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ON THE PREFERABILITY OF EPISTEMIC STRUCTURAL REALISM

ABSTRACT. In the last decade, structural realism has been presented as the most promising strategy for developing a defensible realist view of science. Nevertheless, controversy still continues in relation to the exact meaning of the proposed structuralism. The stronger version of structural realism, the so-called *ontic structural realism*, has been argued for on the basis of some ideas related to quantum mechanics. In this paper, I will first outline these arguments, mainly developed by Steven French and James Ladyman, then challenge them, putting a particular emphasis on a metaphysical principle (the Principle of the Identity of the Indiscernibles) which, even though it is crucial for the whole argument, hasn't been, in my opinion, clearly stated and examined yet. My overall view will be that a weaker version of the form of realism we are considering is more plausible – namely, *epistemic structural realism*.

1. INTRODUCTION: STRUCTURAL REALISM AND ITS VERSIONS

Structural realism has been argued by Worrall (1989) and (1994) both to account for the no-miracle argument for the success of science and to answer the pessimistic meta-induction on the history of science. It basically states that, while the claims at the level of traditional ontology made by the best accredited theories are not continuous in the history of science, there is some significant level of preservation between one accepted theory and the next one at the level of structure.[1]

This idea was first suggested by Poincaré and Duhem, two leading French scientists/philosophers at the turn of the 20th century. Despite differences between them, both saw scientific theories as having two levels: one is that which expresses relations and causal links existing in the physical world through the means of mathematics; the other is that which provides with a more 'intuitive' description of how things are supposed to be. While usually, especially from the point of view of the layman, the two levels are not clearly distinguished, Poincaré and Duhem suggested, the distinction between them is fundamental.

Following these two epistemologists, structural realists maintain that it is rational to believe only in what the theories tell us at the first level. As pessimistic meta-inductions show, often the progress of science completely

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changes things at the 'descriptive' level.[2] But if we stick to the relations expressed by the mathematical apparatus, then we have some extent of preservation. Hence, a realist has neither the possibility nor the need to look for something else: only the mathematical structure expresses something that we can interpret realistically about the world we experience. In sum, we should definitely understand the privileged role of structures as the only real expression of true knowledge about the physical world.[3]

The distinction that I want to examine in this paper is that between epistemic structural realism (ESR) and ontic structural realism (OSR).[4] While the former version states that we can only have a justified realist attitude towards structures but there is, or might be, something more, the latter argues that structures are all there is out there. According to ESR, that is, the intrinsic nature of the physical world exhibiting the relations expressed by the mathematical structures remains hidden. OSR, on the other hand, suggests that there is nothing more in the world than those structures we get to (partially) know through our scientific inquiry.

While the metaphysical claim underlying OSR is uncontroversial, though, I think one has to be careful as to the formulation of ESR. What exactly does it mean that that something else existing beyond structures remains hidden? Obviously, an immediate reply (in the spirit of Poincaré's original formulation[5]), is that that 'something' are the individuals exhibiting the relations constituting the structures, and that they exist but are not known and not knowable in principle. I think this is indeed what whoever endorses ESR actually, at least on a first instance, believes to be the case.

Still, I also think one is entitled to say something more, namely, that since we have favourable evidence as regards structures as partially preserved through theoretical change, we can be realist about these, without any commitment to what exists beyond them. That is, given our well-established conceptual categories, the advocate of ESR can assume the 'traditional' ontology, based on individuals, as unproblematic while also emphasising the role of structures. But s/he by no means needs to *prove* that our ontology *can't be* purely structural. Rather, s/he might opt for some kind of 'suspension of judgement' in relation to ontology and stick to the traditional categories until new, clear evidence in favour of a stronger and more unusual position (as OSR undoubtedly is) is offered.

The burden of the proof, I believe, is on the position which is presented as ontic: as long as who supports it is not able (as, I maintain in the present paper, s/he can't be) to present truly convincing arguments both against classical ontology and for the need for *and the possibility of* radical structuralism, ESR is not only enough, but also the maximum a realist is entitled to maintain.

In short, I think that in a proper interpretation of ESR we should take it to be 'agnostic' in relation to what exists, if anything, beyond knowable structures. Only by doing so ESR can be taken to be an interesting realist position and presented as a plausible alternative to OSR.

This said in relation to ESR, let's move to a closer analysis of the position I will try to criticise. OSR is defended with great conviction by James Ladyman and Steven French. They believe that strong support for it comes from physics and, in particular, from quantum mechanics. Their arguments will be analysed in the present paper, with the aim of showing that they are not as persuasive as they are supposed to be by the advocates of OSR. On this basis, it will be argued that ESR, formulated as suggested above, is the best option for the realist.

2. THE ARGUMENTS FOR ONTIC STRUCTURAL REALISM

In this section I will present what I take to be the basic arguments in favour of OSR. These have been developed by French and various co-authors in the last 10–15 years: some philosophical work on the metaphysics of quantum mechanics which appeared in the late 80s thanks to French and Redhead (1988) has been then developed by French and Ladyman in a series of contributions. Ladyman (1998) then formulated and explicitly stated OSR as the natural conclusion to be drawn from the whole of the previous philosophical elaboration.

The main point these authors make is related to a revolutionary transformation of the concept of individuality that is allegedly required by quantum mechanics. Their basic thesis is that the very idea of an individual entity as a fundamental ontological posit should be abandoned as soon as we get to the quantum domain.

There seems to exist some kind of underdetermination between the non-individuality and the individuality 'metaphysical packages' in quantum mechanics. The former option is immediately suggested by the orthodox 'Received View' of quantum mechanics, but the latter is still defendable by introducing state accessibility restrictions. And if we really want to reject the anti-realist interpretation of this underdetermination, suggested for example by Van Fraassen (1991),[6] French and Ladyman think we are better off dropping the classical conception of an individual object altogether. That is to say that, in the light of evidence coming from quantum mechanics, we should revise our whole ontology, which is wrongly built upon individual basic constituents.

This, French and Ladyman suggest, can best be done by rejecting everything superfluous[7] we have in our description of the world and producing a purely structural conception of reality. In short, quantum mechanics and its alleged consequences for our concept of individuality strongly support the idea that structures are not only epistemically privileged but also *ontologically autonomous*. And this is exactly the core of OSR.

Since this line of reasoning involves reference to the controversial philosophical principle of the identity of the indiscernibles, I think it is necessary to examine first the meaning of this principle. We will focus directly on the analysis of the arguments for OSR in the subsequent sections.

