Towards a Structuralist Elimination of Properties

Valia Allori[1]

Abstract

Scientific realists investigate the ontology of the world and explain the observed phenomena by using our best fundamental physical theories. These theories describe the behavior of fundamental objects in terms of their fundamental properties, which determine their behavior. This paper is the natural companion of another paper in which I propose an alternative to this traditional account of metaphysics, according to which fundamental objects have no other fundamental property than the one needed to specify their nature. In that paper I argue that my view fares better than the traditional metaphysics both in the classical and in the quantum domain. In this paper I compare my view to structuralism. After discussing how my proposal shares many motivations with structuralism, I argue in which ways I think it is superior.

1. Introduction

In discussions about ontology, traditionally one talks about objects and their properties: objects live in three-dimensional space and change in time according to suitable laws of nature. In naturalized metaphysics, following the tradition of scientific realism, the nature of these objects and laws is given by our best fundamental physical theories. In a classical world one has point-like particles (or particles and fields, if we include electromagnetic phenomena). Their temporal evolution is determined by laws of nature like the Newtonian law of gravitation or Maxwell's electromagnetic equations. Particles come into families: electrons, protons, and so on, identified by their intrinsic properties of mass and charge. A distinctive feature of this understanding is that different families move differently under the same circumstances because their properties are different. This traditional approach is therefore an *object-oriented metaphysics grounded on properties.* In a previous article, I have proposed instead a *thin object-oriented metaphysics grounded on structure* based on the idea that fundamental objects have no intrinsic properties *other than* the ones necessary to identify their nature. That is, assuming the world is made of particles, they merely have the property of being localized in space, but they have no additional properties such as mass or charge. Conversely, laws are effectively instantiated multiple times. Therefore, an electron in a magnetic field turning the opposite way of a proton is not explained in term of their opposite charges but in terms of them following distinct 'effective' laws. In my previous paper I have argued that this approach is better than the traditional view. In this article, which is a continuation of my previous work, I first review my approach in section 2, then I compare it with

[1] Department of Philosophy, Northern Illinois University, Zulauf Hall 915, Dekalb IL 60540 USA vallori@niu.edu

(ontic) structuralism. In this approach structure is fundamental, and symmetries play a crucial role. As such, it constitutes a *structure-oriented metaphysics based on symmetries*. In section 3, I argue that my approach and structuralism share many motivations. However, I conclude that my view is to be preferred as it is less problematical in several respects.

2. A New Take on Naturalized Metaphysics

Scientific realists assume that scientific theories are approximately true and use them to investigate questions about the nature of reality. Thus, they engage in naturalized metaphysics: they look at scientific theories to individuate the nature of fundamental entities, their properties, and the laws governing their motion.

2.1. The Traditional View: Thick Object-Oriented Metaphysics Grounded on Properties

Metaphysicians disagree about the nature of the objects that exist in the world (particles, fields, or else). They also disagree about the nature of laws governing their behavior (supervenient over the objects, or not), about the nature of their properties (dispositional or categorical properties), as well as the nature of space (fundamental or emergent). However, most share the common understanding that objects behave differently due to their properties. I have called this the *traditional view*.[2] It can be tracked back to Aristotle, and one of its modern proponents is David Lewis: at the fundamental level, the world is a 'mosaic' of "local, particular matters of fact."[3] For instance, he would say that in a world governed by classical electromagnetism there are point-particles obeying Newton's law, and electromagnetic fields, whose intensity changes from point to point as dictated by Maxwell's laws. Fundamental properties are introduced to account for the objects' different behavior under the same circumstances: two particles accelerate differently in an electromagnetic field because they have different charges. In this sense objects are *thick*: they are 'dressed up' with properties. Consequently, there are families of objects: 'electrons' are particles with negative charge, 'protons' are particles with positive charge, and so on. There is *one fundamental law, and many fundamental properties:* there are many families (electrons, protons, and so on) of the same kind of fundamental entities (particles).

2.2. Objections

The traditional approach seems the natural approach at least until one considers the quantum domain. What are the quantum objects, and what are their properties? As for the first question, it is not clear what the ontology of the theory is. One possibility,

[2] Allori (forthcoming).
[3] Lewis (1986).

dubbed *wavefunction realism*,[4] is to think of quantum mechanics as a theory about the wavefunction, as it is the main mathematical object on the theory. However, the wavefunction, unlike electromagnetic fields which are in three-dimensional space, represents a wave in configuration space, which is a high-dimensional space. Accordingly, wavefunction realists argue that the three-dimensional objects of our experience are emergent or derivative.[5] An alternative to wavefunction realism is the *primitive ontology* approach,[6] according to which the ontology is some three-dimensional entity instead. In contrast with wavefunction realism, this approach preserves most of the classical explanatory schema in terms of compositionality and reductionism: macroscopic objects are composed of the three-dimensional microscopic entities represented by the primitive ontology. The main challenge to this approach is that it is unclear what wavefunction is. There are various proposals,[7] the best of which is, I think, to understand the wavefunction structurally.[8]

Moreover, new intrinsic properties such as spin have been introduced in quantum theory to account for new experimental results. However, they are very different from classical properties, as they are *contextual:* their value depends on the experiment performed to measure them.

