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Humean Perspectives on Structural Realism

Structural Realism (SR) is a moderate variant of scientific realism and can roughly be captured by the idea that we should be committed to the structural rather than object-like content of our best current scientific theories. A quick view on the list of some of the main proponents shows that SR is basically a European philosophy of science movement (and just suits our ESF Programme): John Worrall, Ioannis Votsis, Steven French, Angelo Cei, James Ladyman, Simon Saunders, Michael Esfeld, Vincent Lam, Katherine Brading, Mauro Dorato, Dean Rickles, Fred Muller, and – exceptions prove the rule – Anjan Chakravartty and John Stachel. The list is of course not exhaustive, moreover, the debate has a broad periphery. A notable example of this is Bas van Fraassen's structural empiricism.

The paper is a kind of opinionated review paper. In what follows I will pass through the most prevailing topics in recent debates over SR. My discussion will be organised, perhaps a bit unorthodoxly, in short sections, here and then I will outline my own views.

1 The notion of structure

The notion of structure is notoriously vague, and this is already one of the many problems of SR. The notion is of course not vague as far as the abstract mathematical concept of structure is concerned. Compare, for instance, Shapiro (2000):

> Define a system to be a collection of objects with certain relations among them. [...] Define a pattern or structure to be the abstract form of the system, highlighting the interrelationships among the objects, and ignoring any features of them that do not affect how they relate to other objects in the system.

The mathematical definition says that there are entities, the relata, that come equipped with a structure, but that the relata are determined by structural or relational properties only. Hence, a good working definition for SR is that structures are sets of objects, domains, with sets of relations imposed on them.

The problem is that despite the mathematical definition there exists no practical, straightforward method to extract the structural content from a given scientific theory. The problem is obvious as far as non-formalized theories in the higher special sciences are concerned, but it prevails even regarding fundamental physical theories. In this paper I do not delve into this problem, but I will mostly take the

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symmetry structure as the primary, genuine candidate to characterize the structural content of modern physical theories.

2 Two routes to Structural Realism

SR has a longstanding tradition in the 20th century and even earlier. There is consensus that the modern debate was initiated by John Worrall (1989). The discussion of the last two decades has actually taken two routes to SR, the Worrall-type and French-Ladyman-type route, as I prefer to call them. Worrall, Votsis (2003) and others gave arguments in favour of SR from the philosophy of science – for instance by arguing that SR's commitment to structure and not object-like content can be used as an antidote against prominent anti-realistic arguments like the pessimistic meta-induction or theory underdetermination. French-Ladyman-type authors, on the other hand, try to present arguments from the sciences directly, more precisely from the way modern science, notably physics, informs us about the ontology of the world. Meanwhile, all major fields of modern physics have been considered to strengthen arguments in favour of a structural ontology: Quantum Mechanics (French and Ladyman 2003a, Esfeld 2004), Quantum Field Theory (Cao 2003, Saunders 2003), General Relativity (Dorato 2000, Esfeld and Lam 2008, Stachel 2002), Gauge Theories (Lyre 2004a,b), Quantum Gravity (Rickles et al. 2006) or physics in general (Muller 1998, Redhead 2001). Note that the distinction between the two routes is not the same as the ESR/OSR distinction (see below). Cao (2003), for instance, proposes French-Ladyman-type ESR.

3 Ante rem versus in re structuralism

Debates on structuralism in mathematics show a similarity to structuralism in science, but must ultimately be separated from them. Shapiro (2000) is for instance known to uphold an *ante rem* structuralist position in the philosophy of mathematics, i.e. a Platonist conception of the existence of structures prior to and independent of their exemplification in the physical world. French and Ladyman (2003b) made it sufficiently clear that SR should not be confused with Platonism but is explicitly intended as a realism about structures not as abstract entities but as *in re* structures in the physical world.

4 Epistemic, Ontic and Semantic SR

As is well-known, James Ladyman (1998) first coined the distinction between Epistemic and Ontic SR. While ESR proponents believe in the structural content of theories as an epistemic constraint and, hence, uphold the view that objects may exist, but that our epistemic access is restricted to structures only, OSR proponents, according to Ladyman, take structure to be primitive and ontologically subsistent. I think, however, the distinction should be a bit more refined. In line with the usual threefold distinction between epistemic, ontic and semantic forms of scientific realism, we may accordingly distinguish between the following three options:

- Epistemic SR: science conveys true knowledge about structures,
- Semantic SR: the contents and terms of scientific theories refer to structures,
- Ontic SR: structures exist independently (from our epistemic and linguistic capacities).