2.1. *The Principle of the Identity of the Indiscernibles*

The principle of the identity of the indiscernibles (PII from now on) is a metaphysical principle first formulated by Wilhelm Gottfried Leibniz in the *Discourse on Metaphysics* (1686). PII asserts that $\forall P(Pa \leftrightarrow Pb) \rightarrow a = b$ (where P means property, and *a* and *b* are two individual constants);[8] that is, two substances which resemble each other in every respect are the same thing. Obviously, this entails that for two distinct objects x and y there is at least one property that x has and y does not have (and/or vice versa): McTaggart called this consequence of PII the 'principle of the dissimilarity of the diverse'.

PII can be formulated in a weak version (the quantifier ranges over all properties, including spatial ones) or in a strong version (spatial properties are excluded). In the latter case, we can include or exclude relational properties. This distinction is intended to make the principle interesting, as in the macroworld, and in classical physics in general, weak PII is trivially true. More specifically, at the level of common sense, macroscopic objects, even in the highly unlikely case that two things have exactly all their characteristics in common,[9] we can always be sure that at least spatial positions differ.

Despite this apparent straightforwardness, there is the problem of identifying what (given the constraints) can actually constitute a property to be included in the range of the universal quantifier. If any property is allowed, then PII becomes a logical truth simply stating self-identity independently of the level of reality we are considering (since we can always find a property such as 'being identical with itself' which warrants distinguishability). If, on the contrary, we follow, for example, Wiggins[10] in excluding thing-individuating and equality-involving predicates and so avoid trivialising the PII, we have to restrict ourselves to empirical properties. This would mean interpreting the principle as requiring *our practical ability to distinguish* two things as two different individuals (as the word 'discernible' seems to suggest) in order to be in a position, *from a meta-*

physical point of view, to say they are actually two. But then it might be objected that this is too much, for introducing the restriction to *empirical* properties seems to entail that it is no longer possible to use PII to make 'discoveries' about *metaphysical* identity: after all, it is not absurd to think that two things could happen to be distinct without being discernible (for example, due to contingent technological limitations).

This is the crucial issue. For the 'narrow' empiricist the principle is *absolutely* true. According to him/her, distinct things at any level of reality have to be differently related to us and if they do not we can say they are identical.[11] But the above objection seems correct: are we entitled to draw such a strong conclusion from a consideration of what is empirically accessible to us? Apart from the fact that the very definition of the set of the 'empirically accessible properties' appears problematic, should such a contingent notion define a metaphysical rule?

A plausible reading of PII (at least in the present context) is that according to which the quantifier ranges over all properties appearing in our best scientific theories. Adopting this version of PII, one would not need actual empirical accessibility, as we could take the quantifier to range over the broader domain of the 'theoretical' properties. That is, a 'softer' empiricist reading of PII might suggest that since *in the framework of the currently accepted theory* we attribute exactly the same properties to *a* and *b*, we are entitled, *from the point of view of that theory*, to consider *a* and *b* as one and the same entity.

Still, not all the problems are solved, for in so doing the metaphysical character of individuality is, so to speak, put into parentheses. In what follows, we will temporarily consider this analysis of PII enough and assume the principle as unproblematic. On this basis we will examine the arguments stemming from it, when it is applied to quantum mechanics, in favour of OSR. What we have to bear in mind, though, is that even in its most plausible formulation PII is always on the borderline between constituting an *epistemological* claim about our practical abilities and the contingent status of present theories and representing a much stronger *metaphysical* claim about the way things are in themselves. Later on, we will see what difficulties arise for the principle, and for the structuralist project in general, once this ambiguity is analysed further.

2.2. *The Arguments Against Individuality in Quantum Mechanics*

French and Redhead made a careful analysis of the consequences of PII when it is applied to the quantum world, given the currently accepted theory. They concluded that, if we want to stick to the concept of individuality in the microworld, we have to adopt some kind of transcendental individuality. Further analysis, French and Ladyman say, allows an even stronger conclusion and supports OSR. Let's examine these arguments.

French and Redhead (1988) consider the set of all possible two-particle systems states and show that, while quantum particles can be taken to be individuals despite the peculiar statistics they obey, such individuality cannot be argued for on the basis of McTaggart's principle.

On the one hand, it is true that in quantum mechanics a permutation of particles is not regarded as giving rise to a new arrangement: if we consider two boxes and two particles, we have four possible states in classical mechanics and only three (for particles instantiating the so-called Bose-Einstein statistics) or even just one (for particles characterised by that which is defined as Fermi-Dirac statistics) in the quantum case. Hence, it might seem, for example, that the state with particle A in box 1 and particle B in box 2 is the same as that with particle B in box 1 and particle A in box 2, and we count just one state, because A and B are not distinct individuals. But, as a matter of fact, the peculiar non-classical statistics which applies to the quantum world just corresponds to the kind of states accessible to the particles and does not, by itself, rule out individuality at the microscopic level.[12]

Still, on the other hand, it can be shown that neither weak nor strong versions of PII allow, given this empirical evidence, to identify distinct individuals in the quantum world.

As to the weak version, unlike classical mechanics quantum mechanics does not attribute well-defined trajectories to particles. Hence, the latter do not have definite positions-at-a-time and cannot, consequently, be distinguished from each other on the basis of their spatial locations. That is, we cannot (not even in principle: we are not talking about practical matters relating to measurement) label the particles at some time and then follow their trajectories and tell, at a later time, which one is which.

In relation to the strong version, French and Redhead consider two-particle systems and their state-dependent properties[13] and examine the probabilistic attribution of values to the system's observables.[14] Both for fermions and bosons we obtain, for a system Ψ, two observables Q_1 and Q_2 and two values r and s, that

$$\mathrm{Prob}^{|\Psi>}(Q_1 = r) = \mathrm{Prob}^{|\Psi>}(Q_2 = r)$$

and

$$\mathrm{Prob}^{|\Psi>}(Q_1 = r|Q_2 = s) = \mathrm{Prob}^{|\Psi>}(Q_2 = r|Q_1 = s)$$

This has to be read as: in the two-particle quantum system Ψ, the probability of having a specific value for a chosen observable is the same for the two particles; and the probabilities of one of the particles having one of the two values given that the other particle possesses the other value are also equal.

This means that both the monadic and the relational properties obtain with equal probabilities; this is equivalent, for the nature of quantum mechanics, to saying that the two subsystems have exactly the same properties.[15] The case of paraparticles[16] is only slightly different, for it happens that, when we consider 3-particle systems, 2 particles have all the properties in common.

Technicalities aside, what this all amounts to is that every time we have two 'particles' of the same kind, quantum mechanics tells us that they have exactly the same properties, including spatial location! Therefore, according to PII, they would have to be identical in the sense of being one and the same entity. If we don't want to accept this, we have to either reject PII in the quantum domain or introduce transcendental individuating features in the range of the properties considered.

