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Structural Invariants, Structural Kinds, Structural Laws

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The paper has three parts. In the first part ExtOSR, an extended version of Ontic Structural Realism, will be introduced. ExtOSR considers structural properties as ontological primitives, where structural properties are understood as comprising both relational and structurally derived intrinsic properties or structure invariants. It is argued that ExtOSR is best suited to accommodate gauge symmetry invariants and zero value properties. In the second part, ExtOSR will be given a Humean shape by considering structures as categorical and global. It will be laid out how such structures serve to reconstruct non-essential structural kinds and laws. In the third part Humean structural realism will be defended against the threat of quidditism.

Part 1: Structural Realism and Intrinsicality: OSR extended

Many structural realists agree on two claims: they prefer ontic over epistemic versions of SR and they don't want to dismiss the idea of relata altogether. Therefore non-eliminative versions of ontic structural realism have become fashionable. They start from the idea that there are relations and relata, but that there is nothing more to the relata than the 'structural properties' in which they stand. But what are 'structural properties'? Are they all and only relations? Or must we allow for certain intrinsic properties as well? I do believe that, in order to cope with symmetry structures, one has to accept certain intrinsic features. The main reason is that symmetry structures come inevitably equipped with certain invariants under the symmetry. And symmetries and symmetry considerations play an eminent role in modern physics, notably as external spacetime structures and internal gauge symmetry structures. So SR proponents should take symmetry structure to be the most relevant structure of the world.

A symmetry of a domain D may be considered a set of one-to-one mappings of D onto itself, the symmetry transformations, such that the structure of D is preserved. The symmetry transformations form a group and exemplify equivalence relations (which lead

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to a partitioning of D into equivalence classes). From this we always get invariants under a given symmetry providing properties shared by all members of D. And insofar as such properties belong to any member of D irrespectively of the existence of other objects, they are 'intrinsic'. On the other hand, they do not suffice to individuate the members, since all members share the same invariant properties in a given domain. They are, in a still to be spelled out sense, 'parasitic' on the global structure. In my 2010 I call them "structurally derived intrinsic properties". They violate the strong Leibniz principle: as structure invariants they only serve to individuate domains, not entities.

Now consider non-eliminative OSR as a position characterized by the claim that there are relations and relata, but that there is nothing more to the relata than the structural properties in which they stand. We may then distinguish two versions:

- Simple OSR (SimpOSR): structural properties are only relational properties,
- Extended OSR (ExtOSR): structural properties are relational and structurally derived intrinsic properties (invariants of structure).

ExtOSR is the version favoured here (formerly labelled as „intermediate SR" in my 2010). In the taxonomy of Ainsworth (2010), ExtOSR is either a non-eliminativist OSR1 or close to OSR3, which takes relations and properties as ontological primitives, but objects as derived. And yet none of the categories really fits. The reason why Ainsworth's taxonomy seems to be transverse to ours is that it isn't fully exhaustive, which is why he discusses subcategories of all three versions that basically differ in the way objects are (re-) constructed. I will argue in favour of a modification of a bundle view of objects below.

In Lyre (2010) the Gedankenexperiment of a lone electron is introduced to show the differences between SimpOSR and ExtOSR. Under both eliminative and SimpOSR the lone electron cannot have a charge, since no other objects are left in virtue of which the electron's charge might be considered as relational. Under ExtOSR it is perfectly possible to allow, even in the trivial case of only one member in D, for the object to possess symmetry-invariant properties. I should emphasize that this Gedankenexperiment is exclusively meant to highlight the difference between SimpOSR and ExtOSR – it has a didactic value only. By no means do I claim, nor should ExtOSR proponents claim, that such a possible world is a nomologically possible world. Of course it isn't. It conflicts with QED and other fundamentally physical as well as operational assumptions. But it nevertheless highlights a metaphysical difference. An object may have its invariant properties according to the world's structure, the structure comes equipped with such properties. Moreover, such invariant properties should not be considered as relational to the structure, since this raises the problem of the possible Platonic existence of unexemplified structures. I take it that almost all OSR proponents of any stripe consider themselves to be *in re*-structuralists, not *ante rem*-Platonists. The world structure must therefore be an instantiated structure – instantiated by at least one member of D.