5 Eliminative and non-eliminative SR

What's generally unfortunate with the above distinctions is the fact that everything still depends on our proper understanding of the term "structure". Given the mathematical definition of structure as sets of objects or relata with sets of relations imposed on them, there are, on the face of it, three possibilities:

- Epistemic SR: there are relations and relata, but that we have epistemic access to relations only,
- Non-eliminative OSR: there are relations and relata, but that there is nothing more to the relata than the relations in which they stand,
- Eliminative OSR: there are only relations and no relata.

Note that under this classification the widely debated question whether the slogan "structure is all there is" leads to the problematic position of "relations without relata" does not depend on Ladyman's ESR/OSR distinction, but rather on the distinction between non-eliminative versus eliminative versions of SR. It is perfectly possible to uphold SR as a metaphysical position about the world without being vulnerable to the "relations without relata"-problem. Well-known proponents of eliminative OSR are, or at least have initially been, Steven French and James Ladyman (French and Ladyman 2003a, French 2006, Ladyman and Ross 2007), a proponent of non-eliminative (or moderate) OSR is Michael Esfeld (2004).

6 Structurally derived intrinsic properties

I do actually believe that the above threefold distinction is still not exhaustive. General considerations about symmetry structures enforce us to assume the existence of not only relational but (in a certain sense) intrinsic properties of the relata. Technically speaking, a symmetry of a domain D is a set of one-to-one mappings of D onto itself (a.k.a. symmetry transformations), such that the structure of D is preserved. The symmetry transformations form a group and exemplify equivalence relations (i.e. a partitioning of D into equivalence classes). Naturally and necessarily, we always get certain invariants under a given symmetry. In a physical context, such invariants provide properties shared by all members of D. These properties are intrinsic properties in the sense that they belong to any member of D irrespectively of the existence of other object-like entities. On the other hand, the invariant properties do not suffice to individuate the members, since all members share the same invariant properties in a given domain. Structure invariants do not lead to individuals but to object classes only. This highlights the importance of the invariants: we use them to individuate domains, not individuals.

Now a crucial point: insofar as they are structural invariants, the intrinsic properties `depend' (in a sense still to be determined) on the structure, we should accordingly and properly consider them as "structurally derived intrinsic properties". Nevertheless, they are intrinsic rather than relational, since they subsist irrespectively of the existence of other object-like entities.

7 Intermediate SR

We are thus left with an even more moderate non-eliminative version of SR which I shall dub "Intermediate SR" (cf. Lyre 2009). It is the view that there are relata and structurally derived properties, but that there is nothing more to the relata than the structurally derived properties, where the structurally derived properties comprise relational properties and invariants of structure as structurally derived intrinsic properties. Note further that this is still a viable SR position and does not collapse to old fashioned entity realism, since neither are we committed to essential properties nor are we committed to individuals (see below). Structurally derived properties do not individuate objects but object classes or domains of structure only.

8 An illustration: the lone electron

The following Gedankenexperiment provides an illustration of the particular nature of structurally derived intrinsic properties: Suppose a possible world with one electron only (and with relational spacetime). Does the lone electron possess an elementary charge? Under the classic view that intrinsic properties are properties an object has of itself and independently of the existence of other objects, the lone electron has certainly a charge. It seems, however, that for proponents of both eliminative and moderate OSR, who accept relational properties only, a lone electron cannot have a charge, since there are no other objects left in virtue of which the electron's charge might be considered as relational. From the point of view of Intermediate SR as another non-eliminative version including structurally derived intrinsic properties there is no problem to apply charges to lone objects. For even in the trivial case of only one member in D, the object will possess the said symmetry-invariant properties. The object has the invariance properties in virtue of the structure, the structure comes equipped with such properties. In more physical terms: even a lone electron is a proper instantiation of the *in re* U(1) gauge structure.