French and Redhead indeed conclude "that indistinguishable particles in QM can be treated as individuals, but [. . .], if they are so treated, then, on the most plausible reading of what constitutes a property of a quantal particle, even the weakest form of PII [. . .] is violated both for bosons and fermions, and indeed for higher-order paraparticles".[17] Hence, if we want to stick to the individual-particles picture, we have to maintain that "an individual acquires its individuality by something that transcends its attributes [as they are scientifically checkable and/or defined by the theory;] we shall say that it exhibits transcendental individuality".[18]

In later works, French and Ladyman occasionally suggest that every form of transcendental individuality is philosophically unconvincing.

In particular, they say, we could think of primitive thisness (haecceity)[19] or, alternatively, of a Lockean 'substratum' as that which provides the individual entity with its identity independently of its changeable features. But both options are unsatisfactory. Primitive thisness is a concept introduced in the late XIII century by the scholastic philosopher Duns Scotus in order to solve the problem of universals. It is, he suggested, something neither individual nor universal but able both to individuate concrete particulars from substance and to generalise in the abstracted universals we create at the conceptual level. Such account is undoubtedly hard to accept without reservations in the context of today's philosophy and science. Besides that, adopting it might appear quite ad hoc here. Postulating a substratum is equally problematic. As Locke already realised, being something which individuates a thing beyond this thing's specific, contingent properties, a substratum should correctly be thought of as a property-less 'I don't know what' in order to have the fundamental metaphysical role we want it to. But thinking something like this is indeed, to say the least, difficult.

Anyway, whatever we decide to do of Transcendental Individuality 'TI', French and Ladyman argue, once we have a clear idea of the ontological underdetermination existing in the quantum domain (between the description with individual entities and that which dispenses with them) we have to conclude that the traditional picture of the world has to be profoundly revised. And this, they maintain, directly implies the need for OSR as a way to simply overcome the underdetermination altogether. OSR, as I already said, was firstly explicitly formulated by Ladyman; he perfectly synthesises the basic idea in the following passage: "we should seek to elaborate structural realism in such a way that it can diffuse the problems of traditional realism, with respect to both theory change and underdetermination. This means taking structure to be primitive and ontologically subsistent" (1998, 420).

Adopting OSR, French and Ladyman suggest, we can reconstruct the notions of objectivity and objecthood in purely structural terms. That is, once we realise that 'traditional' individual entities are not fundamental and are, as a matter of fact, a by-product of our experience of the world, we can reconstruct them accordingly as deriving from those complex relational properties which are actually prior and are grasped by our theories via their mathematical apparatuses. Observation of the fertility of mathematical tools such as, for example, group theory in modern physics shows that we can 'build' objects directly out of the properties 'attributed' to things by physical laws. A deep study of such notions, mainly drawing inspiration from the works of Cassirer, Weyl and Eddington, has been carried out by French. He emphasises how invariance and constancy of relations literally create objects: they play the role of 'conditions of accessibility' which immediately become 'conditions of the objects of experience'.[20]

Basically, instead of taking individuals for granted, we begin by giving a representation of a physical system. In relation to it, we use mathematical transformations in order to identify the irreducible and invariant elements which determine classes of particles and (those which are called) many-particle systems. In the face of the underdetermination between individuality and non-individuality, then, it seems not only possible and more 'economical' but indeed more plausible to dispense with the traditional 'individual entities' ontology and adopt OSR. Since the latest developments in microphysics strongly suggest that the very concept of individual entity is a surplus, and relations and properties expressed in structural terms are all we need in order to construct an exhaustive picture of the world, it makes perfect sense to say that there actually isn't anything else.

3. DISCUSSION AND CRITICISM OF THE ABOVE ARGUMENTS

Several points can be made, I believe, against French and Ladyman's theses.

3.1. *What are we Really Allowed to Conclude from the Principle of the Identity of the Indiscernibles?*

PII has been put into doubt, as a principle stating a necessity, already in the past.[21] More generally, as a matter of fact it is far from having a univocal, clear and unproblematic formulation.[22] Hence, a fortiori, it is not absurd to re-evaluate a metaphysical principle introduced three centuries ago in the light of contemporary physics. For example, one might say that what quantum mechanics teaches us is that microparticles can share all the properties or even exist at the same space-time point (failing to be impenetrable) and still be two different entities. Consequently, PII would be what is to be discarded.

Black (1952) and, in a similar flavour, Ayer (1954) proposed in a thought experiment a completely symmetrical universe containing nothing but two exactly resembling spheres. In such a universe the two spheres would be indiscernible: spatial properties would not do the job, for we could only describe the spheres considering the position of each sphere in relation to the other, which would result in attributing the same relational property to each of them.[23]

This is due to the fact that we haven't labelled the two spheres as, say, *a* and *b*. Recurring to self-identity (sphere *a* is equal to itself, and the same applies to sphere *b*) or primitive difference (*a* and *b* only differ in the property of being different, respectively, from *b* and from *a*) would allow us to introduce such labels; but such possibility is ruled out in an empiricist interpretation of PII. Anyway, it's a fact that the existence of two distinct spheres has been hypothesised initially. Hence, the argument seems to suggest that numerical difference can coexist with practical indiscernibility (at least unless the hypothesis turns out to be, on analysis, incoherent) and that strong empiricism is incorrect.

Consequently, we should consider the possibility of some undetectable features of the spheres as those determining the particles' 'thisness' and 'thatness'. One might argue that what "Black's example shows is that, given his description of this universe, it is *impossible for us* to name the spheres and thereby name the properties in virtue of which *they differ*".[24] That is, difference is assumed and, nevertheless, PII gives us no ground to speak of distinct individuals, because the former is tied to something of a *transcendental* nature.

Hence, we have here an epistemological impossibility which is by no means immediately also a metaphysical one. It is easily seen that accepting the idea of transcendental individuality allows to draw from the physical premises quite different conclusions from those suggested by the empiricists.

Hacking (1975) suggested that we could re-interpret Black's two-sphere world as a non-Euclidean universe with only one sphere. Besides the fact that this identification might be impossible in more complicated cases, to this argument one can reply that the possibility of a world with two distinct individuals is not ruled out at all by this counter-example. Hacking just makes a different assumption about the geometry of the universe; and that which he chooses is only one of the possible alternatives. We seem to have a kind of underdetermination between contradictory but empirically equivalent interpretations (exactly as it happens in the quantum domain!); and this only manages to put further emphasis on the impossibility to conclude from indiscernibility to identity immediately as PII requires.

This discussion should have then given more strength to what has been hinted at in Section 2.1: the ontological consequences of PII depend entirely upon our interpretation of it and on the properties we decide to include in the range of its universal quantifier. On a weaker reading PII seems to assert something that is by no means necessary but, at best, only contingently true; that is, true in one of the possible world-pictures. Only endorsing a stronger empiricism would make the consequences of PII necessary truths. But it does not seem that we are entitled to read the necessity of metaphysics off the contingency of our scientific knowledge.