As far as I can see it, the most convincing reason from physics why we must take structure invariants seriously stems from gauge symmetries. I will give another argument, the argument of zero-value properties, below. It is obvious that the content of modern

fundamental theories in physics is mainly given by symmetry structures. And in this respect, gauge theories figure as the most important case. But gauge symmetries are special in the sense that they are non-empirical symmetries. This means that gauge symmetry transformations possess no real instantiations, the physical content of gauge theories is carried all and only by the gauge symmetry invariants (Lyre 2004). Such invariants are mathematically fully characterised (but not solely given) by the Casimir operators of the gauge groups (the Casimirs classify the multipletts and commute with the generators of the gauge Lie groups which correspond to the charges). We get mass and spin as Casimir operators of the Poincaré group and the various charges of the U(1)xSU(2) and SU(3) interaction groups. Hence, mass, spin, and charge (in the most general sense) are the most fundamental `structurally derived intrinsic properties'. By focusing exclusively on relational properties, SimpOSR doesn't have the resources to take gauge theories into account, while ExtOSR apparently does.

But there's more. Elementary particle physics provides us with a taxonomy of the fundamental building blocks of the world. By characterizing particles via mass, spin, and charge, physicists regularly ascribe zero-value properties to particles. They will for instance say that the photon has zero mass or that the neutrino has an electric charge with value zero. As Balashov (1999) points out, such zero values aren't merely absences of quantities or holes in being, they are considered to be as real as non-zero value properties. Balashov makes the following case: „Suppose particle *a* is a bound state … of two particles … having non-zero quantities P+ and P-summing up to 0. … it is more reasonable to say that *a* has zero value of P ... than to insist that it has no P at all. P-hood cannot simply disappear when combined with another P-hood in a productive way.“ He calls this the *argument from composition*. But elementary particles aren't composites. We may, however, extend the argument by using parity and unification considerations to non-composite cases. P-hood may figure as part of the explanation of the generic behaviour of a particle in certain circumstances both in the case of P≠0 and P=0. Conservation laws are the most important case of such explanations. We do for instance predict the behaviour of the yet undetected Higgs boson in part by the fact that it is assumed to have spin zero.

Consider also the well-known classification of elementary particles by means of the irreducible unitary representations of the Poincaré group (cf. also my 2004). The assumption behind it is that physical systems must possess relativistically invariant state spaces with the most elementary, irreducible representations possessing no invariant subspaces. And as we've already seen, the representations of the Poincaré group are mathematically fully characterized by its Casimir operators. This whole consideration affects all particles including the ones with zero mass, zero spin or both, since all particles are considered to be representations of the Poincaré group.

ExtOSR, I claim, naturally embraces the appearance of zero-value properties in fundamental physics by assuming that the world consists of a structure mainly given by the structure of the fundamental physical gauge groups (including the Poincaré group as a gauge group itself). Particles are instantiations of the world structure possessing all

structurally invariant properties irrespective of whether the property value is zero or not. In what follows below I will show how this class of properties can also be accommodated from a non-dispositionalist point of view (pace Balashov (1999) who argues otherwise).

Yet another commentary is necessary here. Recently, Roberts (2010) has coined the term 'group structural realism' for the idea of identifying structure with the structure of symmetry groups. While on the one hand he acknowledges the fact that group structural realism has the advantage to provide us with a precise mathematical notion of structure, he on the other hand side diagnoses an, as he sees it, serious problem: the problem of an infinite regress of structures. Consider for instance the hierarchy that one can produce by ascending from a group *G* to *Aut G*, the group of all automorphisms of *G*, next to *Aut Aut G* and so on. But, as Roberts himself also acknowledges, the structural realist account *"perhaps most closest to the right attitude"* is to accept just the groups that are most naturally suggested by physics as the fundamental bottom of towers of structures. This is exactly the recipe I like to suggest here. While it is true that you can't easily read off your metaphysics from physics, one should nevertheless let physics be the main and solid guide in choosing the right metaphysics. And this in particular holds if we have an underdetermination in metaphysics which can be cured by physics! For this is just what Roberts does: construct an overblown and therefore underdetermined metaphysical hierarchy that can easily be cut back by physics as our primary guide.