How does the traditional view fare in the quantum domain? As I have previously argued,[9] the traditional account is not a good fit for wavefunction realism. In fact, this view requires a substantial revision of the traditional view's explanation based on properties, even without considering spin. Property talk is fictional: useful, but not fundamental. In contrast, being based on a three-dimensional reductionist explanatory schema, the traditional view *may* still be viable for the primitive ontology approach.

---

[4] See Albert and Ney (2013), and then most notably Albert (1996, 2015), Lewis (2004, 2005, 2006, 2013), Ney (2012, 2013, 2015, 2017, 2021), North (2013).

[5] In one approach, macroscopic objects can be functionally defined in terms of their role (Albert 2015). In another approach three-dimensional objects exists as derivative when considering symmetry properties as fundamental facts about the world (Ney 2021).

[6] Dürr, Goldstein, Zanghì (1992), Allori *et al.* (2008), Allori (2013 a, b, 2015 a, b, 2019) and references therein.

[7] Some have argued it is a property of matter (Monton 2002, Lewis 2013, Solé 2013, Esfeld *et al.* 2014, Suàrez 2015). Another approach is to take the wavefunction as a law (see Goldstein and Zanghì 2103, Allori 2018, and references therein for a discussion), which seems particularly fitting to the Humean account of laws (Esfeld 2014, Callender 2015, Miller 2014, Bhogal and Perry 2017). For antirealism about the wavefunction see Healey (2012).

[8] This view has been defended in Allori (2021 b). Another structuralist perspective has also been defended by Lewis (2020), who writes: "the wave function describes the structure instantiated by whatever fundamental entities there may be in ordinary three-dimensional space: particles, fields, flashes, mass density, or something else entirely. A structure is not in itself an object, but rather a way that objects relate to each other."

[9] Allori (forthcoming).

However, there are other, more general, reasons to prefer an alternative view, which I briefly summarize in the next subsection.

2.3. Fundamental Entities without Fundamental Properties: Thin Objects-Oriented Metaphysics Grounded on Structure

The basic idea is that there are fundamental objects, but they have *no property other than the one uniquely characterizing their nature*. Thus, objects are 'thin.' For instance, the only property possessed by particles is their location. The only property possessed by fields is the set of their intensity values. In contrast with the traditional account, therefore, there are no different families of the fundamental entity that constitute matter, and all fundamental entities are *identical*, as far as (non-spatiotemporal) properties are concerned. In this framework the observed different behavior of particles *appearing* to belong to different families is accounted for in terms of laws of nature: fundamental entities behave differently in the same situation because they are *governed by different effective laws*. There is one effective law for what appears to be a different family in the traditional approach. In their mathematical formulation, laws include constants, like the gravitational constant, and parameters describing properties, like masses and chargers. In the traditional approach the constants are part of the definition of the *law*, while the parameters are part of the definition of *matter*: constants remain identical independently of the object the law applies to, while masses do not. In my view instead, the parameters are *part of the definition of the law* too. Thus, a single law 'splits' into a number of effective laws, characterized by the relevant parameters, one for each particle family of the traditional view.[10] Thus, the main idea is the opposite of the traditional view: there one would minimize the number of laws to maximize the number of properties while here we *minimize the number of properties, allowing for as many effective laws of nature as needed to make the theory empirically adequate.* The laws and the effective laws are naturally seen as a *structure*, a network of relations, *grounded on thin objects.*

The nature of the objects and the form laws have an interesting connection with symmetry properties of the theory, which in my approach are symmetries of the objects, not the structure. First, if one cares about theories having symmetries, one should not allow certain entities to be though as fundamental. For instance, the wavefunction thought of as a fundamental object makes nonrelativistic quantum mechanics no longer

---

[10] For example, in case of a gravitational field, there is one effective law for the 'electron,' $Eff\ law_1 = \frac{H_1}{r^2}$, where $H_1 = Gm_eM$, one for the 'proton,' $Eff\ law_2 = \frac{H_2}{r^2}$, where $H_2 = Gm_pM$, and one for the 'neutron,' $Eff\ law_3 = \frac{H_3}{r^2}$, where $H_3 = Gm_nM$ (where G is the gravitational constant, m_e, m_p, and m_n are respectively the mass of the electron, proton and neutron as traditionally intended, while M is the reference mass, and r is the distance between the reference particle and the one under examination). See Allori (forthcoming) for more details.