Where do French and Ladyman stand in this context? I believe they argue for OSR on the basis of exactly the strong empiricism I see as incorrect. More specifically, they seem to agree with a Russellian property-only view of reality; to accept as real the properties attributed to things by theories; to observe the empirical data and interpret them in the light of the theory; to apply PII to the considered properties; and to eventually conclude for strong *identity* (and, then, for OSR) on the basis of simple *equality of properties according to a theory*. But this seems to me an ungranted jump from epistemology to metaphysics. Radical empiricism has had well-known problems in the past, and seems to be even less sensible nowadays: putting it simply, what exactly should allow us to draw conclusions about the way reality 'actually' is from what we know of it? The very move from the epistemic to the metaphysical is indeed something that coherent empiricism has traditionally avoided. In relation to our point, I think we can agree with Bohm and Hiley when they say that "it has often been concluded that particles are not merely indistinguishable, but that they are identical. To do this is to go from an epistemological statement [. . .] to [an ontological one concerning] what the particles are, i.e. one and the same. [. . . E]pistemology and ontology are thus equated. But as we [. . .] stressed before, there is no real necessity to do this".[25]

At best, we have those reasons of 'economy' provided by an application of Ockham's razor to our ontology coherently to what our (provisional) world-picture suggests. But is this enough to put forward such a strong metaphysical claim as that underlying OSR? I don't think so, and I would rather maintain that a clear-cut distinction between indistinguishability and identity on the one side and between PII as a principle of distinguishability and as a principle of individuation on the other has to be kept. Conflating the two issues might give one the totally wrong impression of being in a position to draw new radical conclusions from the available evidence. Rather, keeping them separated allows to easily understand the difference between equality of two sets of data in some respect and metaphysical numerical identity. PII could make it possible to speak of the latter only if transcendental properties were accessible directly (as we need to say that we experience that two things, so to speak, share the same instance of TI). But this obviously means that they wouldn't be transcendental any longer and we would gain empirical access to those features which provide things with numerical identity. If this was the case, we would immediately recognize one or two (or more) things and PII would reduce to a trivial statement of self-identity or primitive difference, that is (see Section 2.1), to a logical truth. The alternative, certainly equally not very appealing, is that of reducing PII to a principle about equality of empirical (accessed and/or accessible) properties. At any rate, it looks like no metaphysical 'discovery' can be made via PII.[26]

3.2. *Does Every Interpretation of Quantum Mechanics Agree With the Proposed Conclusion?*

But let's assume PII as unproblematic: in this case French and Redhead's conclusions are clearly legitimate.

As already explained, they hold that according to every version of PII individuality fails to obtain at the quantum level. Undoubtedly, they argue to this conclusion on the basis of a well-established theory, as quantum mechanics in his 'Received View' form surely is. Nevertheless, one thing is a theory and another thing are its interpretations and further elaborations. And it happens that an important and very interesting possibility which is only *en passant* considered by French, namely that constituted by the so-called hidden variables interpretations of quantum mechanics, allows to draw quite different conclusions.

According to what Bohm and Hiley (1993) call their ‘causal ontological interpretation’, in the quantum world there are fields similar to those which in classical Newtonian mechanics are described by Hamilton-Jacobi equations. Whereas the classical Hamilton-Jacobi field is described by

$$\partial S/\partial t + (\nabla S)^2/2m + V(x),$$

now we have

$$\partial S/\partial t + (\nabla S)^2/2m + V(x) + Q(x).$$

Q(x) is defined as the ‘quantum potential’ and is equal to $-\hbar^2/2m \cdot \nabla^2 R/R$.[27] It determines the specific behaviour of quantum particles and, in general, all the strikingly peculiar features of the quantum world. But despite these peculiar features, the overall picture remains classical.

In particular, position[28] is defined in this interpretation as a determinate property: any of the particles “actually is a particle with well defined position x(t) which varies continuously and is causally determined”.[29] True, position might be not known with certainty, and for this reason we describe it as a ‘hidden variable’ and use probabilities; still, it is always definite and the basic features of the classical Newtonian world remain true here. That is, our epistemic limitations can, and must, coexist with the adoption of an essentially classical ontology, for “there are *particles* following definite trajectories [. . . and . . .] ultimately all manifestations of the quantum field are through the particles”.[30] If, then, *individual particles with definite positions* are the basic ontological constituents of the quantum world in a Bohmian interpretation of quantum mechanics, one immediately sees that weak PII holds without indistinguishability entailing identity, for trajectories become as well-defined as in classical mechanics.

And it happens here that *the theory itself* defines initially *distinct individuals* with distinct spatial locations.[31]

More generally, in such an interpretation the fact that we attribute equal probabilities to two systems in relation to their observables’ values does not imply any longer that they have exactly all the properties in common (as required for a violation of PII) but only that we have the same knowledge in the two separate cases, whereas the actual values *might well be different*. So being, PII can be applied in its strong version as well without the need of concluding from equality of properties to identity.

In sum, a challenge to French and Redhead’s argument against individuality in the quantum world clearly comes from considering hidden variables interpretations of the quantum theory. As also argued by Belousek (2000), such interpretations always imply physical distinguishability and, in addition – depending on our understanding of the basic assumptions of the 'Received View'[32] – possibly statistical distinguishability as well.

The possible rejoinder, that according to which adopting such an interpretation of quantum mechanics is as ad hoc in the present context as recurring, for example, to primitive thisness, does not sound really convincing: Bohm and Hiley introduce the causal hidden variables interpretation in order to solve the problems of the physical theory and provide a unique coherent picture of the microworld. Their main aim is surely not that of imposing a 'traditional-looking' ontology. And exactly (some of) the peculiar features which make their interpretation very successful (like contextuality and non-locality[33]) also make one immediately realise that it is far from being just a simple reiteration of the classical ontology.

3.3. *Does the Suggested Argument Necessarily Imply Strong Non-Individuality?*

As we have seen, we can distinguish fermions from bosons on the basis of the accessible states. Moreover, in the cases of the so-called 'paraparticles', it happens that only 2 particles out of 3 (in a minimal 3-particle system) have all the properties in common. From all this it follows that in the microworld, while at times particles can happen to be indistinguishable from each other, we also experience that:

(i) they differ from particles of a different kind (say, a boson differs from a fermion) and
(ii) they can belong to the same kind and, nevertheless, be different from each other (as, say, particles 1 and 3 in a 3-paraparticle system are identical to each other but differ from particle 2).

