6 Disentangling Nature's Joints

Tuomas E. Tahko

1. Introduction

In the neo-Aristotelian tradition, the category of substance is typically regarded as the most fundamental of the ontological categories. Substance is the starting point of neo-Aristotelian ontology, the root of being *qua* being.[1] The neo-Aristotelian can claim the support of common sense for this commitment to substance: the idea that there are such individual substances like people, cats, and trees is certainly part of everyday ontology. On the face of it, science might seem to support the view too, at least while we remain at a fairly high level of generality. As Hoffman and Rosenkrantz put it, a plausible understanding of 'thing' is just that it means 'individual substance'.[2] But it is well known that this type of common sense approach to ontology faces serious challenges from contemporary science and especially from those philosophers of science who defend *ontic structural realism*. A central tenet of this approach is exactly that science has shown the 'folk ontology' to be misleading, as nothing corresponding to the neo-Aristotelian substance can be found; every 'thing' must go.[3] Perhaps that's not exactly right. After all, even if the individual substances that we typically postulate have to go, there would still be one potential candidate: the world, the universe, the cosmos, the spacetime as a whole.[4] This would lead us towards some type of *monism*, an approach which is enjoying something of a revival, especially due to Jonathan Schaffer's influential work.[5]

How should the neo-Aristotelian friend of substance react to these developments? At the very least, the neo-Aristotelian should examine the relevant arguments. Some of the most influential arguments build on quantum theory and the phenomenon of *quantum entanglement* in particular. Examining these arguments and their consequences for the idea of substance is precisely what I will aim to do in what follows. The focus is on one of Schaffer's central arguments, which will be outlined in the second section. We will then proceed to look at the underlying science in some more detail in the third section and highlight some open questions, which put Schaffer's argument in new a light. It will become apparent that the upshot of Schaffer's argument, if successful, would be even more radical than it first seems, and this poses a challenge for the dialectic of the argument. In the fourth section, a reconciliation is sought and a novel way of understanding substance is proposed, where primitive incompatibility is introduced as a necessary condition for substancehood. Finally, in the fifth section, we will examine how primitive incompatibility might be traced to quantum ontology, with special attention to wave function realism.

2. Schaffer's Monism and the Argument from Entanglement

The type of monism that Schaffer defends is *priority monism*. This is a less radical view than monism understood as the view that exactly one thing exists, sometimes called *existence monism*, which Schaffer takes to be an uncharitable understanding of monism—he in fact refers to Hoffman and Rosenkrantz and associates this type of uncharitable approach with them.[6] Hoffman and Rosenkrantz write as follows:

> Monism [. . .] is inconsistent with something that appears to be an evident datum of experience, namely, that there is a plurality of things. We shall assume that a plurality of material things exists, and hence that monism is false.[7]

But recall that by 'thing', Hoffman and Rosenkrantz mean 'individual substance', whereas Schaffer's view is that there is exactly one *substance*, be it spacetime, the cosmos, or whatever we might want to call it.[8] For Schaffer, 'substance' is a fundamental entity[9], but Schaffer's monism does not deny that there could be other 'things' in the world, it's just that those 'things' are not (fundamental) substances, but rather mere arbitrary parts of the cosmos.[10] So, the view is that the cosmos, the integrated whole, is ontologically prior to these arbitrary parts.[11] Nevertheless, Schaffer thinks that there is exactly *one* substance and indeed exactly one 'thing', if 'thing' is understood to refer to substances: material objects are not a second, distinct kind of substance.[12] To be clear: Schaffer is not denying that there is a plurality of *dependent* 'things', but for him these 'things' cannot be substances, because substances are fundamental entities. Yet, the type of pluralism that, e.g., Hoffman and Rosenkrantz favour, requires that individual substances are not dependent on the cosmos in Schaffer's sense: they are to be regarded as ontologically independent.[13] In fact, Hoffman and Rosenkrantz note that Aristotle's view was precisely that individual substances are fundamental and everything else depends on them, not vice versa.[14] So on this view, pluralism about 'things' is a pluralism about the *fundamental* 'things' and hence in direct opposition to Schaffer's view.

Leaving aside these complications, we can proceed to what is clearly supposed to be one of Schaffer's central arguments for priority monism: the argument from *quantum holism*. We can approach the idea via Quantum Field Theory (or Theories) (QFT), as Schaffer himself does.[15] QFT is sometimes presented as if it is a natural ally for the monist, since it paints a picture of the cosmos as one consisting of *fields* rather than particles. This may seem like an immediate challenge for the pluralist, because if the material things that we typically associate with individual substances are just something like excitations of an underlying field,[16] then they would seem to be only an idealization, not something with sharp *boundaries*.[17] It should be noted that this may be a bit of a simplification, since there could be more than one fundamental field. Moreover, one might question the assumption that QFT is a fundamental theory.[18] It is often thought that some quantum theory is true and universal, and hence, all fields would be quantum fields.[19] In any case, there is little doubt that this type of view—that modern science and QFTs in particular should drive us to abandon pluralism about individual substances—is present in physics, and perhaps even more widespread among philosophers of physics. Schaffer himself mentions several examples, such as H. Dieter Zeh, who claims that the formalism of QFT has always suggested that we ought to abandon the 'primordial particle concept' and replace it with fields.[20] So Schaffer's argument has at least some support among the practicing scientists—we will return to this in the next section. What is the actual argument, though? It proceeds from the phenomenon of quantum entanglement to quantum holism and then straightforwardly to priority monism.[21] Here is a reconstruction:[22]

1. The quantum state of an entangled system contains information over and above the information carried by the quantum states of its components.
2. The cosmos forms one vast, entangled system.
3. Entangled systems are fundamental wholes.
4. The cosmos is a fundamental whole.

Premise 2 requires further support. Schaffer suggests that it can be supported by physics or mathematics.[23] Firstly, if the world begins with the Big Bang, where everything interacts, this initial state of entanglement is preserved if we assume that the world evolves in a linear fashion, e.g., in terms of Schrödinger's equation. Secondly, if we assume that there is a universal wave function, then 'it is virtually certain that it will be entangled since measure 1 of all wave-functions are entangled'.[24] Now, it is worth noting, as Schaffer does, that these reasons in favour of premise 2 are only plausible if wave function collapse is ruled out as a form of the universe's evolution. This clearly rules out collapse approaches to quantum theory, but since Schaffer is quite aware of these limitations, I will set them aside as well (although we will refer to collapse approaches later on).[25] So let us assume that premise 2 is true.