Mention must finally be made that the present account is not bound to group structures. Surely, symmetry groups play a dominant role, but other structures come into play as well. The structural core of quantum theory is for instance given by the non-commutative algebra structure of the observables. It is, again, a physical, not a metaphysical question, what the fundamental structures in nature are.

Part 2: Humean Structural Realism: Structural Kinds and Structural Laws

After laying out ExtOSR as my favoured variant of structural realism, I shall now turn, for the rest of the paper, to the question of whether and in which sense I think structural realism can be combined with a Humean stance. I shall start with the issue of structural laws and then go over, in the third section, to defend non-modal categorical structures.

In its usual form, Humeanism rests on two basic features: first, the idea of an ultimate supervenience base – this is the reductionist spirit behind Humeanism. And, second, a quite rigorous scepticism about modalities – call this is the nominalist spirit. I shall focus on how this affects the Humeanist's view about properties and laws. Let's start with properties. From their nominalist inclinations it seems clear that Humeans will be non-dispositionalists and non-essentialists, that is they will favour categorical over dispositional (or modal) properties. It is of course not part of the Humean agenda that one must favour intrinsic over relational properties as in David Lewis' infamous doctrine of Humean supervenience. Moreover, Lewis' Humean supervenience is in glaring conflict

with both quantum mechanics and gauge theories. In both types of theories non-local effects – EPR correlations on the one hand and holonomy effects on the other – suggest a stark violation of Humean supervenience: intrinsic properties of wholes do not supervene on intrinsic properties of their parts. By way of contrast, intrinsic properties of wholes may very well supervene on non-supervenient relations between the parts.

The natural supervenience base for structuralists consists, of course, of structures. Structures, in turn, seem to be "composed" out of relata and structural properties, being relations and structurally derived intrinsic properties. Leaving notorious questions of ontological priority for a moment aside, we can just say that the Humean structuralist shall consider non-modal, categorical structures as the proper supervenience base. And there are two aspects of such structures that are of interest here. There is on the one hand the aspect of categoricalism – this will be discussed below. On the other hand there's the aspect of such structures as being global entities. This is why the idea of structures as 'composites' must be taken with a grain of salt. If we think of the fundamental symmetry structures in physics, then we better conceptualize them as reflecting global regularity features of the world *in toto*. They neither are abstract mathematical *ante rem*-structures nor are they composed out of universals (as discussed by Psillos, forthcoming). They rather are concrete global and world-like *in re*-structures.

We may capture this characterisation by noticing that the usual metaphysical abstract/particular distinction must be complemented with a global/local distinction. We then arrive at the following matrix:

	concrete	*abstract*
local	particular	universal
global	*in re*-structures	*ante rem*-structures, universal structures, mathematical structures

Particulars or concreta are local and concrete entities, whereas universals are abstract. They are 'local' in the sense that they are instantiated by local exemplars. By way of contrast, structures aren't local, they are global or world entities. They may either be considered as abstract with mathematical structures as a prime example, but they may also be construed as concrete entities in the sense that they are directly given as elements of the spatiotemporal world *in toto*. This, I suggest, is the conception of structures that should be preferred by OSR proponents.

There are of course structuralists that, albeit coming close to the group theoretic considerations here, adopt an *ante rem* view of abstract structures (e.g. Kantorovich 2009 or Cao 2010). Psillos (forthcoming), following Bigelow and Pargeter (1990), discusses the pros and cons of the idea to construe structures as abstract entities or 'structural universals'. He diagnoses various difficulties of this view which can basically be traced back to the idea

that such structural universals may have other universals as parts (as displayed in various cases of molecule configurations). I take this to indicate that we better refrain from characterizing structures as abstract. As far as I can see, however, none of Psillos' arguments speak against the possibility of structures as concrete elements of the world *in toto*. In considering structures as global or holistic entities the question of ontological priority of either relata or structural properties turns out as misguided. If talk of ontological priority makes sense at all, then structures as a whole should be prioritized. Ainsworth's (2010) taxonomy should be supplemented by (at least) a fourth option (OSR4) which takes whole structures as basic and structural properties – relations and intrinsic invariants – as features of such structures. From them relata can be derived or reconstructed in the following sense: they are the placeholders between the relations and they are domain-wise individuated by the structural invariants which serve as structurally derived intrinsic properties of the relata.