Galilei invariant.[11] Moreover, the form of the law of nature is constrained by symmetry considerations: for instance, in the pilot-wave theory, the law for the particles is chosen as the simplest equation which allows for the theory to be Galilei and time-reversal invariant.[12]

To summarize, in my view we have *thin objects*, individuated by their only natural property, namely by the property that uniquely characterizes their nature. Then the law of nature determines how they evolve in time. For the theory to be empirically adequate, the law has to break down into a set of effective laws, each of which applies to a subset of the set of fundamental objects. The laws and the effective laws are naturally seen as a *structure*, a network of relations, *grounded on thin objects.* Moreover, *symmetries* constrain the possible nature of the fundamental objects, and the form of the laws.

2.4. Advantages and Replies to Objections

As I argued in my companion paper, this view extends nicely to the quantum domain, regardless of whether one endorses the primitive ontology approach or wavefunction realism. In fact, in the primitive ontology approach the primitive ontology represents objects, while the wavefunction relates the location of the objects at different times. Moreover, since in wavefunction realism property talk is completely fictional, the derived three-dimensional objects are thin: they have no fundamental property. Wavefunction realism is doubly structural: the structure of the wavefunction allows for the derivation of three-dimensional objects, and it explains the objects' behavior by connecting their locations at different times.

Aside from extending to the quantum domain, my approach also by-passes the debate over the nature of properties, as it focuses on laws.

Also, it is more parsimonious than the traditional view, given that it has an ontology of objects and laws, rather than objects, laws and properties. In this sense, even if it is compatible with other views, my approach may be seen as a natural extension of Humeanism, since it provides the best combination of simplicity and strength.[13]

Moreover, it is more explanatory than the traditional view, as it has less things to account for, like for example the values of the masses of the fundamental particles. In addition, in the framework of classical electrodynamics, my account makes sense of certain asymmetries between particles and fields, like the fact that particles have properties and fields do not.

---

[11] Allori (2018). See also Allori (2015 c, 2019 b, 2021 a) for an argument that electromagnetic fields cannot be thought as fundamental objects otherwise they either would transform at odds with their nature, or we should stop thinking of classical electrodynamics as time-reversal invariant..

[12] Dürr, Goldstein, and Zanghì (1992).

[13] See Esfeld (2014) for a similar argument for his super Humeanism. See also Hall (2015).

Another consideration is that we observe objects that move, not their properties: we see positions that change; we do not see masses, charges, or spin. Furthermore, the problematic contextuality of spin in quantum mechanics goes away, because there is no spin property.
Here are some possible objections.[14] First, this view seems unnecessarily radical, as properties are essential to explanation. However, this is not so: properties add a mysterious ontological category, while their explanatory role can be taken over by the laws. In addition, one may think that the way in which an object 'pairs up' with its effective law is mysterious. Nonetheless, this is merely using a different primitive: while in the traditional view it is a primitive fact that positive charge will result in 'going left' in a given magnetic field, here it is a primitive fact that that effective laws act as they do on the various objects.

3. Structuralism

I have used the word 'structure' to describe my view. However, the dominant metaphysical approach invoking the notion of structure is structural realism (structuralism). In this section I compare these two frameworks. Structuralism is a realist approach partly motivated by the development of quantum theory. Nonetheless, an early version of structuralism was proposed in response to the pessimistic meta-induction argument. This goes after the 'no-miracle' argument for realism: the best explanation for the success of our best theories is their truth, otherwise their success would be a miracle. The pessimistic meta-induction argument states that success is no indication of truth, as some past false theory were successful. In response, if one can show that the entities that are retained in moving from one theory to the next are the ones that are responsible for the empirical success of the theory, then the previous argument is blocked. Structuralists notice that what carries over in theory change is the mathematical structure of the theory.[15] Arguably, one could limit structuralism to epistemology: there are objects and structure, but we can only know about structure. However, other types of structuralism are ontic: they maintain that there is only structure. In this paper I focus on ontic approaches.[16] In particular, I discuss two such views. One is radical structuralism, or *eliminativism*[17] which claims that there are no objects, only relational structures. Another is the so-called *moderate structuralism* according to which, contrary to eliminativism, both objects and relations among them exist but, contrary to the traditional view, objects cannot exist independently on the

[14] For more details of this view, its objections and motivations, see Allori (forthcoming).
[15] Worrall (1989).
[16] Therefore, whenever I write 'structuralism' in the rest of the paper, I mean 'ontic structuralism.'
[17] See Ladyman (1998), French and Ladyman (2003), Ladyman and Ross (2007), French (2010, 2014) and references therein.

structure they are related by.[18] Objects are only characterized by the relations in which they stand, and these relational properties constitute the way the objects can be.[19] While initially the view stated that objects do not possess any intrinsic property, in reply to criticisms it was later amended to include them.[20]

