Nova Ahlinder
Gothenburg University
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# On the possibility of property composition

## A metaphysical investigation of submergent properties in top-down and bottom-up approaches to quantum mechanics

## Abstract

In Schaffer's *Monism: priority of the whole* (2010) an argument from quantum entanglement in favour of priority monism is put forward. The argument is based on quantum entanglement being a case of *emergence* and can loosely be described in terms of failure of property decomposition and success of property composition. The statement of property composition always succeeding has recently been challenged by Calosi (2017). I aim to make a case in favour of property composition by making use of a distinction between top-down and bottom-up approaches to quantum mechanics. My conclusion is that decomposition into components is subjective and partial, while a whole-system perspective is objective and general – wholes therefore contain all information found in parts and should be viewed with ontological priority.


## Introduction

A common discussion in metaphysics is the priority monism/pluralism debate, dealing with the question of whether what is fundamental is one single entity, or a set of multiple entities. Priority monism holds that there is one fundamental entity, the entirety of cosmos, from which all proper parts can be derived. Priority pluralism, on the contrary, argues that all entities are made up by multiple fundamental entities. By law of the excluded middle, priority monism and pluralism are incompatible doctrines: either the totality of cosmos or a set of proper parts is fundamental, but both of them cannot apply (Schaffer, 2010: 56). Arguments in favour of both doctrines have been put forward, so it has not been clear whether to prefer one or the other (Schaffer, 2018).

Ontology must be 'scientifically adequate', meaning that it cannot contradict known physics, and an argument from physics has been put forward by Schaffer (2010) in favour of priority monism. The argument is based on a phenomenon in quantum mechanics (QM) called quantum entanglement. Quantum entanglement is a correlation between particles that cannot be fully explained by looking at the individual particles alone; to get a full account of the particles one must therefore view them in reference to each other. If two entangled particles form a system, then, it is possible that the system itself contains more information than the sum of information found in each particle together (Healey, 2016). In other words, it is possible that the quantum system is holistic in its way of being something over-and-beyond the sum of its parts. The quantum holism of the entangled system, argues Schaffer, means that the system possesses emergent properties. A property being *emergent* means that it is possessed by a composite object, but cannot be traced back to properties of its parts. To fully characterise an object with emergent properties, one must take the entire object into consideration, not just its proper parts and the relations between them. Therefore, if entangled systems have emergent properties, they must be explained from whole to part in order to capture all information. The monist can then argue that entangled systems are best treated as fundamental wholes, and that the universe is one vast entangled system which forms the most fundamental entity (Schaffer, 2010).

In physics, emergence can be described as failure of *property decomposition* (Calosi, 2017). Property decomposition refers to a property of a whole being decomposed into a property of one of its parts (Vermaas 1998). For example, the colour-property that a table might have: ‘the table being green at its left side’, can be formulated as a colour-property of its left side: ‘the left side of the table being green’ (Calosi, 2017). Schaffer (2010: 55) claims that this relation does not hold for emergent properties. Emergent properties only apply to the whole and do not correspond to any property of its parts. Schaffer argues that entanglement cannot be decomposed into a property of the component particles, since there does not seem to exist adequate information in the particles to fully amount to the entanglement property of the whole. On the other hand, Schaffer claims that the opposite - property composition -

*never fails*: properties of parts *always* correspond to properties of the whole. For example, if the left side of a table has the colour-property of being green, it corresponds to a property of the table as a whole, namely, the whole table having the colour-property of its left side being green. What this entails is that while emergence is a metaphysical possibility, *submergent properties* are impossible: there are no properties of parts that are not also properties of the whole. With the possibility of emergence and impossibility of submergence, Schaffer argues that we must give ontological priority to the whole. My observation is that Schaffer's argument rests on two assumptions: (i) it is possible for entangled systems to have emergent properties and (ii) property composition always holds.

Calosi (2017) disagrees with the impossibility of submergence and argues against (ii). More specifically, he claims that it is too strong to assert that property composition always holds. To prove his point, he presents an interpretation of QM where we do not have either property decomposition *or* property composition (Vermaas, 1998; Lombardi and Dieks, 2021); the colour-property of the table being green at its left side, and the colour-property of the left side of the table being green, are two completely different properties. If true, he argues that we would have a case of both submergent and emergent properties, which goes against Schaffer's claim that submergent properties are impossible. Calosi then presents a similar argument from submergence in favour of priority pluralism as Schaffer's argument from emergence, and shows that if we cannot rule out the possibility of submergence, we cannot rule out the possibility of pluralism. The interpretations he bases his argument on fall under the scope of 'modal interpretations of quantum mechanics', an umbrella term for interpretations aiming to solve problems in quantum mechanics using a distinction between the dynamical states and the value states of a quantum system. Not all modal interpretations entail failure of property composition and decomposition and there are ongoing discussions about what interpretations should be embraced (Lombardi and Dieks, 2021).

In this essay, I will discuss the question of whether property composition holds and, consequently, the strength of Schaffer's argument from emergence. I will argue that while there is a possibility that property composition does not hold, we have reasons to believe that it does. To reach this conclusion, I will make use of two articles that both use a distinction between so-called 'bottom-up' and 'top-down' approaches to quantum phenomena. Briefly, the bottom-up approach starts with considering subsystems, a quantum system's parts, while the top-down approach starts with the structure of the system as a whole (Fortin and Lombardi, 2017). I will connect property composition and decomposition to these approaches and argue that where a bottom-up explanation of quantum systems is necessary, we do not have property composition and therefore a possibility of submergence. However, if a top-down approach is necessary, we have good reasons to embrace holistic interpretations of entanglement, which is argued by Ismael and Schaffer (2020) to entail a common ground explanation where whole is prior to part. Further, I will argue that a top-down approach is not just a necessary component when characterising quantum systems, but provides all the information that a bottom-up approach gives us, but with more objectivity and accuracy, making a case for property composition. This conclusion is drawn from Fortin and Lombardi (2017), where a top-down approach is argued to be more general than a bottom-up.