What about premise 3? Schaffer argues that 'Democritean pluralism'—the idea that there are particles that have intrinsic physical properties and stand in external spatiotemporal relations—cannot account for properties of the entangled system. In fact, this idea is already implicit in premise 1 (which Schaffer himself does not list as a separate premise). The idea is that the entangled system is 'emergent' and cannot be reduced to its proper parts: 'The physical properties of the whole are not fixed by the total intrinsic properties of any subsystems'.[26] This idea is elaborated on by Ismael and Schaffer, who propose that entanglement is analysed in terms of *nonseparability*.[27] This leads towards the type of quantum holism that we've seen Schaffer to favour, with some form of emergence as the upshot: the composite system seems to be more than the sum of its parts. As a potential pluralist rejoinder, Schaffer considers the possibility of introducing fundamental, external entanglement relations, which might enable the pluralist to retain particles (and hence individual substances). However, he rightly points out that it's not at all clear that particles could be retained in such a theory, for as we already saw there is no clear place for them in the ontology of QFT (this is assuming that QFT *is* a fundamental theory, of course). Assuming that external entanglement relations will not help in saving pluralism, the conclusion follows from premises 2 and 3.

3. A Tangled Argument

Let us now take a moment to consider the dialectic of Schaffer's argument for priority monism in more detail. In particular, I'd like to highlight the commitment to emergence, which is evident from premise 1 of the reconstructed argument. The background of the idea is in fact something that we can see in the physics literature as well, and since Schaffer draws on this literature, we ought to acknowledge this. One way to introduce the idea is via *decoherence*, which concerns the appearance of classicality when quantum coherence is removed.[28] As our starting point, we can take the double-slit experiment. To get the correct result for the probability of an electron passing through a particular slit, we have to take into account *interference*, which depends on both components of the wave that splits when it encounters the slits. This produces the familiar interference pattern. Now, decoherence becomes evident when this trademark feature of quantum systems, the interference, is not observed, and instead, we have a system that appears to conform to a classical interpretation. But the reason for this appearance of classicality is that a system will also interact with its environment and indeed it will become entangled with its environment. This phenomenon can be produced simply by performing the double-slit experiment and observing the slits. So decoherence gives us the appearance of wave function collapse without requiring that such a collapse really occurs. But decoherence can also emerge spontaneously, because the system unavoidably interacts with stray air particles, etc.

This produces a general problem: the world appears to be classical and to consist of individual and distinct macro-objects, but if there is classicality in *appearance only*, then can we have even 'emergent' macro-objects? If the answer is supposed to be 'yes', then at the very least, we need a story about how this works, ultimately, about how the facts about the 'emergent' macro-objects are grounded in the wave function of a system.[29] We will return to this in section 5, where we discuss the notorious *macro-object problem* in more detail.

Let me tie this idea back to Schaffer's argument. In his most recent work, with Jenann Ismael, one possible approach being considered is *wave function realism*, i.e., the view that 'the wave function is a fundamental object and a real, physical field on configuration space'.[30] This is also a topic that will be discussed in more detail in section 5, but the context of the discussion is the following idea:

> [Q]uantum mechanics seems to allow two entities—call them Alice and Bob—to be in separate places, while being in states that cannot be fully specified without reference to each other. Alice herself thus seems incomplete (and likewise Bob), not an independent building block of reality, but perhaps at best a fragment of the more complete composite Alice-Bob system (and ultimately a fragment of the whole interconnected universe).[31]

The quantum holist faces precisely the type of problem that we saw above with respect to the phenomenon of decoherence, namely, in what sense, besides in *appearance only*, are Alice and Bob individual and distinct at all, if they are fundamentally nonseparable? Ismael and Schaffer entertain various ways in which we might consider Alice and Bob to emerge as 'modally connected non-identical events' from a common portion of reality.[32] For the sake of brevity, I will here discuss just one of these, based on wave function realism. Ismael and Schaffer suggest that: 'For the wave function realist, assuming that there is even such a thing as familiar three-dimensional space, it is to be treated as a derivative (or emergent) structure, and not a fundamental aspect of reality'.[33] We should note here that even though the quantum holist may prefer to talk about 'derivativeness' rather than 'emergence', the basic problem—how do we explain the appearance of classicality and the apparent distinctness of three-dimensional macro-objects such as Alice and Bob—is nevertheless the same.

Returning to Schaffer's original argument, recall that a crucial—although implicit—premise of the argument is that the whole, the cosmos, is somehow emergent and contains information over and above the information carried by the quantum states of its components. It is important for Schaffer's project that even though the emergent whole is prior to its parts, the whole does indeed have parts, and hence, we can get the classical objects, Alice and Bob, out of priority monism: 'the monist can guarantee a complete inventory of basic objects'.[34] Schaffer's various allusions to decoherence suggest that it may be via decoherence that Schaffer hopes to guarantee—or at least motivate—the possibility of maintaining the inventory of basic objects.[35]

The work on decoherence has made it clear that 'nonseparable quantum systems nevertheless typically *approximate* separable closed classical systems very closely'.[36] Even if nonseparable quantum systems are ultimately holistic, they nevertheless seem to have features very similar to those of classical systems. But one might argue that this is not taking nonseparability and the project of quantum holism to its logical conclusion. This line of thought requires tackling the underlying quantum ontology in more detail.