3.1. Arguments from Quantum Mechanics and Other Motivations

One underlying principle that supports structuralism is that we are not justified in postulating the existence of something whose existence cannot be known. This coherence between epistemology and metaphysics leads the structuralist to consider all cases of underdetermination as evidence for their views. This type of argument has been put forward first in quantum theory, but later applied to relativity as well. The idea is that quantum statistics suggest that it is underdetermined whether quantum objects are individuals (i.e., have intrinsic properties) or not, from which eliminativists conclude there is only structure.[21] Similar arguments are based on symmetries and the corresponding invariances,[22] and on the existence of multiple empirically equivalent mathematical formulations of the same theory.[23]

Another argument for structuralism focuses on entanglement. In quantum mechanics, the sub-systems composing an entangled system have no individual wavefunction, and thus they have no intrinsic properties. Therefore, structuralists think they are best understood as *relata* of a common, entanglement structure.[24]

Another argument from quantum mechanics comes from the failure of Humean supervenience, given that the wavefunction is nonlocal, being in configuration space.[25]

---

[18] This view is defended most notably defended by Esfeld (2004) and refined in Esfeld and Lam (2008, 2010, 2012).

[19] This view is inspired by Heil (2007) and Strawson (2008), who argue that the intrinsic properties of an object are the ways that object can be. See also Armstrong (1998).

[20] Esfeld and Lam (2010).

[21] French (2014) and references therein. See Sauders (2006), French and Krause (2006), Muller and Saunders (2008), Ladyman and Bigaj (2010) for further discussion.

[22] Permutation invariance in many-particle quantum mechanics (Muller 2009), gauge diffeomorphism invariance in general theory of relativity (Rickles 2006, Esfeld and Lam 2008).

[23] See Bain (2006, 2009) in the context of the general theory of relativity; however, see Cao (2003), Pooley (2006).

[24] For instance, a singlet state of two entangled spin ½ sub-systems is in a definite spin state, namely 0, but neither of the sub-systems has a definite spin state on its own. As such, it is argued that these sub-systems are best understood as *relata* of the fundamental entanglement relation they stand in, in this case: 'has opposite spin to.' For more on this argument, see Esfeld (2004).

[25] See Teller (1986) for this argument. For discussion, see for instance Maudlin (2007), Ladyman and Ross (2007), Esfeld (2009), French (2014).

Structuralists argue that the nonlocal relations being instantiated by individuals has to be abandoned toward an ontology of structural relations.[26]

Structuralism is also motivated by ontological parsimony and simplicity of description: why postulate two categories (objects and relations), if one (relations) is enough? This is connected to another important aspect of structuralism: the relation between laws and properties.[27] Part of the traditional debate is between the defenders of categorical properties and the defenders of dispositional properties, without any consensus. Structuralists avoid this dilemma by assuming that laws supervene on the fundamental relations, and fundamental properties are emergent. French calls it 'reverse engineering:' while the Humeans take properties as fundamental and laws as emergent, the structuralist takes laws as primary and recovers properties from them.

3.2. Objections

The strongest charge against eliminativism is that it is unintelligible: relations cannot exist without *relata*.[28] However, one could reply assuming these relations are abstract universals, and we are wrong when we think that they need *relata* because they do when they are physically instantiated.[29] Alternatively, moderate structuralism has been proposed to respond to this charge, as the *relata* exist.[30]

In addition, many have complained that the relationship between structure and laws is insufficiently detailed.[31] Nonetheless, I believe the structuralist can overcome this objection taking structure as primitive, and then define laws as 'whatever determines the behavior of such structure.'

Moreover, structuralism seems to be unable to account for intrinsic properties like masses and charges.[32] This charge is address by using symmetries, to recover properties using suitable group representations.[33]

Then, people have objected that the structuralism is unable to account for causation.[34] However, one could simply maintain that in physics there is no room for causation,[35] or propose an account of causal structure.[36]

---

[26] Ladyman (1998), French and Ladyman (2003), Esfeld (2004).
[27] French (2014), and Esfeld (2014).
[28] See for instance Busch (2003), Cao (2003), Chakravartty (2003), Morganti (2004), Psillos (2006).
[29] Esfeld and Lam (2008).
[30] Esfeld (2004).
[31] Chakravartty (2007).
[32] Ainsworth (2010).
[33] See Castellani (1998) and references therein; see also Muller (2009). See Esfeld and Lam (2010) for criticisms.
[34] Psillos (2006).
[35] Russell (1912), Ladyman (2008).
[36] Esfeld (2009), Esfeld and Sachse (2011), chapter 2.