But couldn't we just say that the charge is relational to the structure? The problem is that in this case one cannot exclude the possibility that the structure as a relatum of the exemplification relation can exist for itself. Hence, one opens the door to unexemplified structures – a clear renunciation of *in re* structuralism and a dangerous flirt with Platonism. The idea here is that the structure we are talking about in the lone electron scenario is the U(1) structure displayed in the Maxwell equations and instantiated by that very electron. From an operationalist point of view, of course, such structure can only be observed from the behaviour of more than just one test charge. But structuralism is not *per se* committed to operationalism – both views should logically be kept disentangled.

9 A further argument: gauge invariants

The importance of structural invariants – structurally derived intrinsic properties – can most clearly be seen from the most important case of symmetry structure in modern physics, the case of gauge theoretic structures. One crucial feature of gauge symmetries is that they possess no real instantiations. Note that we must carefully distinguish between symmetries with real instantiations as opposed to symmetries without real instantiations. Examples of the former are for instance the possible space-time transformations of a physical object. Examples of the latter are scale transformations, coordinate transformations, and, in particular, gauge transformations. Therefore, a gauge theoretic characterization of a physical theory is *a fortiori* all and only a characterization by means of the symmetry invariants, since only the gauge symmetry invariants allow for a realistic interpretation. Gauge transformations possess no real instantiations (cf. Lyre 2004a,b). In the case of gauge theories, the SR commitment to structure can only be a commitment to the structure invariants. These invariants are given by the eigenvalues of the Casimir operators of the various gauge groups, which in their physical interpretation are considered to be mass, spin and the various charges. In fact, mass, spin, and charge provide paradigmatic cases of intrinsic properties of elementary particles. They are the attributes by which we classify the fundamental particle zoo. They are, in fact, the most fundamental structurally derived intrinsic properties.

10 Identity, haecceitism and metaphysical underdetermination

Another "structural attack" on traditional entity realism has to do with issues about identity and individuality in modern physics, notably quantum mechanics. The empirical indistinguishability of quantum objects has originally been regarded as a failure of Leibniz' principle of the identity of indiscernibles (PII). French (1989, 1998), however, argues that we are rather left with a kind of „metaphysical underdetermination": either quantum objects violate PII and are no individuals, or they are individuals since PII applies by reference to some kind of primitive thisness, bare particularity or haecceity (or however we may call it). The deeper lesson is that science leaves even the most profound metaphysical question about individuality underdetermined and so, following French, we better give up entity realism altogether and stick with a structural ontology. Obviously, this line of reasoning paves the way to eliminative OSR.

11 Weak discernibles

Saunders (2006) has argued that although fermions are not absolutely discernible (in terms of intrinsic monadic properties), they are nevertheless weakly discernible. Indeed, this observation can be seen as supporting structural non-eliminativism (and to give up haecceitism). To make this claim plausible consider first Black's case of two equal spheres in relational space with a distance d. Do such spheres violate PII? Call objects that violate PII absolutely discernible, but objects which allow for irreflexive relations weakly discernible (Quine 1976). Recall that a relation R is reflexive when for all x in the domain $R(x,x)$ holds. In the case of $\neg R(x,x)$, R is called irreflexive. For instance each Black sphere is a distance d apart from the other but not from itself. So the distance relation is irreflexive. The same holds in the case of fermionic particles in an entangled state for the relation of having opposite spin. Fred Muller (in print) has recently even extended this result to particles irrespective of their spin by considering the Heisenberg "commutation relation" of having complementary position and momentum. We may say that quantum objects are in fact generally weakly discernible due to the possibility of canonically conjugate variables based on the non-commutative algebra structure of quantum theory.

The case of weak discernibles accounts for the existence of relata that are weakly individuated by irreflexive relations. It runs counter to relata-eliminativism, but does at the same time not endorse full entity realism of absolute individuals. Indeed, irreflexive relations are structurally derived relations in the sense that they reflect the allowed quantum states of the non-commutative algebra structure. As in the case of structurally derived intrinsic properties, they are ontologically on a par with the structure without presupposing the independent existence of either the structure or the properties (or the relata). Rather, they are *in re* exemplifications of the structure.

