Structuralism with and without causation

Juha Saatsi
j.t.saatsi@leeds.ac.uk
School of PRHS
University of Leeds
Woodhouse Lane
LS2 9JT Leeds, UK

28th October 2014

Abstract

This paper explores the status of causation in structuralist metaphysics of physics. What role (if any) does causation play in understanding 'structure' in ontological structural realism? I address this question by examining, in a structuralist setting, arguments for and against the idea that fundamental physics deals, perhaps exclusively, with causal properties. I will argue (against Esfeld, Dorato and others) that a structuralist interpretation of fundamental physics should diverge from 'causal structuralism'. Nevertheless, causation outside fundamental physics, and the basic motivation for causal structuralism outside fundamental physics, can be captured with an appropriate conception of causation.

1 Introduction

Structuralism has flourished in the philosophy of science over the past couple of decades. It has thrived in the scientific realism debate, ever since Worrall (1989). Our epistemic humility towards current scientific theories is best delineated—according to epistemic structural realism—with a distinction between knowable structure and unknowable nature of fundamental reality. Structuralism has also bloomed in philosophical accounts of representation, theories and models, ever since Suppes (1967). And, finally, in the metaphysics of physics structuralism has also become a buzzword, along with the growing popularity of the idea that reality, as described by physics, is fundamentally structural in some sense. In this paper I focus on structuralism in metaphysics and philosophy of physics, leaving unexplored whatever connections and family resemblances there may be to other forms of structuralism.

It is not easy to give a substantial characterisation of metaphysical structuralism in general terms. We can say that it involves metaphysical commitment to (non-mathematical) structure as a metaphysical primitive, and an emphasis on relations (or relational structure), contrasted with (non-structural) objects and intrinsic properties. According to Ladyman (2009), a "crude statement of Ontological Structural Realism is the claim that there are no 'things' and that structure is all there is." But this obviously leaves a lot to be clarified. A key issue is evident: what does 'structure' exactly amounts to? This is a difficult issue, and various things have been said about it.[1] We are still far from having a clear idea of what 'structure' amounts to, never mind a consensus. The best way forward in the thicket of structuralism is to keep hacking away by asking and answering sufficiently specific questions about structure. How exactly does it differ from mathematical structure? How exactly does it relate to everyday ontology (of 'tables and chairs')? How do laws of nature (or modal notions more broadly) relate to it? *How does causation relate to structure?* In this paper I aim to advance the debate by exploring the last of these questions.

So, what is the status of causation in structuralist metaphysics, and structuralist metaphysics of physics, more specifically? There are widely different takes on this question in the literature, leaving it unclear what role causation should be given in spelling out the key notion of structure. I will approach the issue by examining the question in relation to arguments for and against the idea that fundamental physics deals, perhaps exclusively, with causal properties. Siding with causal 'anti-foundationalists' who maintain that there is no causation to be found in the fundamental physics, I will argue (against Esfeld, Dorato and others) that a structuralist interpretation of fundamental physics should diverge from so-called causal structuralism. Nevertheless, we will see that there is still plenty of room for causal notions outside fundamental physics, and the basic motivation for causal structuralism outside fundamental physics can still be captured with an appropriate conception of causation.

[1]See French (2014) for a cutting edge exploration.

2 Three lines of metaphysical structuralism

We can identify (at least) three different lines of structuralism in contemporary metaphysics.[2] Since Shoemaker (1980), *Causal Structuralism* regarding property identity has been popular. Since Ladyman (1998), the position of *Ontic Structural Realism* has been developed, primarily (but not exclusively) within the philosophy of physics, involving considerations concerning the identity and individuality of quantum particles and spacetime points and, more generally, the role of fundamental symmetries in physics. Finally, North (2009) has more recently advocated (what I call) *Invariance Structuralism* on the basis of the use of mathematical structures in describing the objective physical reality invariant under transformations between different mathematical representations.[3] I will briefly review these three structuralist lines of thought to set the context for my examination of the role of causation in structuralist metaphysics of physics.

Causal structuralism. According to Causal Structuralism the identity of a natural property is determined by a network of possible causal relations into which a property can enter. A property's 'causal profile'—its potential for entering into causal relations with other properties—is naturally captured in terms of its causal powers. To use one of Shoemaker's original examples, the property of being knife shaped confers an object instantiating this property the power to cut butter, cheese, and wood, when combined with the property of being knife sized and the property of being steely (Shoemaker 1980). The manifestation of this power is the causal effect of the property under appropriate stimulus conditions. Arguably the very identity of the property is a matter of having the potential to enter into a vast array of causal relations of this sort.[4] One can argue for this view of property identity, as Shoemaker does, on epistemic grounds. The thought is that we know of properties only through their effects. If the identity of a property somehow transcends its capacity to enter into a range of causal relations, how could we ever know

[2]Many more can be identified in the history of philosophy. See, for example, Marmodoro (2009).

[3]The idea that objective reality should be identified with invariances originates from Klein's 'Erlangen Programme' (1872). See Ihmig (1999) for an account of its influence on the development of early structuralist philosophy of physics.

[4]Cf. Shoemaker 1980:

> [W]hat makes a property the property it is, what determines its identity, is its potential for contributing to the causal powers of the things that have it. (p. 256)

that?[5]

The structuralist aspect of this causal theory of properties is explicit in Hawthorne (2001). Hawthorne calls the position 'causal structuralism', and he also discusses the view explicitly in relation to fundamental physical properties, not only in relation to mundane properties such as being knife-shaped. Thus regarded, the view encompasses a structuralist metaphysics of physics.