Finally, it has been maintained that structuralism does not defeat the pessimistic meta-induction argument.[37] In particular, it was argued that structuralism fails in the classical-to-quantum theory change: structuralists think that the wavefunction is the structure, but there is no classical analog for it, so how can structure be preserved?[38] This problem is not mitigated in moderate structuralism, given that objects and structure are ontologically at the same level.

3.3. Comparison between the Thin Objects View and Structuralism

The first similarity between my view and structuralism is that they both rely on the notion of structure, which is a network of relations: without *relata*, in the case of eliminativism, definitive of objects, in the case of moderate structuralism, and between thin objects in my case.

Both approaches also work well in the quantum domain, in contrast with the traditional view. At least partially, structuralism was motivated from the desire of understanding quantum theory. My account less so, but if we can make sense of the view that there are no genuine quantum properties like spin, then it also seems natural to extend this attitude into the classical framework and assume that what we called intrinsic properties (mass, charge) are part of the law.

Moreover, both approaches tend to consider the wavefunction as playing a secondary, perhaps instrumentalist role, even in different ways. French (2013) has argued that since it is underdetermined what the wavefunction is. However, this underdetermination can be broken by conceiving the wavefunction as being "constituted by the laws and the associated symmetry principles." Thus, since the wavefunction 'comes out' from the symmetries, it is defined in terms of the fundamental structure. In my view, instead, the wavefunction is part of the definition of the law. As such, in both approaches not only the wavefunction is not a material object but also it may not even be real. That is, unless one has a realist conception of laws, which however is not necessary in this approach. Indeed, both views do not have to commit to a particular account on the nature of laws. They are compatible with Humeanism: laws can still be imagined as the axioms and posits of our best theories. But primitivism or necessitarianism are also not *a priori* excluded.

Also, they both use simplicity as a guide to metaphysics. Structuralism eliminates objects in favor of structure, while I eliminate properties. However, these attitudes come to the same suspicion for properties, and the corresponding desire to have laws and symmetries do the modal, explanatory work. Different is the case of moderate

[37] Chakravartty (2004).

[38] Allori (2019 b).

structuralism that does not get rid of properties: the structure is constituted by the relational properties and by the intrinsic properties.[39]

A final point in common is the importance both approaches give to symmetries, even if in different ways. In my framework, the symmetries of the theory help identify the physical objects and constrain the form of the laws. In this way, thin objects together with symmetries generate the structure, namely the laws and the properties. In structuralism, however, symmetries are ontological prior to objects, so that the structure together with the symmetries generate the laws, the objects and the properties.

This leads directly to the main difference between the two views: my approach is still object-oriented, even if in my case objects are thin. So, in eliminativism we have structure, which through symmetries grounds thick-objects and their properties, while in my view we have thin objects which through symmetries ground the structural relations between thick-objects and their properties. In this sense, my approach is more in line with the traditional object-oriented metaphysics than eliminativism. Instead, both my view and moderate structuralism may be thought of as object-oriented. However, they are very different. In moderate structuralism, objects and structure are ontologically on the same footing: structure is a network of relational properties between objects, which are defined in terms of them. Objects may have intrinsic properties like mass or charge, but mainly they are defined in terms of the relations, which are the ways the object could be. In my view this is not so: there are spatiotemporal relations, but intrinsic properties and relational properties which account for the motion of objects (nomological relations) do not exist. In my view thin objects are 'interconnected' with one another by laws, not properties. Laws do not define objects and objects do not define laws.

3.4. Advantages of the Thin Objects View over Structuralism

To summarize, my view is structuralist: we have thin objects without intrinsic properties, and we have structures, intended as the nomological network needed for the objects to move. It is not an eliminativist view, given that there are objects. It is not a variety of moderate structuralism, as object and structure (in this case, the laws) are not ontologically on the same level: objects constitute matter, and laws either supervene (if Humeanism is true) or not on them, but do not define the objects.

Nonetheless, my approach can account for underdetermination and entanglement. In fact, in the example of quantum mechanics, the way the wavefunction evolves in time is irrelevant, as long as the law such wavefunction defines for matter remains the same. Since different wavefunctions may give rise to the same behavior for the objects, the wavefunction evolution is underdetermined. Nonetheless, in this context it does not pose a problem, since the wavefunction is not material. Rather, the underdetermination

[39] Esfeld and Lam (2010).

regarding objects is naturally broken, since the nature of the fundamental objects is postulated as the ontology that provides the simplest and most unifying explanation, constrained by symmetries. This understanding of the wavefunction is also helpful in accounting for entanglement. While the sub-systems of an entangled system do not possess their own wavefunction, in this framework this does not entail individuals described by the subsystems do not exist: the wavefunction does not describe matter, the thin objects do, and the dependence captured by entanglement is understood in terms of laws.