All this seems to suggest that, rather than abandoning individuality altogether, we might just adopt a view such as, for example, Lowe's. He says that electrons, and microparticles in general, are "entities which can *sometimes* but *not always* be determinately identified [. . . ; they. . .] always have determinate *self*-identity, even though there can be circumstances [. . .] where all talk of numerical identity or diversity between those entities ceases to have meaning" (1998, 170–173).[34] According to Lowe, we have here 'quasi-objects' provided with 'quasi-individuality'. He agrees that, in the case of quantum particles, "identity statements concerning them *can* genuinely be indeterminate" even though we have determinate countability

(1998, 37).[35] But, the possibility of indeterminacy seems balanced by that of genuine cross-kind or even inside-a-kind differences between entities.

It seems then that we have here something in between traditional individuality and strong 'structuralist' non-individuality. This account, that is, points out a 'hybrid' nature of particles in quantum mechanics, which *are individuals* in some respect but not in others. What this might possibly mean is shown, for example, by Hilborn and Yuca (2002). Considering the possibility of violations of SP and the connection between spin and statistics (in particular, on the basis of actual theories like those introducing q-deformed commutators), these two authors argue that, independently of what we say about other properties, permutation symmetry is a holistic property emerging only at the collective level. So, we seem entitled to say that intrinsic properties could be attributed to individuals but there are *also* family-individuating properties which are only collective. This would explain why in some respects we can identify systems of countable entities but not individuals in them but, at the same time, don't need to recur to strong structuralism, for we have nothing more than a case of emerging, holistic properties which do not supervene on the features of the basic individuals: and this is something neither entirely new from the conceptual point of view, nor sufficient in itself to support OSR.

Therefore, once more, it appears clear that some epistemic constraints are not enough to adopt the most 'extreme' alternative to the traditional ontology. That of quasi-individuality is a conceptual option which testifies the possibility of finding a middle ground where the novelties appearing at the theoretical level can still agree (at least partly) with the requirements put forward by our well-established conceptual categories.

The strong conclusions drawn by the supporters of OSR seem, again, unwarranted.[36]

3.4. *Transcendental Individuality: Is a Re-evaluation Impossible?*

One could also examine further the possibility of attributing transcendental individuality to quantum particles. True, we have already expressed our doubts about this strategy, and basically agreed on this point with the criticisms put forward by French and Ladyman. Still, their arguments against transcendental individuality do not go really deep into the analysis, and it may well be of interest to do further research in the field of 'old-fashioned' metaphysics, especially once we consider how blurred, as I repeatedly tried to emphasise, the boundary between the domain of the 'empirical' properties and that of the 'transcendental' ones is.

One could concede to French and Ladyman that 'haecceity' or 'primitive thisness' are philosophically old-fashioned, unclear concepts whose use in the present context might, in addition, look very ad hoc. And we can also accept the argument according to which Lockean 'substrata' are equally, if not inconceivable, to be discarded from the point of view of contemporary science, as they are defined as completely property-less, hence unknowable in principle, basic constituents of the world. Nevertheless, this does not exhaust all the available options.

Some other coherent metaphysical accounts have been proposed which are founded on basic unanalysable individuality-bearers. Loux, in particular, has suggested such a re-elaborated Aristotelian 'substance' account of the material world.[37] He argues that the bundle theories[38] are fatally flawed and, rather than keeping on working on them, we have to recognise that individual entities are metaphysically necessary. In Loux's terms, "substances are irreducible [individual] unities [. . .] subject to a characterization in terms of the concepts provided by their proper substance-kinds, e.g., kinds like *atom* and *quantum*" (1978, 170–173). That is, the basic constituents of the world are individuals defined by their essential properties. Obviously, these properties are, in turn, defined by our theories. Still, the need for irreducibly individual entities stems from metaphysical considerations which are *independent of any contingent knowledge of the physical world*. Loux suggests that "whatever objects the scientists takes to be the building-blocks of reality must be characterized in terms of a framework of substance-kinds" (1978, 173). Hence, according to the account he proposes, "substances are not constituted exclusively by their properties; they incorporate, in addition, an individuating constituent, i.e., a constituent *which guarantees the numerical diversity of indiscernible objects*. This entity *is not bare* [as in a Lockean substratum account]; it has many properties *essentially*; and while it is the possessor of those properties, not it, but the substance into whose constitution it enters is the subject of ordinary property-attributions" (1978, 149).[39]

Lowe, whom we met already, agrees that one is surely allowed to postulate some 'ungrounded entities', for "the regress [in the analysis of the constitution of the material world] can perfectly well be terminated at a level of *fundamental particles*, which have all their intrinsic properties *unchangeably*" (1998, 129). The fundamental particles of modern physics have properties like spin and charge unchangeably and "ultimately, or so we are led to believe, it is in terms of such properties of such particles, together with the relations of such particles to one another, that the whole macroscopic physical realm is to be explained" (1998, 129). That is, yes, relations build the whole of reality as suggested by OSR but, nevertheless, they do so on the basis of fundamental *individual* constituents.[40]

Hence the mysterious nature of bare substrata disappears and, at the same time, the problems of an ontology with properties only are solved: the main advantage of such a neo-Aristotelian account "is that it enables us to resolve a problem that is irresolvable on both the bundle and substratum accounts – the problem of *individuation*" (1998, 166).[41] Loux says: "[I]ndiscernible substances agree in their substance-kinds; but for two or more objects to agree in a substance-kind is *eo ipso* for them to be numerically different. [...We] can call it a substance-theory of substance. It is a descendant of an approach to substance that is expressed in many passages of Aristotle in which [...] he insists that substances are fundamental unities which cannot be reduced to more basic sorts of things" (1998, 164–165).[42]

A substance-theory like Loux's is undeniably and patently in agreement with what physics itself tells us about the alleged ultimate constituents of reality and, most important, *with a traditional individual particles account of the physical world*.[43] And it does not seem to me that such an account is by any means more unattractive than that underlying OSR. At worst, we have yet another kind of unresolvable underdetermination which is by no means to be overcome by adopting radical structuralism.

3.5. *Does Quantum Field Theory Actually Support a Purely Structural Ontology?*

Even if we accepted their whole argument and took individual objects to be derivative, ontic structuralists would still have to construct an alternative metaphysical picture. French and Ladyman suggest that this can be done by referring to the concept of field, which is nowadays widely taken as actually ontologically prior.

In fact, a careful consideration of quantum field theory itself reveals that putting this structuralist program into effect is not that easy and straightforward: one can surely agree that the concept of field is something we can cash out to a certain extent in structural terms, that is, as a net of relations described by the theory's mathematical equations. Still, it is not at all clear whether fields can be wholly explicated structurally.