> [F]or each fundamental property [there is] a causal profile that constitutes the individual essence of a property. ... The relevant profile, we should note, may include facts about how a property figures as an effect as well as how it figures as a cause. Let us call this view 'causal structuralism'. (Hawthorne 2001, p. 362)

This explicitly causal line of structuralism has been recently further defended by Esfeld and others on the basis of various considerations from the philosophy of physics, effectively converging it with a different lineage of structuralism—Ontic Structural Realism.[6]

Ontic Structural Realism. Ontological Structural Realism (OSR) offers an account of fundamental physical properties that is *prima facie* quite different from Causal Structuralism. In particular, it is striking that OSR (as originally developed) makes no mention of causal laws or relations at all. OSR is not trying to capture everyday intuitions about property identity, but is rather concerned with providing an attractive metaphysics of physics.[7]

[5]See Shoemaker (1980):

> My reasons for holding this theory of properties are, broadly speaking, epistemological. Only if some causal theory of properties is true, I believe, can it be explained how properties are capable of engaging our knowledge, and our language, in the way they do. (p. 257)

[6]Cf. Esfeld (2009), for example:

> I maintain that ontic structural realism, as a position in the metaphysics of science that is a form of scientific realism, is committed to causal structures. (p. 180)

.

[7]Cf. French and Ladyman (2003):

> [O]ur understanding of structural realism is also informed by the need to provide an ontology that can dissolve some of the metaphysical conundrums of modern physics... (p. 33)

Furthermore, arguably causal notions play no significant role in the ontology of modern physics; rather, notions such as symmetry come to the fore and give rise to specific metaphysical conundrums regarding the identity and individuality of fundamental entities, for example.[8] Given the nature of these conundrums, OSR is touted as a fundamental "reconceptualisation of ontology, at the most basic metaphysical level, which effects a shift from objects to structures." (French and Ladyman 2003 p. 37)

For instance, with respect to the question, 'What is an electron?', OSR recommends a shift away from thinking about it as an individual object, to construing it as a "'point of intersection' of certain relations." (Ibid, p. 39) Similarly, regarding the basic physical property of electron charge, OSR recommends a shift away from thinking about it as an intrinsic property that features in the relevant laws of physics, to thinking it as node in a structure that is somehow constituted by the relations described by the relevant laws.[9]

If these laws have a causal interpretation, then OSR could be thought to converge with Causal Structuralism. Indeed, as already mentioned, OSR has been given a causal spin by some of its more recent advocates, who effectively aim to converge the two structuralist lines of thought (Esfeld 2009, Esfeld and Lam 2007, Esfeld 2010, Esfeld and Lam 2010). The convergence is motivated on various grounds, with the claimed benefit, for example, of being able to account for the modal nature of physical structures that are thereby also clearly distinguished from mathematical structures.[10] But can the fundamental laws of physics that pertain to the property of electron charge be interpreted in causal terms so as to recommend such convergence of Causal Structuralism and OSR? There are by now well-known arguments to the contrary, suggesting that the laws of fundamental physics should not be given a causal interpretation at all. It is this tension that I will explore in detail below.

[8]Different discussions of OSR have focused on different symmetries, ranging from permutation invariance in quantum mechanics (e.g. French and Rickles 2003), to general covariance of general relativity (e.g. Saunders 2003), gauge symmetries (Lyre 2004), to the role of symmetry groups in particle physics (e.g. Roberts 2011).

[9]Ibid.:

> *Charge*, typically understood as an intrinsic property ... features in the relevant laws of physics and ... what we have here is a reversal of the classical relationship between the concepts of object and law. (p. 39)

[10]French and Ladyman (2003b) also appeal to causation to this effect, claiming that 'causal relations constitute a fundamental feature of the structure of the world'. (p. 75) In their respective later developments of OSR both French (2014) and Ladyman (in Ladyman and Ross 2007) have come to deny that causation plays a fundamental role in OSR.

Invariance Structuralism. For the sake of completeness I want to mention a third structuralist line of thought in the metaphysics of physics. This view, advocated by North (2009), is driven by the fact that physics, taken at face value, routinely speaks of the 'structure' posited by a given theory of physics.

> We say that relativity is a theory about space-time structure. Special relativity posits one space-time structure; different models of general relativity posit different space-time structures. We also talk of the 'existence' of these structures. (p. 57)

In line with OSR, North's structuralism makes no mention of causal laws or relations. Rather, the physical structures in question are represented by (mathematical) spaces in physics, such as a state-space (Lagrangian mechanics), phase-space (Hamiltonian mechanics), or Hilbert space (quantum mechanics). These mathematical spaces need not concern causal relations or have a causal interpretations at all—indeed, arguably the structures of fundamental physics simply do not involve causation in any constitutive way. Rather, the spaces span over (non-causal relations of) spacetime points or quantum states, for example.

North's motivation for structuralism is interesting and goes well beyond the mere recognition of the fact that mathematical structures are employed in physics. 'Structure' for North really has to do with *invariant features* of physical systems under different mathematical descriptions.

> Structure has to do with the invariant features of a space... Structure comprises the objective, fundamental, intrinsic features, the ones that remain the same regardless of arbitrary or conventional choices in description. And we can learn about structure by looking at the invariant quantities under allowable transformations. (p. 66)

Since 'invariance' is intimately related to symmetry, North's position has close affinities with OSR.[11] The main difference lies in its overall motivation and approach to identifying the structure worthy of realist commitment.[12]

[11] See e.g. van Fraassen 1989 (p. 243 ff.) on the connection between invariance and symmetry.