As discussed, eliminativism suffers from the problem of intelligibility: it makes no sense to say that relations exist without *relata*. Moderate structuralism postulates *relata* to avoid this problem, but immediately runs into another problem, namely properties. Indeed, this seems to go against one of the original motivations for structuralism against the traditional view, namely getting rid of properties. Instead, by adopting my approach one avoids the intelligibility objection against eliminativism because there are *relata*, the thin objects. Moreover, one avoids the mystery charge against properties in moderate structuralism, as instead of having properties and laws, one merely has laws.

As far as the pessimistic meta induction argument goes, in my approach if the nature of the object is preserved, then the problem is solved, otherwise it is not, but at least the wavefunction with its non-classical nature is not involved.

To conclude, I have argued that both my approach and structuralism share many motivations but overall, mine has less objections. So, if one is already convinced by the arguments put forward by the structuralists and that radical changes are needed, then one should endorse my view because it is less problematical.

4. Conclusion

In this paper, I have briefly described a view that provides an object-oriented structuralist alternative to the traditional object-oriented metaphysics. In my account there is only one kind of fundamental entity, it has no other fundamental property over and above its spatio-temporal ones. Then, there are structural relations between the fundamental objects, which can be seen as 'effective laws' and which are able to account for what we usually regard as different families of fundamental entities (like protons and electrons). I have argued that this account, in contrast with the traditional view, nicely extends to quantum physics, and captures the main ideas and motivations of structuralism, without falling pray of many of its objections.

References

- Ainsworth, Peter M. (2010): "What is Ontic Structural Realism?" *Studies in History and Philosophy of Modern Physics* 41: 50-57.
- Albert, David Z. (1996): "Elementary Quantum Metaphysics." In: J. Cushing, A. Fine, and S. Goldstein (eds.) *Bohmian Mechanics and Quantum Theory: An Appraisal*: 277-284. Kluwer.
- Albert, David, Z. (2015): *After Physics*. Harvard University Press.
- Albert, David Z. and Alyssa Ney (eds.) (2013): *The Wave-function: Essays in the Metaphysics of Quantum Mechanics*. Oxford University Press.
- Allori, Valia (2013a): "On the Metaphysics of Quantum Mechanics." In: S. Lebihan (ed.) *Precis de la Philosophie de la Physique*. Vuibert.
- Allori, Valia (2013b): "Primitive Ontology and the Structure of Fundamental Physical Theories." In: D. Albert, A. Ney (eds.) *The Wave-function: Essays in the Metaphysics of Quantum Mechanics:* 58-75. Oxford University Press.
- Allori, Valia (2015a): "Primitive Ontology in a Nutshell." *International Journal of Quantum Foundations* 1 (3): 107-122 (2015).
- Allori, Valia (2015b): "Quantum Mechanics and Paradigm Shifts." *Topoi* 32 (2): 313-323 (2015).
- Allori, Valia (2015c): "Maxwell's Paradox: Classical Electrodynamics and its Time Reversal Invariance." *Analytica* 1:1-19.
- Allori, Valia (2018a): "A New Argument for the Nomological Interpretation of the Wave Function: The Galilean Group and the Classical Limit of Nonrelativistic Quantum Mechanics." *International Studies in the Philosophy of Science* 31 (2): 177-188.
- Allori, Valia (2018b): "Primitive Ontology and Scientific Realism. Or: The Pessimistic Meta-Induction and the Nature of the Wave Function." *Lato Sensu: Revue de la Société de Philosophie des Sciences* 5 (1): 69-76 (2018).
- Allori, Valia (2019 a): "Scientific Realism without the Wave-Function: An Example of Naturalized Quantum Metaphysics." In: J. Saatsi, S. French (eds.) *Scientific Realism and the Quantum*. Oxford University Press.
- Allori, Valia (2019 b): "Quantum Mechanics, Time and Ontology" *Studies in History and Philosophy of Modern Physics* 66: 145-154 (2019).
- Allori Valia (forthcoming): "Fundamental Objects without Fundamental Properties: A Thin-object-orientated Metaphysics Grounded on Structure." In: D. Aerts, J. Arenhart, C. De Ronde and G. Sergioli (eds.), *Probing the Meaning and Structure of Quantum Mechanics.* World Scientific.
- Allori, Valia (2021 a): "Primitive Beable is not Local Ontology: On the Relation between Primitive Ontology and Local Beables." *Crítica5 3 (159): x-xx* (2021).
- Allori, Valia (2021 b): "Wave-Functionalism," *Synthese* (2021) https://doi.org/10.1007/s11229-021-03332-z
- Allori, Valia, Sheldon Goldstein, Roderich Tumulka, and Nino Zanghi (2008): "On the Common Structure of Bohmian Mechanics and the Ghirardi-Rimini-Weber Theory." *The British Journal for the Philosophy of Science* 59 (3): 353-389.
- Armstrong, David M. (1989): *Universals. An Opinionated Introduction*. Boulder (Colorado): Westview Press.
- Bain, Jonathan (2006): "Spacetime Structuralism." In: D. Dieks (ed.): *The Ontology of Spacetime:* 37-66. Amsterdam: Elsevier.
- Bain, Jonathan (2009): "Motivating Structural Realist Interpretations of Spacetime." Manuscript.