To give an example of an attempted explanation of quantum holism with the required level of detail, one might endorse something like the Bohm-Hiley project for an 'undivided universe', which 'requires not only a listing of all its constituent particles and their positions, but also of a field associated with the wave-function that guides their trajectories'.[37] This is the idea of a 'pilot-wave' postulated in the de Broglie-Bohm theory, which connects again with the phenomenon of decoherence—although as Bacciagaluppi notes, in the de Broglie-Bohm theory, we effectively have *two* mechanisms connected to apparent collapse and hence the emergence of classicality.[38] So, the Bohmian project as well will have to answer the question of where the classicality emerges *from*, but the reason why it might appear attractive is that the de Broglie-Bohm theory can refer to decoherence when it comes to the emergence of classical structures and *also* provide an interpretation of quantum mechanics that 'explains why these structures are indeed observationally relevant'.[39]

The upshot for Schaffer's project is that none of the intriguing work inspired by decoherence is going to give the priority monist the objectivity that the account needs—not without a completed quantum ontology. One source of the problem specifically for Schaffer is that he wishes to avoid committing to existence monism as it has been traditionally understood, i.e., that there is just one *thing*. As we saw, Schaffer favours priority monism instead, and he takes it that there is a plurality of 'things', albeit only as *parts* of the whole—the cosmos. Chris Fields has recently challenged this.[40] Here is a representative passage from Schaffer:

> [Q]uantum entanglement is a case of emergence, in the specific sense of a property of an object that has proper parts, which property is not fixed by the intrinsic properties of its proper parts and the fundamental relations between its proper parts.[41]

The worry is that Schaffer's account of quantum entanglement as a case of emergence will not get off the ground without an objective sense of 'proper part'—essentially, to view parts as localized 'systems'.[42] Fields suggests that what would be needed here is some reason to think that 'the notion of universal entanglement is consistent with any coherent mereotopology that yields elementary particles or any other proposed propertied fundamental objects as persistently identifiable, localizable parts'.[43] The challenge, due to Fields, is that the phenomenon of decoherence appears to be of no help in achieving anything but the illusion of such objective sense of 'proper part'. Fields insists, quite correctly, that an explanatory gap remains, since the classical world is a 'world of discrete, identifiable, time-persistent *objects*'; decoherence does not give us any principled reason to regard some collection of elementary particles as this type of a discrete object over any other.[44] But some such reason—an account of when and which proper parts compose an object—would be needed if we are to, as it were, reconstruct the classical world. There have of course been attempts to do so in the literature. Fields considers Wojciech Zurek's idea of 'quantum Darwinism', where classicality emerges due to the environment encoding information about a system during the process of decoherence.[45] Zurek suggests that the process is based on a 'Darwinian' mechanism that is ultimately responsible for the fact that only some of the potential collections of elementary particles are recognized (by us, the observers) as objects. But we need not dwell on such speculative ideas, for Schaffer himself does not rely on anything of the sort. This should, at any rate, be enough to highlight that a further story is needed here.

The more general upshot is that given Schaffer's premises, there would appear to be reasons to favour a much more extreme version of monism than Schaffer hoped. This is due to the tension identified by Fields, i.e., taking the cosmos to be an emergent, entangled whole does not appear to be consistent with objective proper parthood. So, if Schaffer holds on to the idea of 'universal entanglement', then he may end up back with the 'uncharitable' interpretation of monism, i.e., that only one thing exists[46]:

> [I]f quantum effects such as entanglement do not disappear at large scales, then the "classical world" is not an approximation but an illusion, and our ordinary notions of objecthood, locality, independence and causation are not approximately right but rather straightforwardly wrong. Such a conclusion flies in the face of all of our intuitions, and is difficult even to consider as a theoretical option.[47]

It is worth highlighting that we seem to have ended up with a position equivalent with the version of monism that we saw Hoffman and Rosenkrantz dismiss as evidently inconsistent with experience. This is the view according to which there are 'no particles, pebbles, planets, or any other parts to the world'.[48] Even Schaffer admits this to be potentially as implausible as Fields suggests in the passage quoted above: 'Perhaps monism would deserve to be dismissed as obviously false, given this interpretation'.[49] The challenge is that Schaffer's argument, at least on the present interpretation of decoherence, may lead us towards this very view. If this is right, then the choice we face is between existence (rather than priority) monism and some version of genuine pluralism. Yet, we have seen that it's difficult to understand how genuine pluralism could be reconciled with quantum mechanics, at least if we assume a non-collapse approach. Let us see if we can make some progress.

4. Substances Disentangled: Primitive Incompatibility

Having observed the tangles in the argument for priority monism from quantum entanglement, one might think that the options are clear: either we should bite the bullet and endorse existence monism rather than Schaffer's priority monism, or we should follow Hoffman and Rosenkrantz and dismiss monism as altogether unpalatable. But perhaps this is uncharitable. After all, Schaffer has plenty of other arguments in favour of priority monism, and even the case presented above is far from conclusive. This is not the place to attempt an assessment of all the arguments in favour of priority monism. Instead, let us approach the issue from the opposite end, by trying to reconstruct a pluralist, neo-Aristotelian substance ontology, given the challenges raised by quantum theory. The goal here will be primarily just to motivate the idea—apparently challenged by some approaches to quantum theory—that there could be such things as individual substances: things, objects, entities with objective boundaries. I shall not attempt to be faithful to Aristotle or even the neo-Aristotelian tradition in what follows. I am merely interested in the basic idea of *joints* in nature, joints that distinguish one kind of thing from another kind of thing. The existence of such joints would not be a sufficient condition for the existence of individual substances, but their existence does at least seem to be a necessary condition.

In fact, the strategy that I propose is to focus on *properties* rather than substances, for if we have some reason to think that there are properties that cannot be had by one thing at the same time—simultaneously instantiated incompatible properties—then we would already have at least a *prima facie* reason to postulate more than one thing and hence some boundary or distinguishing feature between these two (or more) things. As a matter of fact, Aristotle's work is a natural starting point when it comes to this theme, even though he discusses the theme of incompatibility also quite separately from that of substance.

In *Categories*, Aristotle discusses a distinctive feature of substances: that they are able to receive contraries.[50] By this he means that a substance, like an individual man, can be hot at one time and cold at another time. The existence of contraries—properties like hotness and coldness—does not itself in any way imply that there is more than one substance. But it may help to get us started to think about the difference between contrariety and incompatibility, as we see it in Aristotle's work. The important idea is that if contrary properties are instantiated *at the same time*, then it would seem that they cannot be instantiated by one and the same substance. It is precisely this idea of incompatibility that I wish to draw on. I will propose that by taking incompatibility to be *primitive* and *worldly*, we can motivate the acceptance of a plurality of individual substances.