On one side, we could interpret fields as substances whose properties are instantiated at specific space-time locations; on the other, instead, one could see fields as properties of those locations.[44] In both cases, a clarification of the nature of fields seems to be strictly connected to another fundamental debate, that about the nature of space-time. As Redhead puts it, "in particular, TI still seems to be needed, as the source for individuality of the space-time points" (1988, 12).

French and Ladyman suggest following the picture developed by Sunny Auyang and reducing space-time to a fundamental 'architecture' of the world. So conceived, they argue, it can be entirely cashed out in structural terms.[45] In this framework, the whole of reality (fields plus/as space-time) would be explicated according to OSR.

Others, though, draw different conclusions. First, many reject a purely structural account of space-time; more importantly, some authors argue that, independently of the debate on space-time, a structural description of a field does not trivially correspond to a structural reduction of it as a *concrete* entity to a net of causal relations: something is unavoidably left out of the picture by such a reduction.[46]

Besides this basic point, one could agree on the need for a re-evaluation and, possibly, abandonment of the 'myth of substance' once QFT has been adopted. But still, the alternative is far from being unique, leave alone from being easily identifiable with structuralist/properties-only ontologies. Simons (2002), for instance, proposes[47] a factored ontology based upon 11 'modal dimensions' which is allegedly rich enough to be perfectly applicable to any part of reality and, therefore, to physics – and QFT – in particular. And Seibt (2002), just to give another example, suggests a 'process ontology' where the notion of free process is proposed as a fundamental 4-dimensional non countable which can subsume, between other things, non-fully-determinate 'quanta'. Other options could be quanta ontologies *à la* Teller, with aggregable but not individuable quanta as the basic particulars; or occurrent/event ontologies formulated in a more or less Davidsonian flavour.

If, as it seems likely (see Note 39), some kind of bundle theory is the natural ontological option available to the advocate of OSR, this, unfortunately, is not good news for him/her. This view has already been heavily criticised in the past for the concept of trope has to be fundamental, particular and individual for such an ontology to be consistent and yet it actually seems to be, by its very definition, something dependent. Putting aside this problem,[48] I believe the main difficulty for such proposal, as we will see in more detail in the next section, is that trope theories have to face with new problems in a view, like OSR, which aims at constructing a non-individuality based ontology.

We can surely assert then, as after all is acknowledged by French and Ladyman themselves, that the debate concerning quantum field theory is at its first stage and has offered no clear answers yet in relation to the ontological nature of fields. Obviously enough, it follows that the discussion concerning the consequences of quantum field theory for structuralism is still open too. Hence, even if we decided to choose the field description, it wouldn't be clear at all that we have to endorse OSR, for it is by no means agreed that structure is all we need to describe the world, leave alone that structure is all there is out there.

3.6. *Does OSR Solve All the Problems?*

Other criticisms have been/can be levelled against French and Ladyman's ontic structural realism.

The first one I want to examine is that according to which relations need relata. According to it, a purely structural description of the world is impossible in principle because structures are defined by relations but the latter presuppose related individuals.[49] I find this objection flawed, for obviously relations need relata only in the traditional view of reality, where by assumption we take individual things as fundamental. French and Ladyman have no difficulty in replying (as indeed they do) that their proposal requires a deep revision of our conceptual apparatus. And they also show that performing such a revision is actually possible by referring to already existing work.

On one side, they refer to 'quasi-set' and 'quaset' theories in logic, which are based on objects without defined identity conditions and on well-defined relations.[50]

On the other, and here we get back to the point of the plausibility of a purely structural property-only ontology, they re-state the necessity for a metaphysics according to which physical objects are 'knots' of relational properties constituting structures, and try to build a genuinely structural ontology. Starting from the assumption that we should take entities no longer as a *terminus a quo* but, rather, as a *terminus ad quem*, French refers to the work of Mertz with the aim of providing a world picture where structure is really primary.[51]

Mertz (1996) developed what he calls 'network instance realism'. In this framework, the alleged 'tyranny of the monadic' is rejected and "individuated relation instances" become the basic ontic units. They are presented as "*necessary* [...] and *sufficient as* both ontology's 'primary substances' and as the cause *sine qua non* of all plural wholes whatsoever" by French (2002). Without entering into the details of this proposal which, unusual as it may sound, surely is a conceptual possibility, we can say that this shows that the criticism according to which structures cannot in principle be autonomous does not look very promising for detractors of OSR.

Nevertheless, such criticism surely helps in identifying one point, once we reflect on the concept, just encountered, of 'individuated' or 'well-defined' relations. As we said, and as it seems at times openly acknowledged by ontic structural realists, if we reduce ontology to structures we will likely have to adopt a bundle theory of substance. Bundle theories, though, as I also have already hinted at, do not seem to go along well with OSR. The main point is that, since according to them there is nothing else beyond properties, they do not really explain the individuation of objects through their concepts of compresence or co-instantiation of properties. Obviously, a bundle theorist cannot say that properties are compresent and constitute one and the same object because they inhere to the same entity or substratum. So, we have to think of labelable space-time points. These, though, should in turn be conceived as substantial individuals, for reducing them structurally would reiterate the problem. OSR's rejection of the very idea of a basic particular, implies, in addition, that *defining and identifying these properties, constituting the whole of reality, is already a problem* for the radical structuralist. If 'particles' are interpreted as excitations in a quantum field, since excitations are events, and events are particulars, the proposed interpretation is far from doing away with individuality.[52] *What constitutes the individuality of an instance of structure?* If instances of structure are no less particular than the objects OSR seeks to replace, it seems that, instead of solving a problem, OSR multiplies it![53]

How can, then, properties actually be autonomous and self-sufficient, and objects be identified, in a strictly structuralist framework?

To all this, I think, French and Ladyman would reply by clarifying that they don't reject the concept of individuality altogether but only the ontology of individual fundamental entities. That is, by saying that what the theory identifies – via mathematical tools – is a set of invariant properties upon which we can, if we want, build at a later stage an individual-based metaphysics (remember the underdetermination between the two 'metaphysical packages'). Nevertheless, I think more should be said about this, as one thing is identifying something invariant in a group, another thing localising its concrete counterpart. It appears to me that OSR can't perform the second task and is, consequently, unable to construct the whole of reality upon structures alone. That is, even if we take for granted that QFT should be underpinned by a strongly structural ontology, the latter seems in fact very difficult to come up with.

Last but not least, OSR should clarify the relations between the mathematical structures which appear in the theories and which are what is preserved in the history of science, and the physical structures they are taken to represent. French and Ladyman seem to assert both that the boundary between the two is somewhat blurred and that they are clearly distinguishable, with the former being more or less directly isomorphic to the latter. Leaving alone some confusion existing in their position on this point, while we can agree on the idea of a direct relation between the mathematical and the concrete – as this is, I believe, the very basis for structural realism and, consequently, constitutes a building block for ESR as well – it is true, on the other hand, that examining closely the relation between the two levels emphasises further the limits of OSR.