[12] North's main exemplar is her study of the relationship between Lagrangian and Hamiltonian mechanics. In these two formulations of classical mechanics different mathematical structures are used to represent the objective features of the physics, and North has argued that Lagrangian mechanics posits 'excess structure', and that Hamiltonian mechanics is for that reason more fundamental, revealing the 'real structure'. This claim has been criticised by Curiel (2013) and Barrett (2013), for example.

Full analysis of the relationship between North's position and OSR lies beyond this paper, and from here on I will focus exclusively on causal structuralism and OSR, assuming that my conclusions also apply to Invariance Structuralism due to its affinity to OSR.

3 The tension between Causal Structuralism and Anti-foundationalism

Let us now look at the interaction between Causal Structuralism and OSR, on the one hand, and the debate on causal (anti-)foundationalism, on the other. The issue of causal (anti-)foundationalism concerns the status of causation from the point of view of fundamental physics. Is causation part of the fundamental description of reality? Does fundamental physics reveal fundamental facts about causal relations? Causal foundationalists think so; anti-foundationalist think not.[13]

The re-emergence of causal anti-foundationalism in recent years raises interesting questions about the status of Causal Structuralism. If Causal anti-foundationalism is right, is Causal Structuralism in trouble? If so, where does it go wrong? If Causal Structuralism is in trouble, how should one interpret Ontic Structural Realism? How is Ontic Structural Realism compatible with causation at all?

To answer these questions I will proceed as follows. In this section I will briefly recall the case for causal anti-foundationalism to begin with, maintaining that it amounts to a noteworthy challenge to both causal foundationalism and the notion that the identity of fundamental physical properties is given by their causal profiles. (The case for anti-foundationalism, originating from Russell, has been recently much explored in the literature. See, for example, Field 2003, Price and Corry 2007.) In light of this, Causal Structuralism about fundamental physics needs to be properly motivated and defended against the challenge. I can discern two lines of argument to this effect. There is, first of all, the possibility of trying to apply the basic epistemic motivation behind Causal Structuralism to fundamental physics. I will examine this option in section §4, arguing that the epistemic motivation fails to get

[13]Cf. Ney (2009):

> [According to causal foundationalism] causation is fundamentally a microphysical phenomenon, which can be discovered by looking directly at our fundamental physical theories. The obtaining of [all] causal facts depends on the obtaining of facts about physical causation. (p. 741)

traction with non-causal symmetries in fundamental physics, in particular. Secondly, there is the possibility of motivating a thoroughly dispositional theory of natural properties on broader metaphysical grounds, and providing a dispositionalist gloss on modern physics accordingly, regardless of the case for causal anti-foundationalism. I will argue that there are good reasons to resist such preference for a causal conception of all physical properties. For not only is it in tension with the role of symmetry in physics (§4), but the proposed dispositionalist interpretations of quantum mechanics are problematic as well (§5).

Now, let's recall the case for causal anti-foundationalism. It originates in Russell's 1918 'On the Notion of Cause'. Here I follow Alyssa Ney's clear reconstruction of Russell's arguments (Ney 2009). Consider the 'Directionality Argument' first, pointing to the time-symmetric nature of fundamental physical laws:

(P1) Causal relations are *temporally asymmetric*.

(P2) Fundamental physics' laws are temporally symmetric.

(C) There is nothing in fundamental physics to ground causal relations, which are temporally asymmetric.

This argument contends, in brief, that the de facto asymmetry of causation—effects never precede causes (bar recondite cases of time-travel etc.)—cannot be grounded in the laws of fundamental physics, which are deterministic (or have the same indeterministic character) in both time directions. Therefore causation is not part of fundamental physical description of reality.

The second, 'Localization Argument', points to a *global* feature of fundamental physical laws.

(P1) Our concept of a cause requires laws that connect a finite number of quite *localised* events to a particular effect a short time later.

(P2) No proposed law of this sort has a chance of being correct in fundamental physics.

(C) There is nothing in fundamental physics to ground causal relations.

This is less self-explanatory than the directionality argument. Here the idea is that grounding a paradigmatic causal relation—e.g. Suzy's throwing a rock and the window breaking—in the fundamental physics rules in too much as being part of 'the cause', since according to the fundamental physics we must take into consideration facts about the past light cone that go well beyond what we intuitive identify as the cause. For instance, we must take into account the fact that no pointed gamma ray burst came from afar to knock the rock off its window-breaking course. Such facts about the past light cone are not intuitively speaking part of the cause, but there is nothing in the fundamental physical description of the system that could be identified, in and of itself, as underwriting this intuition. Therefore, again, causation is not part of the fundamental description of reality.

These two arguments comprise the Russellian case for causal anti-foundationalism.[14] Ney (2009) brings out, among other useful points, some possible objections to the Russellian, and I agree that the case is far from being watertight. For instance, there is scope for finding time-asymmetry in fundamental physics, if one adopts GRW interpretation of quantum mechanics, involving spontaneous localisations of the quantum wafe-function. (I will consider further the status of causation in GRW in section §5.) Having said that, it is far from trivial to defend causal foundationalism in the face of this prima facie serious Russellian challenge. Ney, for example, defends foundationalism, but in doing so she must relinquish the asymmetry of causation altogether at the level of fundamental physical causal facts!