12 The problem of unintended domains

Let's come to some more intricate problems of SR. Reconsider the idea of structure invariants as derived intrinsic properties. The crucial question is whether and how we will ever know about such properties as intrinsic natures of objects. Taken literally, the idea to individuate theories by means of their pure structural content (in the sense of pure mathematical structure) is far too weak. The reason lies in what one might call the "problem of unintended domains". There are in fact lots of cases where distinct physical theories show basically the same mathematical structure, hence we must qualify the structure's domain. Here are some physics examples of such "structural equivalents": (i) classical electrodynamics and hydrodynamics are based on more or less the same mathematical apparatus about unspecified `currents' including continuity equations, theorems of Gauss and Stokes etc.; (ii) the gauge theories of strong and weak isospin are both based on SU(2); (iii) the group U(1) figures in quantum physics both as the group of temporal automorphisms and as the gauge group of QED.

Surely we've said that the domains are individuated by the structure invariants as derived intrinsic properties, but so far we did not spell out whether and how they provide an independent way to make contact with such invariant properties. Let's leave this open for the moment and discuss some further related issues first.

13 Structural underdetermination

We may exercabate the problem of unintended domains to the problem of structural underdetermination. According to the Worrall-type route to SR (as mentioned in section 2), SR can be seen as an antidote against theory underdetermination (TUD). The idea is that while TUD undermines entity content, SR seems to avoid this by not committing us to the theory's entity content but to structural content only. However, as I've argued elsewhere (Lyre, in print), there is, on the face of it, no way to make sure that the structural content of theories is not underdetermined either. On the contrary, there seem to exist cases in our best fundamental science, notably in theories of gravity, where we are directly confronted with cases of structural TUD. This means that we are confronted with structurally inequivalent but empirically equivalent theories. In such cases the structure of a theory is underdetermined by empirical evidence.

14 The Ramsey-Carnap-Lewis-account of theoretical terms

We may reiterate and generalize the two problems mentioned above. In order to do so we must reconsider the Ramsey-Carnap-Lewis-account of theoretical terms (cf. Lewis 1970). As a variant of scientific realism, SR is a realism about the unobservable. Take the classic distinction between observational and theoretical terms o_i and t_i. The Ramsey sentence of a theory T can be understood as a machinery for expressing the structural content of T. It is obtained by replacing the theoretical terms of T with bound variables: $T(t_1, \ldots t_n, o_1, \ldots, o_m) \rightarrow \exists x_1, \ldots \exists x_n\, T(x_1, \ldots x_n; o_1, \ldots o_m)$. Under such an account the theoretical terms are not eliminated but are expressed in terms of the structural relations between the variables x_i in T. The Ramsey sentence leaves us with a pure structural description of the theoretical knowledge about the world. The early Russell and Carnap took this as a motivation to uphold an extreme epistemic structuralism.

15 Multiple realizability, quidditism and Ramseyan Humility

Multiple realizability is in fact an immediate consequence of the Ramsey-Carnap-Lewis-account of theoretical terms. Our knowledge about the referents of the theoretical terms is just knowledge about the occupants or placeholders of descriptive causal roles. The quiddistic nature of the placeholders is indetermined, they are thus multiply realizable. A possible response is to advocate Ramseyan Humility about quiddities.

Recall that haecceitism is the view that a permutation of individuals (or tokens) makes a difference. It amounts to assume primitive thisness. We've already seen that SR, clearly in its non-eliminativist branch, dismisses haecceitism (section 10). Quidditism, on the other hand, is the view that a permutation of properties (or types) makes a difference. It amounts to assume primitive suchness. So structuralists usually reject haecceitism, but should they reject quidditism as well?

The problem not only for SR but in fact for any variant of scientific realism which commits itself to the Ramsey-Carnap-Lewis-account of theoretical terms is that quidditism amounts to making a difference without a difference. Nevertheless, David Lewis (2009) subscribes to quidditism, but at the same time advocates Ramseyan Humility, a term he has borrowed from Rae Langton's (1998) Kantian Humility. Kantian Humility, in turn, should capture Kant's view that things as we know them, phenomena, consist entirely of relations and that we have no knowledge of the intrinsic properties of things in themselves. So following Langton Kant's attitude is no idealism, but rather an epistemic humility. Accordingly, Ramseyan Humility is the view that "no amount of knowledge about what roles are occupied will tell us which properties occupy which roles" (Lewis 2009, p. 204).