- Bhogal, Harjit, and Zee Perry (2017): "What the Humean Should Say About Entanglement." *Noûs* 1: 74-94.
- Busch, Jacob (2003): "What Structures Could Not Be." *International Studies in the Philosophy of Science* 17: 211-223.
- Callender, Craig (2015): "One World, One Beable." *Synthese* 192, 3153–3177.
- Cao, Tian Y. (2003): "Can we Dissolve Physical Entities into Mathematical Structure?' *Synthese* 136: 57-71.
- Castellani, Elena (1998): "Galilean Particles: An Example of Constitution of Objects." In: E. Castellani (ed.): *Interpreting Bodies: Classical and Quantum Objects in Modern Physics:* 181-194. Princeton: Princeton University Press.
- Chakravartty, Anjan (2003): "The Structuralist Conception of Objects." *Philosophy of Science* 70: 867-878.
- Chakravartty, Anjan (2004): "Structuralism as a Form of Scientific Realism." *International Studies in Philosophy of Science* 18: 151–171.
- Chakravartty, Anjan (2007): *A Metaphysics for Scientific Realism*. Cambridge University Press.
- Dürr, Detlef, Sheldon Goldstein, and Nino Zanghí (1992): "Quantum Equilibrium and the Origin of Absolute Uncertainty." *Journal of Statistical Physics* 67: 843-907.
- Esfeld, Michael A. (2004). "Quantum Entanglement and a Metaphysics of Relations." *Studies in History and Philosophy of Modern Physics*, 35: 601–617.
- Esfeld, Michael A. (2009): "The Modal Nature of Structures in Ontic Structural Realism." *International Studies in the Philosophy of Science* 23: 179-194.
- Esfeld, Michael A. (2014): "Quantum Humeanism, or: Physicalism without Properties." *The Philosophical Quarterly* 64: 453-470.
- Esfeld, Michael A., and Vincent Lam (2008): "Moderate Structural Realism about Space-time." *Synthese* 160: 27-46.
- Esfeld, Michael A., and Vincent Lam (2010): "Ontic Structural Realism as a Metaphysics of Objects." In A. Bokulich and P. Bokulich (eds.) *Scientific Structuralism*. Springer.
- Esfeld, Michael A., and Vincent Lam (2012): "The Structural Metaphysics of Quantum Theory and General Relativity." *Journal for General Philosophy of Science* 43(2): 243–258.
- Esfeld, Michael A., Dustin Lazarovici, Mario Huber, Mario, and Detlef Dürr (2014): "The Ontology of Bohmian Mechanics." *The British Journal for the Philosophy of Science*, 65, 773–796.
- Esfeld, Michael A., and Christian Sachse (2011): *Conservative Reductionism.* London: Routledge.
- French, Steven (2010): "The Interdependence of Objects, Structure, and Dependence." *Synthese* 175: 89–109.
- French, Steven (2013): "Whither Wave Function Realism?" In: D. Albert, A. Ney (eds.) *The Wave-function: Essays in the Metaphysics of Quantum Mechanics:* 76-90. Oxford University Press.
- French, Steven (2014): *The Structure of the World: Metaphysics and Representation*. Oxford University Press.
- French, Steven, and Decio Krause (2006): *Identity in Physics: A Historical, Philosophical and Formal Analysis*. Oxford University Press.
- French, Steven, and James Ladyman (2003): "Remodelling Structural Realism: Quantum Physics and the Metaphysics of Structure." *Synthese* 136: 31-56.
- Goldstein, Sheldon, and Nino Zanghì (2013): "Reality and the Role of the Wave-Function in Quantum Theory." In: D. Albert, A. Ney (eds.) "*The Wave-function: Essays in the Metaphysics of Quantum Mechanics*: 91-109. Oxford University Press.