> [It] is not obvious that the foundationalist about causation should worry about there being an objective and analytic distinction between which relatum of a causal relation is the cause and which is the effect. . . . To some it may sound objectionably revisionist to allow that there may be no fundamental difference between causes and effects. But if the universe does not have any fundamental, built-in temporal asymmetries, this seems to be what we are left with. There is still causation, because there is still physical determination. But the distinction between what is the cause and what is the effect may not be fundamental. (Ney 2009, p. 752)

This is a radical move, to say the least. Unless, of course, it is merely a terminological one, in which case it threatens to be uninteresting. Since we all undeniably agree that fundamental physics describes determination relations (possibly interpreted in a Humean spirit), we can all quite trivially agree that fundamental physics describes causal relations, albeit in a radically revisionary sense.

The Russellian challenge against causal foundationalism also challenges Causal Structuralism about fundamental physics. If there is no causation

[14] See Field (2003) and Ney (2009) for further details and discussion.

to be found in the fundamental physics, then the relations described by the fundamental physical laws—the relations that describe and identify fundamental physical properties—cannot be causal relations. But if we accept this upshot of the Russellian challenge, where does Causal Structuralism go wrong? Or is it the case that Causal Structuralism is worth hanging onto, and the Russellian challenge needs faulting (somehow)? I will next criticize arguments to the latter effect, and in doing so I will identify where Causal Structuralism goes wrong.

4 Causal Structuralism and symmetries

Recall the broadly epistemological roots of Causal Structuralism. We begin with an intuition that we only know of properties through their effects, motivating a view according to which the nature of a property is exhausted by all the potential causal relations into which the property can enter. Anything going beyond this causal nature of properties amounts to a 'quidditative extra', an unnecessary metaphysical posit without scientific backing. As Hawthorne (2001) puts it:

> The best case for thinking that the causal profile of a property exhausts its nature proceeds . . . via the thought 'We don't need quidditative extras in order to make sense of the world.' Let us return to negative [electric] charge. All scientific knowledge about negative charge is knowledge about the causal role it plays. Science seems to offer no conception of negative charge as something over and above 'the thing that plays the charge role'. (p. 368)

There is something right and something wrong about this line of thought. Surely Hawthorne is right in that science offers no conception of negative charge as something over and above 'the thing that plays the charge role'. But is it really the case that all scientific knowledge about negative charge pertains to its *causal* role? What exactly is the 'the charge role' delineated by physics? And how does causation feature in it?

To answer these question we need to look at the physics of negative (electric) charge in a bit more detail. We can get started with *Wikipedia*.[15] The very first thing said of electric charge reflects nicely both the common conception of charge and the Causal Structuralist interpretation: "Electric charge is the physical property of matter that causes it to experience a force when close to other electrically charged matter." So far, so good. But Coulomb's

[15] http://en.wikipedia.org/wiki/Electric_charge

law that quantifies this causal conception of charge is not, of course, a fundamental law of nature. Quantum physics provides a more fundamental conception of electric charge (as I will explain below), and even *Wikipedia* summarizes theoretical explications of charge that do not seem to conform to the causal conception.

Take, for example, the critical elementary fact that electric charge is *conserved.* This is a basic feature of electric charge, and our most fundamental grasp of this feature does not seem to be causal in any way. Rather, as *Wikipedia* correctly has it, charge conservation is a profound consequence of a *symmetry*: charge conservation is best understood through the famous Noether's theorem, according to which each conservation law is associated with a symmetry of the underlying physics. In the case of electric charge conservation, the associated symmetry is the gauge invariance of the electromagnetic field. More generally, even the *dynamics* of charge is arguably largely determined by the requirement of gauge (or phase) invariance of the quantum wave equation for a charged particle. Our knowledge of these fundamental features of charge—features that beautifully unify our conception electric charge with the rest of the fundamental physics—does not seem to be knowledge of causal relations at all. It is certainly not knowledge about potential causal effects of electrically charged things, in the way in which Coulomb's law can be taken to be, and the onus is on the Causal Structuralist to give a causal gloss on the prima facie non-causal physics.

Let's review the relevant physics in a bit more detail to bring out its prima facie non-causal character.[16] The most fundamental theories of charge—whether electromagnetic charge, or some other 'Noether charge' (isospin, the charge of colour octet state, etc.)—are so-called gauge field theories, i.e. field theories that exhibit a symmetry called (local) gauge invariance. These theories hinge on a deep, intimate relationship between symmetries, conservation laws, and dynamics that has completely revolutionised physics' conception of elementary particle interactions. The intimate connection between symmetries and conservation laws is encapsulated in Noether's theorem that associates a conserved, time-independent charge with any continuous symmetry (of the Lagrangian describing a physical system).[17]

---

[16]Full details can be found in any gauge/quantum field theory textbook, e.g. Ryder (1985).

[17]*Continuous symmetry* is one specified by parameters that can be varied continuously starting from arbitrarily close to the 'identity transformation' (which does not transform the system at all). *Lagrangian* is a function that completely encodes the dynamics of a system in the sense that it yields the correct equations of motion by substitution into the Euler-Lagrance equation.

Noether's theorem expresses a completely general fact about the connection between conservation laws and symmetries. In the specific case of electric charge the symmetry in question is an *internal* one, involving transformation in the two components ϕ_1 and ϕ_2 of complex-valued scalar field ϕ, amounting to a rotation in the complex plane[18]

$$\phi \to e^{i\Lambda}\phi, \text{ where } \phi = \frac{1}{\sqrt{2}}(\phi_1 + i\phi_2).$$

This 'gauge transformation' is equivalent to a phase shift in the wavefunction of a charged particle

$$\psi' = e^{i\Lambda}\psi.$$

Noether's theorem entails that corresponding to the symmetry of a relevant Lagrangian under this transformation there is a conserved quantity. This quantity can be identified with electric charge, and thus we know of electric charge that its conservation is intimately related to a symmetry of quantum mechanical description of a charged particle. This is not knowledge of the 'causal role played by charge'.