The idea of primitive incompatibility is certainly traceable to Aristotle, but I should note that the idea has crept up repeatedly in more recent literature, especially in well-known attempts to define negation and to come up with truthmakers for negative truths.[51] I will not discuss these attempts here, interesting though they are. All we need for the argument at hand is the idea of primitive incompatibility. In Aristotle, the idea of incompatibility is at its clearest in some of his formulations of the law of non-contradiction (LNC). The following is my personal favourite:

> The same attribute cannot at the same time belong and not belong to the same subject in the same respect.[52]

This formulation of LNC focuses on attributes, which make for a particularly intuitive example of primitive incompatibility: it seems plausible that, say, a particle cannot at the same time both be charged and not be charged. Once we have grasped this idea, we can expand on it to the case of mutually exclusive properties. A particle cannot only both have and not have a charge at the same time, it also cannot both have a negative and a positive charge at the same time—these properties are incompatible. In *Categories*, Aristotle writes about 'contrariety' rather than 'incompatibility', but as I noted, it is in fact the latter which will be our focus here. It may nevertheless be helpful to compare the two notions. There is an aspect of contrariety that differs significantly from incompatibility: the former would seem to come in degrees, whereas the latter does not. We might ask: how many contraries can a proposition have? Following the Aristotelian formulation of LNC, it would seem that any incompatible attributes are also contraries. But even if incompatibles are also contraries, contrariety clearly comes in degrees: saying of something black that it is not white is different from saying that it is not grey, even though whiteness and greyness are just as incompatible with blackness—we might think that being grey is closer to being black (and closer to being white) than blackness and whiteness are to each other. Or, if colours are confusing here, think of properties like being tall and being short. The idea is clear from Aristotle himself:

> Since things which differ from one another may do so to a greater or a less degree, there exists also a greatest difference, and this I call "contrariety".[53]
>
> It seems that in defining contraries of every kind men have recourse to a spatial metaphor, for they say that those things are contraries which within the same class, are separated by the greatest possible distance.[54]

Here it seems that Aristotle in fact suggests to use 'contrariety' to describe absolute dissimilarity—at least sometimes. But simply the suggestion that there could be a spatial metaphor of contrariety distances the notion from the understanding of primitive incompatibility that I have in mind.

We might illustrate contrariety as follows:[55]

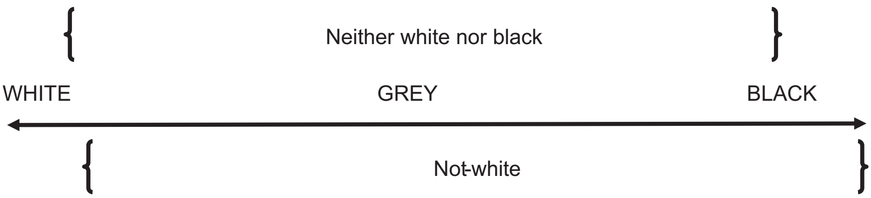

Figure 6.1

Based on *Figure 6.1*, we can define polar contraries (white and black) and immediate contraries (white and not-white), where immediate contraries are incompatible precisely in the sense that we are interested in.[56] If we wish to insist that primitive incompatibility itself does not come in degrees, which is indeed central to our argument, I now suggest to set contrariety aside and focus on incompatibility proper. This happens fairly naturally if we try to adapt the previous illustration to a case like charge:

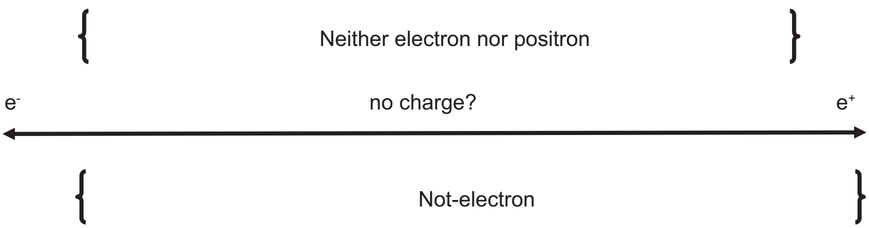

Figure 6.2

In *Figure 6.2*, there are no degrees of contrariety. Electrons have a unit negative charge (the elementary charge), which has an interesting role: all freely existing charged particles have a charge similar in magnitude either to the unit negative charge or an integer multiple of it. So it appears that the route from electron to positron could only involve neutral charge as an intermediate contrast; there are no degrees. Moreover, a neutral particle is a very different kind of thing than a charged particle (it is subject to different laws, for one thing), so it doesn't really perform the same job as 'GREY' does in *Figure 6.1*. This simple case of electron vs. positron gives us an easy example of incompatible properties. Since we are dealing (supposedly) with fundamental particles, this gives us at least a preliminary reason to think that incompatibility could be a fundamental feature of reality.[57] The case is really not that different from charge: macrophysical objects don't tend to manifest charge in the same way that subatomic particles do, even though their existence requires bonding behaviour that is enabled exactly by the charges of their constituent particles. When we study charge, it's exactly the unit negative charge of electrons—also known as the *fundamental unit of charge*—that turns out to be the most interesting. I will not attempt to construct a further argument here in favour of taking incompatibility as a primitive, worldly feature, but let me note that the idea has been (re-)gaining popularity. Francesco Berto's recent account is a good example; he thinks that there's evidence that incompatibility 'carves nature at its joints'.[58] Berto himself focuses on the semantic and logical aspects of the account and is interested in incompatibility as a basis for negation, but for our purposes, it is precisely the idea that incompatibility is a genuine feature of reality that is important. Does this idea survive when we move on to quantum ontology?

5. Substances Disentangled: Incompatibility and the Wave Function

So far, I've been speaking quite loosely about the idea of primitive incompatibility. One might, for instance, question the previous example concerning electrons, since it was assumed that electrons are *particles*—individual substances. But all this was just to get an initial understanding of incompatibility. In order to use the idea of incompatibility in an argument in favour of pluralism, we of course better not assume at the outset that there is a plurality of things. So, let us get back to quantum theory, which is what motivated Schaffer's argument in favour of monism. As we have seen, the key issue here is *how* classicality emerges at the macroscopic level, for the macroscopic world at the very least looks and feels as if it is classical and contains a plurality of objects with objective boundaries. Not that I propose to solve this problem here; we are effectively dealing with one of the central interpretive problems concerning quantum mechanics, what Alyssa Ney calls the *macro-object problem*: 'the problem is to explain how the wave function of a system could ground facts about macroscopic objects'.[59] One thing that is important to note here is that the solution to this problem—or more specifically, the possibility of pluralist substance ontology—does not necessarily depend on which approach to quantum mechanics is adopted. This is because there are versions of all the major approaches that may enable the type of ontology that the neo-Aristotelian seeks. In fact, it seems that we might be able to classify approaches to quantum mechanics that could do the trick on the basis of a single feature: whether or not the approach favours *wave function monism*.[60] This is the view that, fundamentally, a wave function is all there is; this view also assumes wave function realism, a view which we already mentioned in passing above: 'the wave function is a fundamental object and a real, physical field on configuration space'.[61]

However, as I will go on to speculate, even wave function monism may leave room for primitive incompatibility as it was introduced in the previous section.