This is also the reason why structuralism doesn't entirely collapse to variants of a bundle ontology. For instance, because of its nominalist spirit (and as will become clear in the next section), the ExtOSR version defended in this paper is close to an ontology of trope bundles. But bundles are usually construed as local. The picture I'd like to advocate is rather that the world consists of a global structure which can only approximately be reconstructed by a collection of more or less localizable objects. Another way of spelling out the worries about the 'local' is to say that structuralism seems to directly conflate with pointillisme – the doctrine that a physical theory's fundamental quantities are defined at spacetime points and represent intrinsic properties of point-sized objects located there (cf. Butterfield 2011 as a forceful attack on pointillisme).

As we've seen, the structural invariants emphasized here provide us with properties that are shared by all members in a structure domain and thus serve to individuate such domains. In fact, they provide us with a concept of kinds – natural kinds. Generally speaking, natural kinds are human-independent groupings or orderings of particulars in nature. And it is one of the major tasks of science to reveal the kinds in nature, for if such kinds exist then we may expect our scientific explanations to become forceful precisely when they generalize over such kinds. But while it is straightforward to think of kinds as shared properties, the real problem is to understand what the reason for this 'sharing' is. Yet Humeanists usually don't provide an answer to this problem, since nine times out of ten they stick with a regularity view of laws. The orthodox account of natural kinds is therefore bound to essentialism, the view that there are essences in nature. Under such a view the shared properties that make up a kind are essential properties. Essential properties are modal properties in the sense that the particulars that possess them necessarily belong to the kind.

A rigorous Humean framework is incompatible with an essentialist conception of natural kinds. A remarkable feature of structural invariants, I claim, is however that they provide us with a non-modal Humean understanding of kinds without giving up the possibility of a further explanation for the universal sharing of certain features. For we may understand

the perplexing empirical fact that, say, all electrons posses exactly the same property values for mass, spin and charge. These properties are in this sense universal properties. From the point of view of ExtOSR we may just trace this universality back to the globally built-in regularity of the world as possessing particular symmetry structures. That is to say we must not acquiesce the individual property-likeness of particular electrons as a brute fact of nature, as the traditional regularity view has it, but reduce it to the global world structure (e.g. particular gauge groups). Note that no necessity is involved in this conception since the global world structure itself is non-modal in the sense that it is a brute fact of nature that just this particular global structure exists. We have thus shifted the regularity one step further, from the level of local to global concrete entities. This conception of natural kinds might be dubbed a 'structural kinds' view. It is the conception of kinds offered by ExtOSR within a Humean framework.

To invoke structural kinds also means to invoke structural laws. For laws generalize over kinds. Structural laws, in turn, generalize over structural kinds. This is tantamount to say that structural laws just reflect the structures in nature. In the case of the fundamental physical structures the structural laws are essentially the mathematical equations that display the relevant symmetries. The symmetries are global built-in regularities of the world in the sense that other symmetries could exist as built-in instead. Obviously, this is in tune with a strict non-necessitarian conception of laws – and goes beyond structural realists' talk about 'modally informed' laws (Cei & French 2010 – though I'm of course very much in favour of the general tendency of this paper). Moreover, and as I've pointed out in my 2010 (sec. 22), the Humean structural laws view has the resources to overcome well-known problems of the orthodox regularity view such as non law-like regularities (by considering only global structures) and empty laws (by considering instantiated *in re*-structures only).

Part 3: Humean Structural Realism: Categorical Structures

Humean SR sees structures as non-modal, categorical structures. They bring about nothing and constitute the Humean structuralist's supervenience base. They are "just there". Other structures could have been instantiated – or could be instantiated at any new moment in time (although more must be said, but cannot be said in paper due to lack of space, about the temporal structure of the 4D world; see also the short remarks in the conclusion). As non-modal, categorical and determinate structures they should be taken as brute facts, ontologically irreducible, and primitive.

But there's a strong movement within structural realism to prefer modal or causal structures (e.g. Chakravartty 2007). The perhaps most outspoken proponent of this movement is Michael Esfeld (2009, 2011, Esfeld and Lam 2011). As he sees things, „the fundamental physical structures possess a causal essence, being powers" (Esfeld 2009). Esfeld claims to overcome a couple of well-known difficulties connected to structural realism. The two most relevant problems are:

(1) The mathematical/physical distinction of structures,
(2) The problem of quiddities and humility.