Furthermore, the dynamics of electric charge, as described by Maxwell's equations, also arise as a consequence of symmetry; namely, the invariance of the Lagrangian under the corresponding *local* gauge transformation.[19] And in the context of gauge field theories the electromagnetic field itself is seen as a 'gauge field', the presence of which is required to guarantee the relevant local invariance. Thus, the nature of both electric charge and electromagnetic field, and the coupling thereof, is largely a matter of the world exhibiting certain fundamental symmetries. Altogether, the metaphysical picture painted of charge by the fundamental physics is rather different from the Causal Structuralist image. Metaphorically: for God to create the fundamental charge properties as we know them, she only needs to ensure that the fundamental laws exhibit certain symmetries. Since the fundamental laws do not describe causal relations (according to the causal anti-foundationalist, at any rate), and the symmetries in question do not seem to be amenable to (never mind require) a causal reading either, we can make sense of 'the charge role' at the fundamental level without bringing causation into play at all. Again, clearly we know a huge deal about charge going beyond its causal role.

[18]External symmetries involve spatiotemporal variables: translations, time displacements, rotations.

[19]In the local transformation the rotation Λ (in the internal variable space) is a function of spatiotemporal location x.

OSR is motivated by the foundational role that non-causal relations involved in gauge and other symmetries play in the most fundamental theoretical description of quantities like electric charge. If one focuses on a mundane description of the electric charge, in terms of the forces that push and pull electrically charged particles and objects in electromagnetic fields, one may be tempted to associate 'structure' in the sense of OSR with Causal Structuralism. But, as I have indicated, this mundane description of charge is quite far removed from our deepest theoretical conception of these matters. This more fundamental conception gives a beautifully unified account of various conserved 'Noether charges', including also conserved charges in quantum chromodynamics, for example, associated with its own local gauge symmetry. The connection between observations and theoretical knowledge of Noether charges and the associated structures is much less direct than is suggested by Hawthorne's reference to the causal role of charge. In the case of quarks, for example, we completely lack the kind of access to inter-quark forces that we associate with a mundane Coulomb-law description of the electric charge. In a realist spirit we can sum up the epistemic access, as Esfeld (2009) does, by saying that "in short, the fundamental physical structures are theoretical entities, and we recognise them because they *explain* the observed phenomena." (p. 184, my emphasis)

But Esfeld (as a Causal Structuralist) immediately commits a non sequitur thereafter, as he continues: "The explanation in question is a causal one: those structures are the causal origin of the observed phenomena." For this does not follow from the above characterisation of fundamental physical properties, and it is exactly what the causal anti-foundationalist denies. The anti-foundationalist denies that the fundamental laws and symmetry principles, such as those associated with quantum field theory, describe causal relations that furnish causal explanations of the observed phenomena, such as charge conservation. This denial is supported by the fact that no theoretical account of charge conservation in terms of Noether's theorems, for example, speaks of causes, or is naturally interpreted in causal terms. In the face of the causal anti-foundationalist challenge the onus in on the Causal Structuralist to provide such an interpretation, describing a 'charge role' in purely causal terms in a way that does justice to the theoretical role that charge plays in the relevant theories of physics.

I regard the prospects of providing such an interpretation dim. As far as I am aware, no Causal Structuralist has faced this challenge head-on. Bird (2006) comes closest to addressing it in connection with his defence of dispositional essentialism. Bird is at pains to defend the explanatory completeness of dispositionalism against the idea that symmetries and conservation laws are further, indispensable non-causal explanatory assumptions.[20] Bird does recognise that the non-causal nature of conservation laws and symmetries fits rather badly with the idea that the (alleged) causal nature of fundamental properties exhausts all there is to fundamental reality. But while he admits that dealing with the issue properly requires further work, Bird suggests that a dispositional essentialist could regard symmetry principles as 'pseudo-laws' that need not be an integral part of our conceptions of fundamental properties.

> It may be that symmetry principles and conservation laws will be eliminated as being features of our form of representation rather than features of the world requiring to be accommodated within our metaphysics. (Bird 2007, p. 214)

Is such a purely *epistemic* reading of the non-causal cornerstones of fundamental physics a live option? Whatever the answer, Bird's justification for thinking so is highly questionable. This justification begins with the idea that contemporary physics ultimately seeks theories that are free of *background structures:* structures that on the one hand partly determine how entities can be acted upon, but on the other hand cannot be acted upon themselves. (A paradigmatic example of background structure is the classical conception of spacetime as a stage against which things and laws act, but which is not involved in the action itself. General relativity, by contrast, is an example of a background-free theory in which spacetime itself is also a recipient of action.) Whether or not we can expect to be able to ultimately formulate a background-free 'theory of everything' is currently a mere point of speculation. However this may be, I find no justification for Bird's further claim that *invariances* should be construed as in-principle eliminable background structures: "Invariances are background features—they decree that certain features remain unchanged while others do. Thus invariant structures are background structures." (Ibid. p. 214) Furthermore, some advocates of OSR have argued that general relativity as a background-free theory supports OSR *precisely due to* the symmetries it involves (Rickles, 2008).

A naturalistic metaphysician should find, moreover, a major clash between Bird's eliminativist attitude towards symmetries, and that of physics, which largely regard symmetries as nothing short of fundamental to our metaphysical conception of reality.[21] While we of course should not want to rule

[20] See also Livanios (2010) for a convincing criticism of dispositional essentialism from a perspective that is closely related to mine.