- Hall, Ned (2015): "Humean Reductionism about Laws of Nature." In: B. Loewer, and J. Schaffer (eds.) *A Companion to David Lewis*: 262-277. John Wiley and Sons.
- Healey, Richard (2102): "Quantum Theory: A Pragmatist Approach." *British Journal for the Philosophy of Science* 63 (4):729-771.
- Heil, John (2003): *From an Ontological Point of View*. Oxford: Oxford University Press.
- Ladyman, James (1998): "What is Structural Realism?" *Studies in History and Philosophy of Science*. 29: 409-424.
- Ladyman, James (2008): "Structural Realism and the Relationship Between the Special Sciences and Physics." *Philosophy of Science* 75: 744-755.
- Ladyman, James and Bigaj, Tomasz F. (2010): "The Principle of the Identity of Indiscernibles and Quantum Mechanics." *Philosophy of Science* 77: 117-136.
- Ladyman, James and Ross, Don (2007): *Everything Must Go: Metaphysics Naturalized*. Oxford University Press.
- Lewis, David (1986): *Philosophical Papers*, Volume II. Oxford: Oxford University Press.
- Lewis, Peter J. (2004): "Life in Configuration Space." *The British Journal for the Philosophy of Science* 55: 713–729.
- Lewis, Peter J. (2005): "Interpreting Spontaneous Collapse Theories." *Studies in History and Philosophy of Modern Physics* 36: 165–180.
- Lewis, Peter J. (2006): "GRW: A Case Study in Quantum Ontology." *Philosophy Compass* 1: 224-244.
- Lewis, Peter J. (2013): "Dimension and Illusion." In: D. Albert and A. Ney (eds.) *The Wave-function: Essays in the Metaphysics of Quantum Mechanics*: 110-125. Oxford University Press: 110–125.
- Lewis, Peter J. (2020): "On Closing the Circle." In: V. Allori, A. Bassi, D. Dürr, and N. Zanghì, N. (eds.) *Do Wave Functions Jump? Perspectives on the Work of GianCarlo Ghirardi*: 121-132. Springer.
- Maudlin, Tim (2007): *The Metaphysics within Physics*. Oxford University Press.
- Miller, Elisabeth (2014): "Quantum Entanglement, Bohmian Mechanics, and Humean Supervenience." *Australasian Journal of Philosophy,* 92, 567-583.
- Monton, Bradley (2002): "Wave Function Ontology." *Synthese* 130: 265–277 (2002)
- Morganti, Matteo (2004): "On the Preferability of Epistemic Structural Realism." *Synthese* 142: 81-107.
- *Mu*ller, Fred A. (2009): "*Withering Away, Weakly*." *Synthese* 180 (2), 223-233.
- Muller, Fred A. and Saunders, Simon (2008): "Discerning Fermions." *British Journal for the Philosophy of Science* 59: 499-548.
- Ney, Alyssa (2012): "The Status of Our Ordinary Three-dimensions in a Quantum Universe." *Noûs* 46, 525–560.
- Ney, Alyssa (2013): "Ontological Reduction and the Wave-function Ontology." In: D. Albert and A. Ney (eds.) The Wave-function. New York: Oxford University Press, 168-183.
- Ney, Alyssa (2015): "Fundamental Physical Ontologies and the Constraint of Empirical Coherence." *Synthese*, 192(10), 3105–3124.
- Ney, Alyssa (2017): "Finding the World in the Wave-function: Some Strategies for Solving the Macro-object Problem." *Synthese* 1-23.
- Ney, Alyssa (2021): *Finding the World in the Wave Function*. Oxford University Press.
- North, Jill. (2013): "The Structure of the Quantum World." In Albert, David Z., and Ney, Alyssa (eds.) *The Wave-function: Essays in the Metaphysics of Quantum Mechanics*: 184–202. Oxford University Press.
- Pooley, Oliver (2006): "Points, Particles, and Structural Realism." In: D. Rickles, S. French and J. Saatsi (eds.): *The Structural Foundations of Quantum Gravity:* 83-120. Oxford: Oxford University Press.

- Psillos, Stathis (2006): “The Structure, the Whole Structure and Nothing but the Structure.” *Philosophy of Science* 73: 560-570.
- Rickles, Dean (2006): “Time and Structure in Canonical Gravity.” In: D. Rickles, S. French, and J. Saatsi (eds.): *The Structural Foundations of Quantum Gravity*: 152-195. Oxford: Oxford University Press.
- Russell, Bertrand (1912): “On the Notion of Cause.” *Proceedings of the Aristotelian Society* 13: 1-26.
- Saunders, Simon (2006): “Are Quantum Particles Objects?” *Analysis* 66: 52-63.
- Solé, Albert (2013): “Bohmian Mechanics without Wave Function Ontology.” *Studies in History and Philosophy of Modern Physics* 44: 365-378.
- Strawson, Galen (2008): “The Identity of the Categorical and the Dispositional.” *Analysis* 68: 271-282.
- Suarez, Mauricio (2015): “Bohmian Dispositions.” *Synthese*, 192 (10): 3203-3228.
- Teller, Paul (1986): “Relational Holism and Quantum Mechanics.” *British Journal for the Philosophy of Science* 37: 71-81.
- Worrall, John (1989) “Structural Realism: The Best of Both Worlds?” *Dialectica,* 43, 99–124.