A second answer to the problem of quidditism is that we might nevertheless be in contact with quiddistic natures, i.e. to advocate a more direct realism than suggested by the indirect causal and nomological knowledge provided by the Ramsey sentence (see also Schaffer 2005). And there might even be a third stance as regards quidditism, namely simply to dismiss it as an exaggerated metaphysics while at the same time claiming this to be a viable realist answer despite its apparent empiricist flavor. I will make no further attempt here to decide which way to go (in part also since, again, the problem is not special to SR but affects realism in toto).

16 The Newman problem

As is well-known, Max Newman (1928) raised a serious objection against Russell's (1927) early version of SR (see Demopoulos and Friedman (1989) for a modern resumption). The idea is that if abstract structure is all we can know from our theories about the unobservable world, then only cardinality questions are open to empirical discovery. As Newman (1928, 140) put it:

> … given any 'aggregate' A, a system of relations between its members can be found having any assigned structure compatible with the cardinal number of A.

And further:

> … the doctrine that only structure is known involves the doctrine that nothing can be known that is not logically deducible from the mere fact of existence, except ("theoretically") the number of constituting objects.

So structuralism is near-vacuous, in effect it collapses to empiricism. All we can know is just cardinality.

The point of the Newman problem is not only that relations do not suffice to pick out the intrinsic nature of the objects in the domain, but that also the nature of the relations themselves remains indetermined! According to the early Russell only *abstract* mathematical structure is known. But without further empirical qualification, any such abstract structure can be imposed on a given set (modulo cardinality constraints).

In a sense, the Newman problem is the inverse of multiple realizability. Whereas in the latter case we have multiple instantiations (collections of entities) that fit the structural description, Newman's problem amounts to saying that a given collection of entities can be endowed with any arbitrary structure, as long as the collection has the right cardinality. As van Fraassen (2008) has pointed out, Newman's problem shows an interesting similarity to Putnam's model-theoretic problem, but we shall not delve into the details of disentangling them here.

17 Four problems revisited

We've discovered four problems in connection with SR: unintended domains (section 12), structural underdetermination (13), multirealization (15) and Newman's problem (16). They actually come in pairs. While the first pair has to do with the practical and vague notion of structure in physical theories (for instance the symmetry structure given by the symmetry groups in physics), the latter pair has to do with the precise logico-mathematical structure of a theory (cf. section 1). The difference between the two pairs is that the symmetry structure of T is most certainly not exhaustive, since the complete structure of T is almost certainly more extensive. By way of contrast, the logico-mathematical structure of the Ramsey sentence is exhaustive, insofar as the Ramsey sentence of a theory provides a complete description of T. Despite this distinction, problems 12 and 15 as well as 13 and 16 are more or less variations of the same theme – with 12 and 13 as special practical cases of the more generalized abstract cases 15 and 16. It is not at all implausible to assume that all four problems (or at least three, structural TUD is perhaps more special) are so strongly connected that they seek for a common answer. And basically, there are two routes from here, a Humean and an anti-Humean route, as I shall outline in the final sections.

18 Modal structures

Several SR proponents in recent debates have argued in favour of modal or causal structures (Chakravartty 2004, 2007; Esfeld (in print); Ladyman & Ross 2007). This means that structures are conceived as dispositional rather than categorical. The basic idea, notably in Chakravartty (2004), is to endow structures themselves with causal powers. Esfeld (in print) considers this an inevitable step in order to cope with the problem of quidditism (section 15) by assuming that the metaphysical causality behind the observable regularities has its root not in epistemically hidden quiddities but in the causal nature of the structures themselves. While Lewis believes that because of the Ramsey account of theoretical terms we have no epistemic access to quiddities (but to causal roles, i.e observable regularities only), the causal structure assumption dismisses quiddities altogether (and is, therefore, rather a dissolution to the problem).

Others even see causal structures as a possible way to overcome Newman's problem. Russell's early structuralism was about abstract structures, not about concrete *in re* structures. It was, in other words, about second and not first order relations. To overcome Newman's problem the structuralist must consider first order relations with causal powers as instantiations of abstract structures.

The causal structures strategy is perhaps a way out of the conundrum of problems 12 and 16 in particular. But, as usual, one has to pay a price. The strategy includes a double-step: first, to invoke first order relations and, second, to invoke causal powers. And the second step portrays a decisive non-Humean element, the allegedly modal or dispositional nature of structures. There are well-known difficulties connected with modal or dispositional ontologies, notably unclear identity conditions, which I shall not explore here. Rather, my project will be to outline the perspectives of SR from a strict Humean point of view.