[21] For just one example, consider Steven Weinberg: "Symmetries are fundamental, and possibly all that one needs to learn about the physical world beyond quantum mechanics itself." (Weinberg and Feynman, 1987, p. 79)

out radically revisionary metaphysical interpretations of physicists' proclamations, such metaphysical divergence from the physics taken at face value requires a serious justification.

I will end this section with a critical clarification. It is important to note that the above misgivings about Causal Structuralism regarding fundamental physics only concern its causal dimension, leaving the structuralist dimension intact. Nothing in causal anti-foundationalism support quidditism, in particular; the argument against Causal Structuralism is not an argument in favour of 'quidditative extras'. On the other hand, the (good) reasons to avoid quiddities do not suffice to motivate *Causal* Structuralism regarding property identity, either. The structuralist, in the spirit of OSR, can (and in my view should) hold onto the idea that the nature of fundamental properties is completely captured through their theoretical role, where this role is described through a complex network of relations. This OSR response to quidditism should not, however, be motivated by affiliating it with Causal Structuralism, as Esfeld does, for example.[22]

5 OSR and quantum dispositions

So far I have argued that the basic epistemological motivation for Causal Structuralism does not offer an adequate motivation for developing OSR in a causal spirit, and that there are good reasons to resist the proposal that a causal gloss can be put on symmetry-laden fundamental physics notwithstanding the anti-foundationalist challenge. I will now argue that there are also serious problems with the proposal that quantum physics—the heart of fundamental physics—can be given a dispositionalist interpretation.

The Russellian anti-foundationalist challenge is, as I already admitted, far from being watertight. Some of its loopholes have been utilised by Esfeld and others who wish to spell out OSR in causal structuralist terms, in terms of dispositions. One of the loopholes hinges on the possibility of grounding the time-asymmetry of causation—thereby undermining at least the 'directionality argument'—in the spontaneous localisations of the quantum wavefunction in the GRW interpretation. According to Esfeld (2009, 2010)[23]

[22]Cf. Esfeld (2009)

> One can avoid these [quidditistic] commitments by taking the essence of the properties to be tied to the causal and nomological relations in which they stand (Shoemaker 1980). (p. 183)

We can delete 'causal' in the above without affecting the central idea.

[23]See also Dorato and Esfeld (2010).

these spontaneous localisations are also something that can be interpreted in dispositional, causal terms.

> The GRW version of quantum theory lends itself to an account in terms of dispositions, conceiving the fundamental physical structures as causal powers: insofar as the structures of quantum entanglement are certain qualitative physical structures, they are the disposition or power—more precisely, the propensity—to produce product states, that is, classical physical properties with definite numerical values localised in classical space-time…(Esfeld 2009, p. 187)

Thus we seem to have a converge of OSR with Causal Structuralism again.

There are some notable problems here, however. In addition to the obvious issue of saddling the Causal Structuralist with the task of defending a very specific interpretation of quantum physics, there are worries about the nature of such fundamental quantum dispositions. How good a grasp do we have of such propensities, and the nature of causation involved in them, in particular? The striking feature of the spontaneous and stochastic GRW-collapses is that they are exactly that: spontaneous. Thus, as dispositions they do not need or even leave room for any external stimulus conditions to trigger the 'causal' effect. I find such un-caused spontaneous causal effects rather mysterious, in as far as they are meant to involve a causal relation.[24] Notwithstanding the well-known difficulties in providing an analysis of dispositions in terms of stimulus conditions and a manifestation, we have a reasonably solid handle on the notion of disposition as a property that, roughly speaking, does *this*, in response to *that*, under *these* conditions. This basic characterisation of disposition exhibits the causal nature of the property in a way that can be readily grasped: there is a causal relation between the event involving the stimulus, and the event involving the manifestation. The notion of disposition must be made extremely plastic for it to be applicable to a property that only conforms to a one-third of the above basic characterisation of disposition. All the more so, in as far as dispositional monism,

[24] Cf. Esfeld (2009, p .188), who talks about such dispositions being 'irreducible':

> This disposition is irreducible: it is not grounded on non-dispositional, categorical properties. It belongs to the ontological ground floor. It is a real and actual property, not a mere potentiality. It is therefore appropriate to talk in terms of a power for spontaneous localization, this disposition being a causal property that brings about spontaneous localizations. This disposition does not need external manifestation conditions: that is why GRW conceive the disposition in question as one for spontaneous localization.

the view that all physical properties are dispositional, is motivated as a *unified* theory of properties. Esfeld (2009, p. 192) argues, for example, that a dispositionalist interpretation of GRW serves to show how the metaphysics of dispositions holds "all the way down from common sense [...] to fundamental physics [in a way that] provides for a complete and coherent view of the world." But in light of the idiosyncratic character of GRW-propensity it should not be presented as 'just another disposition'; rather, it should be offered as a metaphysical primitive that can be justified by its theoretical usefulness. But what theoretical work does this sui generis quantum disposition do, apart from serving the purpose of squaring dispositional monism with quantum physics?