According to wave function monism, there are no particles, except perhaps as derivative, emergent entities, in the sense that decoherence *may* suggest. But we have seen that there are reasons to think that this is, at best, an illusory sense, and if this is right, then wave function monism would really seem to amount to a type of existence monism. Note that, on the face it, the Bohmian approach, which we mentioned in passing above, will not be compatible with wave function monism. This is because the Bohmian approach does hold that there are, in addition to the wave function, particles with determinate locations in three-dimensional space.[62] But Ney observes that there are also versions of the Everettian and Ghirardi-Rimini-Weber (GRW) approach to quantum mechanics (although we will not discuss them here; GRW is a collapse approach) that are compatible with the denial of wave function monism.[63] However, there are similarly different versions of the Bohmian approach and it may be that only some of them would be compatible with a pluralist view—after all, we saw earlier that there is a clear element of universal 'connectedness' in the Bohm-Hiley version in particular. Regarding the GRW approach (and other collapse theories), David Albert notes that the world will consist of just one physical object, namely, the universal wave function.[64] While I cannot hope to analyse the ontological status of the wave function in detail here—partly because I simply lack the competence to do so and partly because the story will differ depending on the interpretation in question—I do hope to make it clear that the neo-Aristotelian pluralist has not yet been driven to a corner, whereby only some speculative approach to quantum mechanics would save the day.[65] All of the options mentioned here are live.

Let us take a closer look at what the wave function might tell us about incompatibility. Specifically, what does the wave function tell us about the case of seemingly distinct, objective 'particles' that at least look as if they could motivate pluralism about individual substances? Consider a two-particle wave function for a system of identical, indistinguishable particles. Quantum theory tells us that the probability density of the two particle wave function must be identical to the wave function in a situation where the particles have been interchanged. There are two ways that this can happen: the symmetric and the anti-symmetric case. In symbols, the symmetric case is $\psi(r_1, r_2) = \psi(r_2, r_1)$, and the anti-symmetric case is $\psi(r_1, r_2) = -\psi(r_2, r_1)$. Details of wave-function symmetry aside, it turns out that particles with symmetric wave functions in this scenario have integer or zero intrinsic spin—they are known as bosons—whereas particles with anti-symmetric wave functions have half-integer intrinsic spin—they are known as fermions. So, here we have what seems like a relatively simple but quite general case regarding the incompatibility of two types of fundamental particle, fermions and bosons. If this is correct, then it looks like the fermion vs. boson distinction is one of the best candidates for a distinction that 'carves nature at its joints'. If such fundamental incompatibilities do exist, then they may be seen as tracking worldly incompatibility in Berto's sense.[66] In other words, if incompatibility itself is fundamental, then fundamental incompatibilities like the fermion vs. boson distinction could be seen as grounded in this worldly incompatibility.

In the fermion vs. boson case, the incompatibility concerns the representations of the wave function, so one might still doubt whether we have arrived at genuinely incompatible properties that must be possessed by two distinct 'objects' (if we consider the wave function in the lines of wave function monism). So the problem is that those who favour wave function monism in particular might regard this story to be inherently misleading: we do not really have closed systems like the two-particle system described in this example. All we have is the universal wave function and fermions and bosons are just aspects of the universal entangled web, loosely speaking. Still, the incompatibility featured in this story about fermions and bosons must be rooted in something, and since it can be modelled with the wave function, even the wave function monist should be able to appreciate this. Forget about 'particles', what I wish to suggest is that they can be understood as a placeholder for features of the wave function that are ultimately responsible for the possibility of macro-objects. But insofar as one thing cannot possess two incompatible properties at the same time, it seems as if the wave function monist must either insist that this incompatibility itself is only an illusion, admit that there are at least two distinct things, or try to reduce the distinctness into something else. If the friend of substances is right, then we would also have the beginnings of a potential solution to the *macro-object problem*. On this approach, what grounds facts about macro-objects (and we can here think of any appearance of a 'particle' to be a macro-object) is the incompatibility that can be traced to the wave function itself.[67]

It is worth noting that the speculative approach being developed here assumes a form of wave function realism. I don't wish to make any commitments in this regard myself, but since the universal role of the wave function understood in a realist fashion is typically adopted in arguments that are causing trouble for neo-Aristotelian substance ontology, it seems that for the sake of argument it would be best to adopt this approach and see if we can deal with it. This type of realism about the wave function could be considered to suggest that the wave function is at least 'quasi-material', i.e., something close to what we regard as ordinary material reality, even if not quite the same thing.[68] As Goldstein and Zanghì note, it turns out to be quite tricky to determine the ontological status of the wave function—we would first need to know what quantum theory says. I cannot hope to make much progress with this issue here. Instead, I've focused on tracing the idea of incompatibility all the way down to the wave function, since I posited incompatibility as a necessary condition for pluralism about substances. But even if we regard the wave function as 'real'—presumably, as a field[69]—part of the problem that we now face is how to express incompatibility in terms of the 'parts' of one universal field. It might be suggested that this simply means that if *this* part of the wave function has a certain peak, then *that* part of the wave function cannot have a certain peak. Simplistic as this description is, it may be the only way that we can 'solve' the macro-object problem. Note that this would seem to apply even in the case of wave function monism. Ney herself suggests something quite similar, although without explicitly referring to incompatibility:

> Somehow the wave function grounds the existence of, for example, my desk. This is not because my desk is spread out all over the configuration space with parts corresponding here to a leg and there to a top. Rather, the persistence of peaks of the wave function grounds the existence of my desk. Point-sized regions of these peaks correspond to slightly different (classical) ways of there being a desk there, slightly different configurations of particles that could make up a desk, among other things. If instead, the peaks of the wave function were centered in a disjoint region of configuration space, then my desk would not have existed, or there would have been a very different kind of desk.[70]