Let's start with the mathematical/physical distinction (1). Esfeld believes that by assuming categorical structures Humean SR collapses to mathematical structuralism. He argues that while mathematical structures do not cause anything, real physical structures clearly distinguish themselves from mere mathematical structures in that they are causally efficacious.

I have two worries here. First, Esfeld raises the problem in such a way that it doesn't come out as a special problem of (particular versions of) structural realism, but of Humeanism or categoricalism in general. Any non-modal account of entities is affected by his kind of reasoning: causal efficacy cannot be accounted for by a Humean mosaic of non-dispositional properties but only by dispositional ones. But should we really consider this to be a knock-out argument against Humeanism? Dispositionalism will then become true by fiat. But you can't decide metaphysical debates like that. Humeans and non-Humeans agree that there are cause-effect regularities in our world. They disagree about the way how to conceptualize them metaphysically. It is of course true that we know about the various structures in physics by means of their causal efficacy. But this says nothing about the metaphysical conception of causation. Causal efficacy can very well be captured in regularist terms. Nothing in Esfeld's arguments enforces a metaphysically thick modal nature of structures.

But perhaps the real worry of Esfeld about structures with 'no causal contact' to the world lies elsewhere. In his 2009 he still sticks with SimpOSR and, hence, rejects any intrinsic properties (withdrawn by Esfeld and Lam 2010, sec. 8.4). Under this conception the question of how regularities of a pure microscopic web of relations hinge together with macroscopic causes and effects might indeed cause a certain uneasiness. However, the problem at this point is not the metaphysics of causation, but the notorious multirealizability of purely relationally individuated structures. By way of contrast, ExtOSR introduces structurally derived intrinsic properties to individuate structure domains. This provides us with an account to circumvent the problem of 'unintended domains' (cf. Lyre 2010, sec. 12ff). By introducing structure invariants the nature of the relations and relata in the structure is no longer completely indetermined. The idea is that in our experimental practice we are (more or less directly) acquainted with the intrinsic structure invariants. Hence, no multirealizability arises.

So let's go over to the second class of problems centred around quidditism and humility (2). As Esfeld (2009: 182) puts it: *„If the fundamental properties are categorical and intrinsic, then there are worlds that are different because they differ in the distribution of the intrinsic properties that are instantiated in them, although there is no difference in causal and nomological relations and thus no discernible difference between them. This position therefore implies quidditism and humility.“* My first answer is that this is (again!) no special problem of SR, but of categoricalism in general. This seems to be granted by Esfeld: *„what accounts for*

quidditism and humility is the categorical character of the fundamental properties, not their supposed intrinsic character" (Esfeld 2009: 187). In fact, he considers the threat of quidditism to be *the* master argument against categoricalism: only causal properties prevent from quiddities, because if all properties are causal and, hence, individuated by their causal profile only, then there's no room for extra quiddistic factors over and above the causal profile.

I certainly share Esfeld's worries about mysterious extra-metaphysical factors, which is what quiddities really are. But, I'm afraid, the antidote of causal properties isn't as strong as Esfeld wants it to be. This has rightly been pointed out by Psillos (forthcoming) by means of the following consideration. Suppose a world W1 in which two properties A and B work in tandem to produce a certain effect E but, taken individually, don't have any effect at all. Dispositionalism cannot distinguish W1 from a world W2 in which E is brought about by one single property. The metaphysical difference between W1 and W2 goes beyond causal roles. So this would be my second answer to (2): quidditism is the view that nomological roles do not supervene on properties, but nomological roles do not supervene on causal properties either!