GRW is not the only interpretation of quantum mechanics to have inspired a dispositionalist reading. The ontology of Bohmian mechanics is allegedly also hospitable to fundamental causal powers (Esfeld et al. 2013). In this formulation of Bohmian quantum theory the quantum wave-function is given a nomological reading: instead of being some kind of 'pilot-wave' or 'guiding field' to be added to the primitive ontology of particles, it is taken as a law that pertains to the movements of all the particles in the universe. There is a dispositionalist option amongst different metaphysical interpretations of this sui generis law of motion in Bohmian mechanics:

> The universal wave-function ... represents the disposition to move in a certain manner at [a given] time. This disposition is a holistic property of all the particles... (ibid., p. 13)

The fundamental quantum disposition is furthermore structural by virtue being a holistic property of all the particles in the universe together: it is "a relational property that takes all the particles as relata." (ibid.) Esfeld et al. put forward some broad comparative virtues of this dispositionalist interpretation in relation to Humean and other alternatives, thereby effectively offering a 'package deal' argument for Causal Structuralism.[25] This methodology of cost/benefit analysis of armchair metaphysical virtues is unlikely to move all advocates of OSR.[26] But even in their own terms Esfeld et al.'s comparison of the metaphysical virtues downplays, or even fails to recognise, some serious costs of committing to the kind of holistic quantum disposition at stake.

To begin with, there is again a worry regarding the spontaneity of the disposition in question. Even admitting that "there is no metaphysical reason

[25] Esfeld et al. (2013) only focuses on the ontology of Bohmian mechanics and is not at all concerned with structuralism. I'm reading it in the context of Esfeld's wider campaign for a Causal Structuralist construal of OSR.

[26] See e.g. Ladyman et al. (2007) for a structuralist critique of this kind of metaphysics.

to hold that dispositions necessarily depend on external triggering conditions for their manifestation ... [they can] manifest themselves spontaneously" (ibid.), one can argue that we have now lost too much of the intuitive grasp on the causal nature of disposition as a metaphysical primitive. All the more so, in as far as the 'package deal' for overarching dispositionalism turns on its claimed explanatory advantages over Humean and other views of laws of nature: it is not at all clear how explanatory edge can be obtained with prima facie mysterious, unexplainable primitives.

Another problem is that the dispositionalist interpretation fails to face up to the Russellian challenge (and the 'Directionality Argument' more specifically), since Bohmian mechanics (unlike GRW) offers no natural source for the time asymmetry that is arguably needed to ground causation. It seems that in order to accommodate the time asymmetry of causation the holistic disposition of the whole universe of particles should be time-asymmetric in some sense. But this time-asymmetry is not part of Bohmian mechanics in and of itself, and it threatens to render the Bohmian dispositions even more elusive as a basic metaphysical *causal* posits.

Reflecting further on the exact nature of the Bohmian disposition reveals that the posit involves much more serious ideological costs than first meets the eye. Esfeld et al. give the impression that the interpretation enjoys considerable ontological parsimony:

> [B]ecause there is only one universal wave-function . . . there is no reason to commit oneself to anything more than sparse dispositions: there is exactly one disposition that fixes the form of motion of all the particles by fixing their velocities. . . That single disposition is sufficient to account for the motion of any particle (or any sub-collection of particles) in all possible circumstances. (p. 15)

Allegedly Ockham would have sported a broad smile of acceptance to dispositional Bohmian mechanics: we manage explain a huge deal by reference to a single fundamental disposition. But, of course, this structural property encompasses infinite complexity, in a sense, for it encodes the trajectories of all particles for all possible spatial configurations! So, the ideological costs of this kind of ontological parsimony is rather steep. Furthermore, in the absence of any clear identity conditions for counting dispositions it is quite unclear what justifies one to think of the universe as instantiating a *single* Bohmian disposition, as opposed to a vast multitude of more specific dispositions. The complex information encoded in the wave-function can be packaged in different metaphysical ways, even if we agree to go down the dispositionalist route.

On the whole, the prospects of Causal Structuralism about quantum physics do not seem promising to me. To the extent the extant dispositionalist interpretations of quantum physics respond to the Russellian challenge at all, they face other problems that weigh down the prospects of Causal Structuralism as an attractive metaphysics of the kinds of fundamental physical properties that OSR wishes to capture in relational terms.

6 Conclusion: whither Causal Structuralism?

What is the fate of Causal Structuralism in the light of the foregoing difficulties of reconciling causation and structuralism in the sphere of fundamental physics? It must be admitted that however implausible Causal Structuralism may seem with respect to the fundamental physics, Shoemaker's guiding thought still seems fully applicable to properties such as *being knife shaped*, and it is still the case that even fundamental physical properties, such as *electric charge*, can often be associated with—as opposed to being completely characterised by—a causal profile. For example, we all immediately associate with electric charge the disposition to "experience a force when close to other electrically charged matter."

There is no need to forsake Causal Structuralism with respect to properties that are completely characterised by their causal profiles. For this the rejection of causal foundationalism is neither here nor there. And we can capture the sense in which an electromagnetic field causes a free electric charge to accelerate, for example, in terms of a *difference-making* conception of causation, without any commitment to a fundamental causal *production* of the effect. (cf. Hall 2004) The question of the reality or otherwise of causation captured by such a difference-making conception is a tricky issue that I am not going to get into here (See e.g. Price and Corry 2007). Regardless of this, it is undeniable that a causal conception of properties is indispensable in numerous contexts. For example, in the context of electronics it is indispensable for us to conceive of charge as causal. Perhaps it is even the case that all relevant scientific and engineering knowledge about negative charge pertaining to electronics is knowledge about the causal role played by this property. Nevertheless, I hope to have shown that there are good reasons to resist the temptation to apply Causal Structuralism motivated by this conception of charge to the proper domain of OSR—the metaphysics of fundamental physics.