This is certainly a controversial story about how we might reduce ordinary three-dimensional objects to a wave function in configuration space, but it seems clear that in order to address the macro-object problem, something on these lines is a promising way to go. By 'something on these lines', I simply mean the requirement that there are persistent peaks in one region of the wave function that will rule out certain other peaks, just like Ney describes. Consider another passage, from Jill North:

> For example, there being a table in three-space consists in nothing but the wave function's having a certain shape in its high-dimensional space. It's *true* that there is a table in three-space; it's just that this holds *in virtue of* some other, more fundamental facts. The truth about three-space (the grounded) is not a further fact beyond the truth about the wave function's space (the grounds)—that is, it isn't a fundamental fact—even though it is distinct from the grounds and is itself a real fact.[71]

This passage may remind someone of the earlier reconstrual of Schaffer's strategy to get a plurality of entities via the nonfundamental parts, while the cosmos as a whole is fundamental. We have seen that this strategy is problematic. Ney and North both appear to be in the business of explaining how we might get our beloved 'things' (why is it always tables?) back as nonfundamental entities that are grounded in or reduce to the universal wave function in 3*N*-dimensional space. On any such view, one will have to postulate some *structure* that corresponds with the classical ways of being. North suggests that this structure could be specified, e.g., by the dynamical laws.[72] In Ney's story, the relevant structure seems to come from the persistence of the peaks of the wave function. If some story of this type turns out to be correct, then my thesis about primitive incompatibility is corroborated: you don't get even emergent, nonfundamental 'things' without fundamental incompatibility, because something like this must always be built-in to the relevant structure. Otherwise there could be no correspondence to the classical ways of being that Ney alludes to. I wish I could say more about what that fundamental, primitive incompatibility amounts to, but the problem here is that, being primitive, we might not be able to specify it very much beyond the type of stories that I've quoted above. Instead, we might attempt a *reductio ad absurdum*: consider what the world would be like if there were no incompatibility. I think that the best illustration of this might be something like Dummett's 'amorphous lump', a view according to which the world is structureless 'dough'.[73] We do not need to dwell on the anti-realist aspects of this idea—the point is simply that any kind of structuring will require some limiting principles, be it the dynamical laws or something else, and this immediately introduces an element of incompatibility. If this is right, then on any view where there is an underlying structure, there is also incompatibility. Presumably, Schaffer himself would not deny this, but the question is: who can give the most plausible explanation of this incompatibility?

Do we get the typical neo-Aristotelian conception of substance out of all this? Probably not. But nor do we get any other very clear ontological picture: the jury is still out on quantum ontology. Of course, we do know some things. For instance, it seems undeniable that on all the major approaches, some kind of holism will be present in quantum ontology. However, this does not necessarily entail monism, it only entails that there may be more dependence in the world than we once thought. To be sure, pluralism will need to be qualified at the end of the day, but if we can trace the source of incompatibility to quantum ontology, then there is at least some hope to settle the *macro-object* problem in a manner that preserves the key aspects of neo-Aristotelian pluralist substance ontology.[74]

Notes

1 For a general overview on substance, see Hoffman and Rosenkrantz (1994, 1997). I will not attempt to make any claims about Aristotle's own views regarding substances here, but for discussion linking the historical notion of substance and the neo-Aristotelian one, see Hoffman (2012); see also other articles in Tahko (2012a) for various views on categories. I should also add a caveat: although this article defends the possibility of maintaining the category of substance, I am myself thoroughly fallibilist about this issue. Should science conclusively show that substance is not a feasible category, I would be prepared to give it up. Hence, my own approach to the neo-Aristotelian tradition is very much methodological rather than substantial (see, e.g., Tahko (2013) for further discussion).

2 Hoffman and Rosenkrantz (1997: 1).

3 Ladyman and Ross et al. (2007).

4 Schaffer (2009).

5 E.g., Schaffer (2010a, 2010b).
6 Schaffer (2010a: 32), Hoffman and Rosenkrantz (1997: 77).
7 Hoffman and Rosenkrantz (1997: 78).
8 See Schaffer (2009).
9 Schaffer (2009: 131).
10 Schaffer (2010a: 49).
11 Schaffer puts forward an argument from common sense, which is supposed to establish that the many proper parts of the cosmos are arbitrary portions of the cosmos and hence that the cosmos is prior to its many proper parts. For a discussion and an attempted refutation of this argument, see O'Conaill and Tahko (2012); see also other articles in Goff (ed.) (2012) for further discussion on various versions of monism and their history.
12 Schaffer (2009: 133).
13 At least in one sense or another; see Tahko and Lowe (2015) for discussion.
14 Hoffman and Rosenkrantz (1994: 35).
15 Schaffer (2010a: 54).
16 Schaffer (2009: 143).
17 Schaffer (2010a: 48); compare with Tahko (2012b).
18 Thanks to the editors of this volume and especially Nic Teh for these observations.
19 Thanks to Alastair Wilson for pointing this out.
20 Zeh (2003).
21 When two systems become *entangled* via some physical interaction and then separate after some time, they cannot be described in the same way as before (Schrödinger 1935). Or as Schaffer (2010a: 51) puts it: 'An entangled system is one whose state vector is not factorizable into tensor products of the state vectors of its *n* components'. Importantly, entanglement is the cause of the seemingly unavoidable nonlocality, 'spooky action at a distance', which Einstein found unpalatable and which Bell's famous theorem demonstrated. See Bub (2015) for further details. Note that the argument at hand does not concern QFT as such—any approach to quantum theory must engage with the phenomenon of entanglement one way or another.
22 Based on Schaffer (2010a: 50–7); see premises 6–8.
23 Schaffer (2010a: 52).
24 Ibid.
25 Note also that we should distinguish between the Copenhagen interpretation -style collapse theories and objective collapse theories such as the GRW approach.
26 Schaffer (2010a: 53). Schaffer (2010a: 55) goes on to offer an argument from the possibility of emergence in favour of monism, but as we can see, that would not really be a distinct argument, as some sort of emergence is implicitly assumed already in the argument at hand.
27 Ismael and Schaffer (Forthcoming: §2.1.3).
28 For an in-depth introduction to decoherence, see Bacciagaluppi (2016). For an accessible account of the philosophical implications of decoherence, see Crull (2013). See also Wallace (2012) for an extensive discussion of decoherence and the emergence of 'macro-objects'. As Crull (2013: 879) notes sometimes 'classicality' is just understood as 'lack of interference'.
29 Thanks to Christina Conroy for pressing on this issue.
30 Ney (2013a: 37).
31 Ismael and Schaffer (Forthcoming: 1).
32 Ismael and Schaffer (Forthcoming: 12ff).
33 Ismael and Schaffer (Forthcoming: 17).
34 Schaffer (2010a: 57).
35 E.g., Schaffer (2010a: 53n31), Ismael and Schaffer (Forthcoming: 21).