Cao, for example, argues that physical structures are not autonomous and cannot easily and straightforwardly be reduced to mathematical ones. The latter, he says, cannot represent qualitative features and, in general, need an interpretation. In order to fulfil this need we have to move to concrete structures. These are characterised by structuring laws that govern the behaviour of *constituents whose existence has to be ontologically presumed as that of irreducible tangible individuals*.[54]

From the points summarised in this section, therefore, more conceptual difficulties for a purely structural account of the physical world emerge very clearly. We can accept the idea that our current conceptual (metaphysical) schemes are by no means necessary and unique. But as long as a logic, a semantics and a metaphysics of pure structures will not be convincingly developed it seems legitimate, and indeed quite sensible, to prefer the traditional picture of reality.

4. CONCLUSIONS: UNDERDETERMINATION AND THE ADVANTAGES OF ESR

We have shown that evidence from quantum mechanics is not conclusive in favour of OSR. As a matter of fact, it cannot even be taken, as French and Ladyman argue, as lending strong support to the project of a structural redescription of our ontology as the best choice to be made in order to accommodate the conceptual problems that we get once we attempt to provide a coherent and exhaustive description of the microscopic world.

I believe most of the apparent strength of OSR derives from an ambiguity existing on the very point of underdetermination. Claiming that basically all the forms of metaphysical underdetermination related to quantum mechanics push towards OSR is quite incorrect. True, strong structuralism could seem to dissolve the problems stemming from the necessity of choosing a specific metaphysical package in relation to *individuality*. Nevertheless, even if we adopt it, structuralists still have to explain how to describe *reality and its basic constituents*, which is another matter. By no means, given the underdetermination concerning individuality, radical structuralism can be straightforwardly presented as the necessary or most commendable choice.

It is my opinion, rather, that further elaboration of the issue of how to interpret the new evidence stemming from quantum mechanics as regards the nature of individuality can only push us exactly towards ESR.

On the one hand, I have tried to show that the underdetermination is not so radical and traditional individuality might be preserved (see the discussion of PII, TI, quasi-individuality and Bohmian theories). On the other, I argued that I) we can't make the move from the epistemic underdetermination to radical structuralism as an ontological position unless we make a contentious naïve empiricist move; and that II) if we want to do it, anyway, we don't have at present the means to build a coherent and consistent purely structural ontology. Therefore, why not apply a sceptical *epochè* in relation to ontology and go for ESR?

As suggested in Section 1, the proper interpretation of ESR is, I believe, exactly that according to which we are rationally entitled to believe in some level of preservation of structures (more or less faithfully representing reality) in the history of science but, considering the uncertainty existing at the level of our tentative ontological description of the universe, we should be 'agnostic' about what exists beyond those structures. That is, ESR is better conceived as a position according to which *there could be* something more beyond structures than as one which asserts that *there surely is* something, but we cannot know it. We simply assume that there actually is something, and that it has to be described in the terms of classical, individual-based ontology, because such ontology is well-established and works. In other words, while OSR has to come up with truly persuasive arguments, ESR just needs to trust our well-established intuitive categories and that conclusive arguments against them not be given.[55]

So conceived, ESR seems to be the best choice for the realist as soon as we realise that such a strong claim as that underpinning OSR should be supported by equally strong arguments and evidence which, as a matter of fact, as I tried to show in the present paper, do not exist at the moment.

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NOTES

[1] ‘Traditional ontology’ is intended here as the Aristotelian, common sense one, dominant for the last twenty centuries, according to which reality is composed of individual objects with intrinsic properties and relations are derivative. As we will see, ontic structural realism challenges this assumption and suggests that relations are primary.

[2] Which is called by Duhem the ‘explanatory’ part of the theory.

[3] Some authors, like Redhead (2001) believe that structures are to be intended as abstract higher-order ones, while others, mainly Chakravartty (1998, and recent unpublished work), argue that we can be realist about concrete structures, directly related to physical properties. Even though I tend to be more sympathetic with the latter approach, I will not get into this issue here.

[4] This distinction is due to Ladyman. It first appears in his (1998), where he defines OSR ‘metaphysical structural realism’; Van Fraassen speaks of ‘moderate structuralism’ and ‘radical structuralism’/‘reification’ – see Van Fraassen (1999).

[5] See Poincaré (1902).

[6] Van Fraassen’s constructive empiricism is based upon the strong assumption that theories are to be held as true only insofar as they ‘save the phenomena’, that is, explain the observable evidence. Once we get to the theoretical level “to have even a sketch of one interpretation is valuable and brings understanding. To appreciate, however dimly, its horizon of alternative possible interpretations brings more insight. There cannot be in principle, but only as historical accident, convergence to a single story about the world” (1991, 481–482). This is a challenge to which the realist has to reply, as it questions the abductive reasoning (presenting realism as the best available explanation of the ‘convergence to a single story’) which is a fundamental instrument for the realist. Anyway, I will not try to do it here, since it would exceed the scope of the present paper. For the time being we are more or less assuming the realist perspective. I will just point out that it seems to me that Van Fraassen’s criticism of abduction is more problematic than the arguments for antirealism from the alleged equivalence of different descriptions of the quantum world that French takes as requiring us to choose between anti-realism and OSR. As a matter of fact, I don’t think the latter arguments actually imply such choice: it is exactly in this spirit that I will argue for the preferability of ESR.

[7] Namely, what belongs to the ‘explanatory’ level, in the sense, introduced above, intended by Duhem.

[8] It is customary to use the equality symbol (=) to mean that two things are identical. I will stick to this tradition here, but I think it would be better, and it would clarify many ambiguities existing (as we well see) in relation to PII, to distinguish equality in some respect and strong (numerical) identity by using the specific symbol ($\equiv$) expressing the latter concept when referring to it.

[9] Which, anyway, Leibiniz seems to have held to be impossible.

[10] See Wiggins (2001, 61–63).

[11] Russell (1940, 127), for example, stated that he saw no reason to talk of two things if one is not acquainted with (at least) one distinguishing (empirical) property owned by one of them but not by the other.

[12] All we are entitled to do is to distinguish, on the basis of the particles’ statistical behaviour, between fermions, particles with non-integer spin and forming systems with antisymmetric wave functions, and bosons, with integer spin and symmetric wave functions. The accessible states are, respectively, $|r>_1|r>_2$, $|s>_1|s>_2$ and $1/\sqrt{2}[|r>_1|s>_2 + |s>_1|r>_2]$

for bosons and $1/\sqrt{2}[|r>_1|s>_2 - s>_1|r>_2]$ for fermions, where r and s are two exclusive and exhaustive values of any observable.

