, when it comes to quantum mechanics we have, in a sense, too much structure and we need to introduce some further element or device to yield the appearances, whether that be 'typicality', the precepts of decision theory, consciousness or whatever. In both cases, it seems, we have to engage in a kind of 'Act of Self-Location' as a form of making concrete the abstract structural forms that the mathematics offers us.

## Final Remarks

Of course, these moves of 'pinning down' the structure and establishing 'existential witnesses' are fallible and revisable across a range of respects and degrees. Thus, nothing said here goes against van Fraassen's insistence that '… we have the freedom to follow the contemporary abstract structural forms now prevalent in the advanced sciences …' (2008, p. 267). Indeed, exercising that freedom is a source of significant scientific development. Consider Dirac's famous equation in relativistic quantum mechanics: putting things very simply, from a mathematics perspective this has both positive and negative energy solutions. The latter might be understood as constituting 'surplus' structure that can be dismissed as non-physical, thereby 'pinning down' the physical solutions. However, as is well known, and again summarising things rather crudely (for more details see Bueno and French 2018, Ch. 7), Dirac exercised the freedom that van Fraassen mentions and interpreted this particular surplus structure in terms of what we now understand as anti-matter. As Redhead emphasised many years ago, we can find this exploration and interpretation of surplus structure time and again in the history of physics (Redhead 1975). Sometimes it pays off, as in Dirac's case and sometimes it doesn't, as when quarks were briefly characterised as paraparticles. In both cases, however, we can see the 'pin' sliding, as it were, across the structures that are available. Indeed, we can perhaps see that history as a series of such explorations together with appropriate ‘pinning down’ to yield descriptions of either – depending on your stance – how the world is or how it could be. And, I would insist, what we should focus on, when it comes to the philosophy of science, are the *practices* associated with these moves, and, returning to the opening remarks of this essay, what we should acknowledge is the diversity of devices that we, as philosophers of science, can deploy to make sense of these practices.

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