36 Ismael and Schaffer (Forthcoming: 21).
37 Healey (2016: §9). See, also Bohm and Hiley (1993).
38 Bacciagaluppi (2016: §3.2.1).
39 Bacciagaluppi (2016: §3.2.1). For further discussion, see Pylkkänen et al. (2015).
40 Fields (2014a).
41 Schaffer (2010a: 55). Also quoted in Fields (2014a: 143).
42 Fields (2014a). See also Dorato (2016), where Schaffer's priority monism is put to test with reference to Rovelli's relational approach to quantum mechanics (RQM)—Dorato's conclusion is that RQM does not support monism.
43 Fields (2014a: 144); see also Fields (2014b).
44 Fields (2014a): 137.
45 Zurek (2003, 2009).
46 Schaffer (2010a: 32, 52).
47 Fields (2014a: 144).
48 Schaffer (2010a: 32).
49 Ibid.
50 Aristotle, *Categories* 4a10–21.
51 See, e.g., Demos (1917), Price (1990), Molnar (2000), and Berto (2015).
52 Aristotle, *Metaphysics* 1005b19–20.
53 Aristotle, *Metaphysics* 1055a4–6.
54 Aristotle, *Categories* 6a15–19.
55 Adapted from Horn (2001: 38).
56 On 'polarity', see also Beall (2000).
57 One might argue that this is just a nomic rather than a metaphysical feature of reality, in which case, incompatibility might not be fundamental. But even if this is the case, those who consider (some) laws of nature to be metaphysically necessary could arrive at the desired result. I will not discuss the status of the laws of nature here, but see Tahko (2015) for discussion. Thanks to Alastair Wilson for pointing out this issue.
58 Berto (2015: 11); see also Berto (2008).
59 Ney (2013a: 25–6).
60 See Maudlin (2010).
61 Ney (2013a: 37).
62 Ney (2013a: 38).
63 Ibid.: 42.
64 Albert (2013): 54.
65 The debate concerning the ontological status of the wave function is heated and interesting; see the essays in Ney and Albert (eds.) (2013) for a representative selection.
66 Berto (2015: 11).
67 As Nic Teh pointed out to me, there is an argument to be constructed here also on the basis of Pauli Exclusion Principle (PEP), which states that no two fermions in a closed system can have all the same quantum numbers at the same time: the PEP can be seen as a necessary condition for the stability of matter. From this we can infer that the fact that matter is extended is itself at least partially based on primitive incompatibility. However, I will not develop this argument in more detail here, as I have discussed very similar arguments based on PEP elsewhere, e.g., in Tahko (2009) and (2012b).
68 See Goldstein and Zanghì (2013) for a helpful survey.
69 See Ney (2013b: 169); 'The wave function is a field in the sense that it is spread out completely over the space it inhabits, possessing values, amplitudes in particular, at each point in this space'. Another problem here concerns three-dimensional space: we tend to think of material objects as existing in three-dimensional (or four-dimensional) space, but wave function realism would seem

to suggest that three-dimensional space is just an illusion, as we need to move to 3*N*-dimensional configuration space (Ney 2013b: 177ff.). For further discussion, see North (2013); North argues that although three-dimensional space is not fundamental, it can be seen to exist nonfundamentally rather than being merely an illusion (ibid.: 197ff.). So, there are some subtleties relating to high-dimensional quantum space, which is typically described as a configuration space. Strictly speaking, even this is not quite right, as configuration space is typically used to describe the coordinates of particles. I will leave these complications aside, as the idea of incompatibility does not depend on the number of dimensions. Similarly, I will leave aside complications relating to relativistic quantum mechanics, as do the authors of many of the articles that I have been discussing.

70 Ney (2013b: 180).

71 North (2013: 198).

72 North (2013: 200).

73 See Dummett (1981: 577).

74 I'd like to thank the editors of this volume, Christina Conroy, and Alastair Wilson for comments on previous drafts of this article. The research for this article was supported by two Academy of Finland grants (No. 266256 and No. 274715).

References

Albert, D. Z. (2013) 'Wave Function Realism', in A. Ney and D. Z. Albert (eds.) *The Wave Function*: *Essays on the Metaphysics of Quantum Mechanics* (Oxford: Oxford University Press): 52–7.

Aristotle. (1963) *Categories and De Interpretatione*, trans. with notes by J. L. Ackrill (Oxford: Clarendon Press).

——— (1984) *Metaphysics*, trans. by W. D. Ross, revised by J. Barnes (Princeton, NJ: Princeton University Press).

Bacciagaluppi, G. (2016) 'The Role of Decoherence in Quantum Mechanics', in E. N. Zalta (ed.) *The Stanford Encyclopedia of Philosophy*, Fall 2016 edition, at http://plato.stanford.edu/archives/fall2016/entries/qm-decoherence/.

Beall, J. C. (2000) 'On Truthmakers for Negative Truths', *Australasian Journal of Philosophy* 78: 264–8.

Berto, F. (2008) 'Adynaton and Material Exclusion', *Australasian Journal of Philosophy* 86: 175–90.

——— (2015) 'A Modality Called "Negation"', *Mind* 124(495): 761–93.

Bohm, D. and Hiley, B. J. (1993) *The Undivided Universe* (New York: Routledge).

Bub, J. (2015) 'Quantum Entanglement and Information', in E. N. Zalta (ed.) *The Stanford Encyclopedia of Philosophy*, Summer 2015 edition, at http://plato.stanford.edu/archives/sum2015/entries/qt-entangle/.