Acknowledgments Earlier versions of this paper were presented at University of Leeds and University of Cologne. I would like to thank audiences at these talks. Special thanks to Michael Esfeld, Steven French, Andreas Hüttemann, and Jakob Sprickerhof. I would also like to acknowledge that this paper was partly written during my visiting Fellowship at Durham Institute of Advanced Studies (IAS).

References

Barrett, T. W. (2013). On the structure of classical mechanics. Preprint (Foundations of Physics 2013 conference), http://philsci-archive.pitt.edu/9603/.

Bird, A. (2007). *Nature's metaphysics: Dispositions, Laws, and Properties.* Oxford: Oxford University Press.

Curiel, E. (2014). Classical mechanics is Lagrangian; it is not Hamiltonian. *The British Journal for the Philosophy of Science 65*(2), 269–321.

Dorato, M. and M. Esfeld (2010). GRW as an ontology of dispositions. *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics 41*(1), 41–49.

Esfeld, M. (2009). The modal nature of structures in ontic structural realism. *International Studies in the Philosophy of Science 23*(2), 179–194.

Esfeld, M. (2010). Physics and causation. *Foundations of Physics 40*(9-10), 1597–1610.

Esfeld, M., M. Hubert, D. Lazarovici, and D. DÃijrr (2013). The ontology of Bohmian mechanics. *The British Journal for the Philosophy of Science*. Advance access.

Esfeld, M. and V. Lam (2011). Ontic structuralism as a metaphysics of objects. In A. Bokulich and P. Bokulich (Eds.), *Scientific structuralism*, pp. 143–159. Springer.

Feynman, R. P. and S. Weinberg (1987). *Elementary particles and the laws of physics: The 1986 Dirac memorial lectures.* Cambridge University Press.

Field, H. (2003). Causation in a physical world. In M. Loux and D. Zimmerman (Eds.), *The Oxford Handbook of Metaphysics*, pp. 435–360. Oxford: Oxford University Press.

French, S. (2014). *The Structure of the World: from Representation to Reality.* Oxford: Oxford University Press.

French, S. and J. Ladyman (2003a). Remodelling Structural Realism: Quantum Physics and the Metaphysics of Structure. *Synthese 136*(1), 31–56.

French, S. and J. Ladyman (2003b). The Dissolution of Objects: Between Platonism and Phenomenalism. *Synthese 136*(1), 73–77.

French, S. and D. Rickles (2003). Understanding Permutation Symmetry. In K. Brading and E. Castellani (Eds.), *Symmetries in Physics: Philosophical Reflections*, pp. 212–238. Cambridge: Cambridge University Press.

Hall, N. (2004). Two concepts of causation. In J. Collins, E. Hall, and L. Paul (Eds.), *Causation and counterfactuals*, pp. 225–276. The MIT Press.

Hawthorne, J. (2001). Causal Structuralism. *Philosophical Perspectives 15*, 361–378.

Ihmig, K.-N. (1999). Ernst Cassirer and the structural conception of objects in modern science: The importance of the 'Erlanger programme'. *Science in Context 12*, 513–529.

Ladyman, J. (2013). Structural realism. *The Stanford Encyclopedia of Philosophy.* (Summer 2013 Edition) http://plato.stanford.edu/archives/sum2013/entries/structural-realism/.

Ladyman, J. and D. Ross (2007). *Every thing must go: metaphysics naturalized.* Oxford: Oxford University Press.

Livanios, V. (2010). Symmetries, dispositions and essences. *Philosophical studies 148*(2), 295–305.

Lyre, H. (2004). Holism and structuralismin U(1) gauge theory. *Studies in History and Philosophy of Modern Physics 35*, 597–624.

Marmodoro, A. (2009). Do powers need powers to make them powerful? from pandispositionalism to Aristotle. *History of Philosophy Quarterly 26*(4), pp. 337–352.

Ney, A. (2009). Physical causation and Difference-Making. *British Journal for the Philosophy of Science 60*, 737–764.

North, J. (2009). The "structure" of physics: a case study. *Journal of Philosophy 106*, 57–88.

Price, H. and R. Corry (2007). *Causation, physics, and the constitution of reality: Russell's republic revisited*. Oxford: Oxford University Press.

Rickles, D. (2008). Who's afraid of background independence? *Philosophy and Foundations of Physics 4*, 133–152.

Roberts, B. W. (2011). Group structural realism. *British Journal for the Philosophy of Science 62*(1), 47–69.

Ryder, L. (1985). *Quantum field theory*. Cambridge university press.

Saunders, S. (2003). Physics and Leibniz's principles. In K. Brading and E. Castellani (Eds.), *Symmetries in Physics: Philosophical Reflections*. Cambridge: Cambridge University Press.

Shoemaker, S. (1980). *Identity, Cause and Mind* (Second expanded edition, 2003 ed.)., Chapter Causality and properties, pp. 206–33. Oxford University Press.

Suppes, P. (1967). What is a Scientific Theory? In S. Morgenbesser (Ed.), *Philosophy of Science Today*, pp. 55–67. Basic Books.

Van Fraassen, B. (1989). *Laws and symmetry*. Oxford: Oxford University Press.

Woodward, J. (2007). Causation with a human face. In H. Price and R. Corry (Eds.), *Causation, physics, and the constitution of reality: Russell's republic revisited*, pp. 66–105. Oxford University Press.

Worrall, J. (1989). Structural Realism: The Best Of Both Worlds? *Dialectica 43*, 99–124. Reprinted in Papineau, D. (ed.) *The Philosophy of Science* (Oxford: Oxford University Press), pp. 139–165.