[13] The state-independent properties are the same by definition: for example, two electrons will always have exactly the same charge and the same mass.

[14] The modification of PII to the extent that probabilities are considered instead of exact values seems justified by the very nature of quantum mechanics. Indeed, it is commonly held that probabilities are objective at the quantum level and do not merely express our ignorance. However, more will be said about this in a following section, concerning hidden variables interpretations.

[15] French and Redhead (1988, 239–242).

[16] Paraparticles are particles which obey a specific type of quantum statistics which includes, but generalises, the ordinary Fermi-Dirac and Bose-Einstein statistics. Paraparticles are allowed in local relativistic quantum field theory but have not yet been experimentally discovered.

[17] French and Redhead (1988, 242).

[18] French and Redhead (1988, 235).

[19] An excellent analysis of the relation of thisness to the PII is made by Adams (1979).

[20] See French (2000, 2001, 2003). French and Ladyman (forthcoming) is also interesting in this connection.

[21] Moore, between others, simply rejected the principle as evidently “not true” (1922, 307).

[22] PII does not even seem to be one single principle. It rather looks like a ‘principle-schema’ which can change depending on the conceptual assumptions on the basis of which we formulate it and include/exclude properties in/from the range of its universal quantifier.

[23] Obviously, attributing primitive thisness to the space-time points themselves would only reiterate the problem.

[24] Loux (1978, 138), italics mine.

[25] Bohm and Hiley (1993, 154).

[26] For some ‘classical’ works on the alleged consequences of PII for quantum mechanics, see Cortes (1976), Barnette (1978), Ginsberg (1981) and Teller (1983). See also Castellani and Mittelstaedt (2000) and Hilborn and Yuca (2002) for more recent studies.

[27] S is the pseudo-classical field, determining the particles’ momenta according to $p = \nabla S(x)$. R is a further new parameter for which $\Psi = R \exp(iS/\hbar)$ and $P(x) = R^2(x) = |\Psi(x)|^2$ (the basic distribution postulate of Bohm’s theory).

[28] And momentum, but this is less important in the present context.

[29] Bohm and Hiley (1993, 29). The combined system of particle and field is what is causally determined, as the wave-field carries ‘active information’ which influences the particle.

[30] Bohm and Hiley (1993, 105).

[31] Of course, a narrow empiricist interpretation of PII would still conclude that the two particles are identical, for Bohm and Hiley acknowledge that we might not practically distinguish them from each other. But remember the passages above in which I argued that a radical, narrow empiricism is unconvincing and that one needs to link PII to our actual well-established theories in a ‘milder’ way.

[32] PSM is the fundamental Postulate of Statistical Mechanics, giving equal a priori possibilities to any of the possible microstate configurations compatible with a given macrostate. Assuming it, and the Symmetrization Postulate according to which any many-particle system of identical particles is either totally symmetric or totally antisymmetric, while

PSM+statistical indistinguishability Bose-Einstein statistics and PSM + statistical indistinguishability + Pauli's exclusion principle Fermi-Dirac statistics – see Belousek (2000, 5) – the same usual quantum statistics can be obtained from *random a priori probability distributions plus statistical distinguishability* (and the exclusion principle) – see Belousek (2000, 12).

33 Which allow Bohmian interpretations to satisfy the requirements put forward by, respectively, Kochen and Specker's paradox and Bell's inequalities.

34 The talk of self-identity reintroduces the concept of transcendental individuality. A further examination of this concept will be the subject of the next section.

35 Italics mine.

36 Obviously, French and Ladyman need something stronger than the fact that two particles *can* be indistinguishable at times or the fact that a particle can happen to lack criteria of identification. What they need is a proof that this *invariably* happens in the quantum world.

37 See Loux 1978, especially Chap. 9.

38 Which seems the natural choice for the supporters of a pure structuralist ontology, as they do away with individuals as property-bearers and reduce reality to the properties which science allegedly gets to know. It's worth distinguishing bundle theories, which, as argued for example by Russell, reduce objects to set of compresent properties, from trope theories, which deny that properties are instances of universals and define them as individuals (there are as many, say, 'rednesses' as the number of exemplifications of red things). Usually, bundle theories are formulated in terms of properties as tropes but this does not seem to be a necessity.

39 Italics mine.

40 As pointed out to me by an anonymous referee, one has to bear in mind the difference between essential properties and intrinsic properties. To give an example, for particles spin is intrinsic, but only its magnitude is essential. Note that Loux refers to the essential properties of the basic individual constituents and Lowe to intrinsic ones in the passages quoted above.

41 Italics mine.

42 Loux refers to passages such as those in the *Categories*, 5 and in *Metaphysics*, books Z and H.

43 Such an ontological conception (microparticles provided with self-identity and individuality as the fundamental, ungrounded and not further analysable constituents of reality) seems to be that underpinning the causal ontological interpretation of quantum mechanics, proposed by Bohm, which we examined earlier.

44 Is according to one of these two options that we have to explain the concept of 'local' field.

45 See Auyang (1995, esp. Chaps. 4, 5 and 6; and 2001). On quantum field theory in general (and for the idea that it forces us to abandon the concept of classical particle in favour of a new idea of 'quantum'), see Teller (1995, esp. Chap. 2).

46 This is part of a generalised criticism which Cao addresses to OSR on the basis of the idea that confusion is made between mathematical and physical structures. See Cao (2003). The autonomy of a purely structural account once we analyse the relations between the mathematical formalism and the concrete causal physical structures will be examined in the next section.

47 After having pointed out, while commenting Quine's structuralism based upon set theory, that "the real world is not merely structural: it has qualitative content". See Simons (2000, 38).

[48] And that related to the possibilty for bundle of trope theories to explain individuation and sameness in time, which has been put in doubt by some commentators, but which can probably be done by recurring to some concept of persistence of (essential?) properties.

[49] This point is insistently made by Stathis Psillos. See, for example, Psillos (1995, 1999).

[50] See, for example, Krause (1992).

[51] This idea has been proposed recently. See French (2002).

[52] It seems then that not even a Davidsonian event ontology, mentioned above, could help here.

[53] These remarks are suggested by recent still unpublished work by Anjan Chakravartty.

[54] We see now clearly the point Cao makes in connection to the nature of fields: even if we take for granted that they are completely describable structurally, as soon as we move from the theory to the 'real world' we immediately realise that something over and above structures is needed. A substance account of reality like that suggested in Section 3.4 seems to be what Cao has in mind.

[55] Even if they were, it should still be demonstrated that one specific ontology is to be preferred and that it allows one to know more than structure. If this was not the case, clearly ESR would remain the best option.

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