Crull, E. (2013) 'Exploring Philosophical Implications of Quantum Decoherence', *Philosophy Compass* 8/9: 875–85.

Demos, R. (1917) 'A Discussion of a Certain Type of Negative Proposition', *Mind* 26(102): 188–96.

Dorato, M. (2016) 'Rovelli's Relational Quantum Mechanics, Anti-Monism, and Quantum Becoming', in A. Marmodoro and D. Yates (eds.) *The Metaphysics of Relations* (Oxford: Oxford University Press): 235–61.

Dummett, M. (1981) *Frege. Philosophy of Language*, 2nd edition (Cambridge, MA: Harvard University Press).

Fields, C. (2014a) 'A Physics-Based Metaphysics Is a Metaphysics-Based Metaphysics', *Acta Analytica* 29: 131–48.

——— (2014b) 'Consistent Quantum Mechanics Admits No Mereotopology', *Axiomathes* 24: 9–18.

Goff, P. (ed.). (2012) *Spinoza on Monism* (New York: Palgrave Macmillan).

Goldstein, S. and Zanghì, N. (2013) 'Reality and the Role of the Wave Function in Quantum Theory', in A. Ney and D. Z. Albert (eds.) *The Wave Function*: *Essays on the Metaphysics of Quantum Mechanics* (Oxford: Oxford University Press): 91–109.

Healey, R. (2016) 'Holism and Nonseparability in Physics', in E. N. Zalta (ed.) *The Stanford Encyclopedia of Philosophy*, Spring 2016 edition, at http://plato.stanford.edu/archives/spr2016/entries/physics-holism/.

Hoffman, J. (2012) 'Neo-Aristotelianism and Substance', in T. E. Tahko (ed.) *Contemporary Aristotelian Metaphysics* (Cambridge: Cambridge University Press): 140–55.

Hoffman, J. and Rosenkrantz, G. (1994) *Substance Among Other Categories* (Cambridge: Cambridge University Press).

——— (1997) *Substance: Its Nature and Existence* (London: Routledge).

Horn, L. (2001) *A Natural History of Negation* (Stanford, CA: CSLI Publications).

Ismael, J. and J. Schaffer, "Quantum Holism: nonseparability as common ground," *Synthese* (Sept. 9, 2016), Doi 10.1007/s11229-016-1201-2 <https://doi.org/10.1007/s11229-016-1201-2>

Ladyman, J., Ross, D., Spurrett, D. and Collier, J. (2007) *Every Thing Must Go: Metaphysics Naturalized* (Oxford: Oxford University Press).

Maudlin, T. (2010) 'Can the World Be Only Wave Function?', in S. Saunders, J. Barrett, A. Kent and D. Wallace (eds.) *Many Worlds?: Everett, Quantum Theory, and Reality* (Oxford: Oxford University Press): 121–43.

Molnar, G. (2000) 'Truthmakers for Negative Truths', *Australasian Journal of Philosophy* 78: 72–86.

Ney, A. (2013a) 'Introduction', in A. Ney and D. Z. Albert (eds.) *The Wave Function*: *Essays on the Metaphysics of Quantum Mechanics* (Oxford: Oxford University Press): 1–51.

——— (2013b) 'Ontological Reduction and the Wave Function Ontology', in A. Ney and D. Z. Albert (eds.) *The Wave Function*: *Essays on the Metaphysics of Quantum Mechanics* (Oxford: Oxford University Press): 168–83.

Ney, A. and Albert, D. Z. (eds.). (2013) *The Wave Function*: *Essays on the Metaphysics of Quantum Mechanics* (Oxford: Oxford University Press).

North, J. (2013) 'The Structure of a Quantum World', in A. Ney and D. Z. Albert (eds.) *The Wave Function*: *Essays on the Metaphysics of Quantum Mechanics* (Oxford: Oxford University Press): 184–202.

O'Conaill, D. and Tahko, T. E. (2012) 'On the Common Sense Argument for Monism', in P. Goff (ed.) *Spinoza on Monism* (New York: Palgrave Macmillan): 149–66.

Price, H. (1990) 'Why "Not"?', *Mind* 99(394): 221–38.

Pylkkänen, P., Hiley, B. J. and Pättiniemi, I. (2015) 'Bohm's Approach and Individuality', in A. Guay and T. Pradeu (eds.) *Individuals Across the Sciences* (Oxford: Oxford University Press): 226–49.

Schaffer, J. (2009) 'Spacetime the One Substance', *Philosophical Studies* 145: 131–48.

——— (2010a) 'Monism: The Priority of the Whole', *Philosophical Review* 119: 31–76.

——— (2010b) 'The Internal Relatedness of All Things', *Mind* 119: 341–76.

Schrödinger, E. (1935) 'Discussion of Probability Relations Between Separated Systems', *Proceedings of the Cambridge Philosophical Society* 31: 555–63.

Tahko, T. E. (2009) 'The Law of Non-Contradiction as a Metaphysical Principle', *The Australasian Journal of Logic* 7: 32–47.

——— (ed.). (2012a) *Contemporary Aristotelian Metaphysics* (Cambridge: Cambridge University Press).
——— (2012b) ‘Boundaries in Reality’, *Ratio* 25: 405–24.
——— (2013) ‘Metaphysics as the First Philosophy’, in E. Feser (ed.) *Aristotle on Method and Metaphysics* (New York: Palgrave Macmillan): 49–67.
——— (2015) ‘The Modal Status of Laws: In Defence of a Hybrid View’, *The Philosophical Quarterly* 65(260): 509–28.
Tahko, T. E. and Lowe, E. J. (2015) ‘Ontological Dependence’, in E. N. Zalta (ed.) *The Stanford Encyclopedia of Philosophy*, Spring 2015 edition, at http://plato.stanford.edu/archives/spr2015/entries/dependence-ontological/.
Wallace, D. (2012) *The Emergent Multiverse: Quantum Theory According to the Everett Interpretation* (Oxford: Oxford University Press).
Zeh, H. D. (2003) ‘There Is No First Quantization’, *Physics Letters A* 309: 329–34.
Zurek, W. H. (2003) ‘Decoherence, Einselection, and the Quantum Origins of the Classical’, *Reviews of Modern Physics* 75: 715–75.
——— (2009) ‘Quantum Darwinism’, *Nature Physics* 5: 181–8.