19 A Humean response to Newman

Confronted with Newman's objection, Russell immediately realized that he must refine his position. In order to justify a particular, intended structure, we must somehow be directly acquainted with certain structural relations. Russell thus demanded "spatiotemporal copunctuality" between sense-data and physical objects as a basic relation. I cannot not discuss here whether Russell's proposal of spatiotemporal copunctuality is already the correct answer to the quest for basic relations, but I want to emphasize that his idea of knowledge about structures by acquaintance rather than mere description is, in principle, a viable solution to the notorious problems 12 and 16, perhaps even 15. It is, in fact, a solution which is also open for modern proponents of SR paving the way for a Humean conception of SR.

The essential clue is that we are not bound to relational properties only. For as we have already seen, SR must take structurally derived intrinsic properties into account (sections 6-9). We might therefore envisage direct observational acquaintance with structurally derived intrinsic properties. Whether and which placeholders of a structural description exist, i.e. whether and how a structure is instantiated, is an empirical question. And whether it is, for instance, electromagnetic or hydrodynamic current has to be distinguished on the level of observational phenomena and cannot be known from the pure theoretical and structural content alone (given the structural equivalence of the mathematical accounts). In our experimental observations we are "in contact" with the categorical, structurally derived intrinsic nature of the currents.

So the idea is basically this: Insofar as they are (structurally derived) intrinsic we need not invoke acquaintance with (causal) structures and insofar as they are categorical we need not invoke causal properties at all (be they structural or not). This paves the way for a Humean response. And finally, insofar as we assume "direct" acquaintance with them we rediscover Russell's option to circumvent Newman's problem. So we get a hybrid of a Humean and Russelian response to

Newman. Note, moreover, that weakly discernible relations are also perfectly categorical: they do not involve any quantum probabilities.

20 Humean perspectives on structural realism

A proper Humean perspective on SR is to demand categorical structures and to dismiss mysterious modalities (cf. Sparber 2009 for an account similar in spirit). Humean metaphysics, as usually construed, is based on at least three conditions:

1. a micro-physicalist supervenience base of fundamental intrinsic and categorical properties,
2. regularity (i.e. non-necessitarian) view about laws, and
3. reductionism about laws.

In an attempt to combine Humean metaphysics with SR, at least one of the three conditions must be changed. Let us consider them subsequently in the following sections.

21 Subvenient holistic structures

The first condition is best characterized in Lewis' famous conception of Humean supervenience, his view of "the world [as] a vast mosaic of local matters of particular fact" with "no difference without difference in the arrangement of qualities. All else supervenes on that" (Lewis 1986, ix-x). Meanwhile however, it is widely accepted that Humean supervenience is bound to fail. It fails according to modern science – according to the cases of quantum entanglement and gauge theoretic holism (cf. Healey 2007, chap. 4.5; Lyre 2004b; Maudlin 2007, chap. 2). Lewis even acknowledges the threat of quantum entanglement:

> maybe the lesson of Bell's theorem is exactly that there are physical entities which are unlocalized, and which might therefore make a difference between worlds … that match perfectly in their arrangements of local qualities. Maybe so. I'm ready to believe it. But I am not ready to take lessons in ontology from quantum physics as it now is. First I must see how it looks when it is purified of instrumentalist frivolity … and – most of all – … of supernatural tales about the power of the observant mind to make things jump. If, after all that, it still teaches nonlocality, I shall submit willingly to the best of authority.

But whether the quantum measurement problem has to do with frivolity or not – since the case of nonlocality can be made in gauge theories as well (a fact Lewis was obviously not aware of), it is time to realize that Humean supervenience must definitely be given up.

For proponents of Humean SR this is no bad news, since it is exactly this condition about the Lewisean Humean base which must be rejected. Instead of a mosaic of intrinsic, categorical properties, Humean SR considers *whole structures* in the supervenience base. This is a dismissal of naïve micro-physicalism, not about the categorical nature of such structures. Structures are holistic and global rather than local entities, physically exemplified and manifestly categorical. There is no need to assume causal structures, as we already saw in the discussion of Newman's problem and as we'll see now in the discussion of the second Humean condition.