So it seems that neither the dispositionalist nor the categoricalist can entirely get rid of any mysteriously hidden metaphysical factors. But clearly it would be neat if in particular the structural realist could obviate the threat of quidditism – at least to a certain extent. Well, I believe he can. This paves the way to a third answer to Esfeld's worries about quidditism. Here's a passage from Lewis who famously pronounced humility against quiddities: *„I accept quidditism. I reject haecceitism. Why the difference? It is not, I take it, a difference in prima facie plausibility. ... In both cases alike, however, we can feel an uncomfortable sense that we are positing distinctions without differences. […] To reject haecceitism is to accept identity of qualitatively indiscernible worlds; to reject quidditism is to accept identity of structurally indiscernible worlds – that is, worlds that differ just by a permutation or replacement of properties. [...] It would be possible to combine my realism about possible worlds with anti-quidditism. I could simply insist that ... no property is ever instantiated in two different worlds. … It could be for the sake of upholding identity of structurally indiscernible worlds, but I see no good reason for wanting to uphold that principle"* (Lewis 2009: 209-210). While Lewis doesn't see a good reason for upholding the identity of structurally indiscernible worlds, structural realists certainly should. For structural realism is precisely the doctrine that is based on such a principle. We may even use the identity of structurally indiscernible worlds, or, shorter, the *identity of isomorphs*, to define SR and its major variants. While ESR is captured by the claim that the world is known up to structural isomorphs, OSR is the view that the world exists up to such isomorphs only. Surely, Lewis wouldn't be convinced by such a manoeuvre of simply 'quining quiddities' by means of the identity of isomorphs, since I've given no *metaphysical* reason to dismiss quiddities. Nevertheless, the identity of isomorphs is empirically supported to the extent to which structural realism is empirically supported by modern physics. So let me repeat the recipe already suggest at the end of section 1: one should let physics be the main and solid guide in choosing the right metaphysics, particularly in cases of seemingly metaphysical excesses.

A fourth and final attempt to counter worry (2) is the following. Quidditism claims primitive suchness. It's the idea that a permuation of properties (or types) makes a difference. It follows that quidditism may also be understood as upholding the principle of trans-world property identity, since quiddities are instantiated at different possible worlds. This is quite in analogy to the traditional idea of universals as being instantiated in different spacetime regions. But why should one uphold such a principle? A Humeanist clearly wouldn't. Tropes as well as categorical structures violate trans-world property identity, since both tropes and categorical structures as (examples of) entities suited to constitute a proper Humean base are individuals. So neither tropes nor categorical structures are ever instantiated at two different worlds. While Esfeld's master argument wants to tell us that Humeanism implies quidditism, the contrary seems to be true: Humeanism virtually contradicts quidditism.

So neither is there any special problem with the distinction between the mathematical and the physical for Humean SR, nor does dispositionalism fare so much better in rejecting quidditism. But then the question must be raised what makes dispositionalism attractive at all. And here, as far as I can see, we should be quite reluctant. For the real problem with traditional dispositionalism is that it sticks with pointillism, the view that the fundamental quantities in physics are defined at local regions of spacetime. Structuralism, as we've seen, should however be construed as fundamentally holistic and conforming to globally defined entities, which is just what structures are. By way of contrast, the picture of local powers is a hopelessly outdated and naïve metaphysical picture of physics (to say the least). From this perpective, to combine dispositionalism with structuralism then means to try to combine two deeply opposing pictures, which in turn means that to prevent from quiddities by introducing mystic causal powers amounts to curing one metaphysical exaggeration with another one.

Conclusion

In this paper I've argued for an extended version of OSR, ExtOSR, that takes structural properties as ontological primitives, where structural properties are understood as comprising both relational and structurally derived intrinsic properties (structure invariants). ExtOSR is best suited to accommodate gauge invariants and zero value properties. I've then connected this with a Humean approach, in which one considers categorical and global structures to constitute the Humean supervenience base. As global entities the structures display a built-in global regularity and serve to understand the universality of the fundamental properties without invoking essences and, thus, providing us with a concept of non-essential structural kinds and laws.

The Humean position of structural realism just sketched avoids mysterious modal powers and ungrounded dispositions – but raises new questions, too. Of particular interest is most certainly how dynamics and temporal change fit into the overall picture of non-modal and

global structures. A straightforward answer is that the group of temporal automorphisms of the state space is of course itself a structure. Another straightforward but at the same time extreme option would be to adopt something along the lines of either a perdurantist view or a block universe conception and take the entire four-dimensional world structure for granted. To whatever extent the structural realist wants to address these questions, it's definitely a topic that deserves further scrutinization.

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