22 Structural non-necessitarianism about laws

Humean SR is actually in accordance with the second condition from section 20. Structures are not arbitrary, but regular global sets of relations. Hence – and this is a quite important point – regularity, the crucial ingredient of laws, is already entailed by invoking structures. Structures are law-like. Take, for instance, the Minkowski spacetime structure of special relativity. It is a global geodesic structure exemplified by the trajectories of free falling bodies – a seemingly regular behaviour. Moreover, the behaviour of a free particle to follow geodesics is no disposition of the particle, nor is it a disposition of the geodesic structure, it is an exemplification of the manifest, categorical *in re* structure of spacetime. The same holds for other fundamental structures, for instance, the U(1)-structure of the world being exemplified by charge conservation.

Remarkably, such a structuralist regularity view about laws offers to avoid well-known problems of the orthodox regularity view. One problem is that not all regularities are law-like. Indeed, not all regularities are laws, only structures are. Under Humean SR, structures should be conceived as "world-built-in patterns" or global regularities. The holistic aspect of structures is crucial here: the particle following a geodesic is not a subsequence of disparate events which, without further explanation, show a regular behaviour. It is an exemplification of a global regularity itself – the geodesic structure.

There is, again, no reason to assume that there are "empty" laws. *In re* structuralism considers only exemplified structures. Such structures aren't necessarily exemplified at any (world) time, but they are at least globally exemplified on the whole spacetime extension. This is perhaps the most straightforward way to think of exemplification in Humean structural worlds: consider a world in which only one particle at an infinitesimally small time period has travelled a likewise infinitesimal spatial path. This particle is a proper instantiation of the full spacetime structure of that possible world.

Humean SR has furthermore the resources to explain the obvious universality of structure invariants without recourse to essentialism. Because of the holistic or global nature of structures, the structural invariants behave as universally valid. But such universality does not come equipped with mysterious necessity. It supervenes on the Humean base of structures. It is a mere regularity itself that some particular structure is instantiated. No necessities are involved here.

It follows from the same logic that Humean SR can account for exceptionless laws. Any instantiation of a structure will show the same regular behaviour encoded in the structure. Exceptions must not be expected, unless, however, the whole structure itself changes. This latter possibility can of course not be ruled out. After all, structures provide the Humean base, whether a particular structure subsists or not is a matter of pure regularity itself.

23 Non-realism about laws

The idea that structures provide the Humean base guarantees that Humean SR is in accordance with the third condition from section 20. Laws are reduced to structures, laws supervene on the structural Humean base. Some might think that SR is committed to a realism about laws because of the following argument: according to SR structures are real and laws are structures, so laws must obviously be real too. But, as we've seen, Humean SR just considers structures as global regularities and items of the Humean base. So again: whether a particular structure subsists or not is a matter of pure regularity itself. Laws aren't literally structures, and structures are only law-like in the sense that laws can be reduced to global regularities (which we call structures).

24 Transfer theory of causation

How should Humean structural realists finally construe causality? They might in fact welcome a transfer theory of causation (cf. Dowe 2000). The rough idea is that a causal process is the transmission of conserved quantities with causal interactions as intersections of such processes providing an exchange of the conserved quantities. According to fundamental physics, conserved quantities are identified with structural invariants. This is due to Noether's theorem which states that to every continuous symmetry generated by local actions there corresponds a conserved quantity. Such conserved quantities and, in turn, the causal processes and interactions are exemplifications of the fundamental structures. Structures come equipped with conserved quantities.

Some might complain that the transfer theory is non-Humean. But this is at best a problem for a micro-physicalist Humean base (according to condition 1). If we consider whole structures in the Humean base then causal processes and transfer of conserved quantities supervene on that base. And this is all the Humean needs.

25 Preliminary conclusion

Sections 18 to 24 present arguments against causal structures and provide perspectives for a Humean SR. There is no need to endow structures with causal powers. What's still missing in the picture is, perhaps, how dynamics comes into the world. We've basically outlined a static picture. And this is presumably the biggest neglect so far. Non-Humean SR with causal structures, however, doesn't solve this problem either. Metaphysical causation and physical dynamics are distinct topics, proponents of causal structures have no better grip on dynamics than opponents. Here's certainly much to be done in the future.

Admittedly, this paper was largely programmatic. We could merely touch upon some few motives and perspectives on Humean SR. But the perspectives are quite promising, perhaps promising enough to pursue them in more elaborated examinations.

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