## Overview

I will begin with giving some background to quantum systems and the holistic explanation of entanglement, as well as presenting Schaffer's and Calosi's arguments in more detail. In sect. 1 I introduce the distinction between bottom-up and top-down approaches to QM through the problem of indistinguishability, and look at possible relations between them. In sect. 2 I argue for the necessity of a top-down approach, and what that entails. In sect. 3 I argue that we have reasons to choose an interpretation where property composition holds.

# Background

## Quantum states and entanglement

In quantum physics, a system is defined as a field of possible *observables*, which is the correlate to type-properties in physics; namely, quantities that can be measured. A particle counts as a quantum system and is constituted by observables such as spin, mass, charge etc.. The properties of the system are the definite values of the observables, such as having a charge of $1.60217662 \times 10^{-19}$ coulombs. Further, a system's *quantum state* is used to describe the probability of outcomes when measuring different observables. In other words, the quantum state describes the probabilities of observables having certain definite values (Ismael, 2021).

According to some explanations, the quantum state of a composite system allows for *entanglement*, where the quantum states of the system's components are determined by the quantum state of the system as a whole. For example, if an entangled system made up of two particles has a total spin of 0, and one of the particles is measured to have an x-spin clockwise, the other particle will be measured to have an x-spin counterclockwise so that the sum of the particles' spin is 0. Therefore, the probability of particles displaying different definite values seems to depend solely on the quantum state of the entangled system; quantum states of the components are dependent on the state of the whole system (Healey, 2016). Consequently, if two entangled particles always measure correlated values of spin, it means that they do not have a complete (or 'pure') spin state by themselves (Ismael, 2021). This explanation of entanglement advocates the holistic idea that "the whole is more than the sum of its parts", which Schaffer claims supports monism.

## Argument from emergence

The argument in favour of priority monism comes from the possibility of the whole universe being one vast entangled system. It is likely that everything in the universe has interacted at some point (the Big Bang), and so everything is correlated.[1] Further, the holistic nature of entangled systems points us towards the idea that entanglement is a case of *emergence* (Schaffer, 2010). This holds because if an entangled system is *more than the sum of its parts*, there are properties of the whole which cannot be characterised by its parts, meaning that entanglement is an emergent property. Schaffer argues that when characterising an object with emergent properties, nothing short of the whole object is enough to fully characterise it. If the universe is an entangled system with emergent properties, then, we need to consider the whole universe in order to capture everything that exists.

In the monist/pluralist debate, entangled systems seem to make it so that the pluralist has no clear fundamental base which will account for the whole universe, because any division of the universe ultimately leaves out information. Schaffer concludes that entangled systems are best treated as fundamental wholes, and so it is possible that the universe is a fundamental whole.

Of course, this is only true if an entangled system can fully explain all properties of its parts. If there exists *submergent* properties (the converse of emergence), then a whole-to-part structure of the world might not be the case after all, since everything cannot be derived from a fundamental whole (Calosi, 2017). This is no problem, claims Schaffer, because such properties are impossible; all properties of parts correspond to properties of the whole, whereas properties of wholes do not always correspond to properties of their parts. In other words, property composition always holds while property decomposition sometimes fails. He

[1] See Toraldo di Francia (1998: 28): “Since any particle has certainly interacted with other particles in the past, the world turns out to be *nonseparable* into individual and independent objects. The world is in some way a single object.” See also Schaffer (2010: 52).

calls this the *asymmetry of supervenience* and it is this asymmetry that reveals the grounding direction from whole to part.

## The possibility of submergence

In his article *On the Possibility of Submergence* (2017), Calosi argues that QM may not entail Schaffer's asymmetry. At least not in all its interpretations. As previously mentioned, the interpretations Calosi bases his argument on fall under the scope of modal interpretations of quantum mechanics. 'Modal interpretations' aim to solve problems in quantum mechanics by using a distinction between dynamical states and value states of a quantum system, a distinction introduced by Van Fraassen (1972, 1974, 1991). The dynamical state describes what properties a system *might* have, while the value state describes what properties it *does* have. In other words, the dynamical state describes all the *possible* values of observables, while the value state accounts for what the definite values are. Two central theories of this kind are the biorthogonal-decomposition and spectral-decomposition modal interpretations (BDMI and SDMI) (Lombardi and Dieks, 2021). It has been argued by Vermaas (1998) that the BDMI and SDMI violate property composition and property decomposition. This entails that properties of wholes and parts do not correspond to one another. Calosi presents the following example of property composition/decomposition, where the type-property is 'shape':

"As for a further example, take a 747-aeroplane and the property 'shape'. Let 'being warped' be one of the possible values of the property 'shape'. Consider the claims:

- The left-wing of the 747 has the property of being warped
- The 747 has the property that its left-hand wing is warped" (Calosi, 2017: 504, changed numbered list to bullet list)

If property composition and decomposition do not hold, the left-wing's property of having the shape of being warped, and the 747's property of having a left-hand wing having the shape of being warped, are two completely different properties. Calosi puts this in the framework of QM: the type-property 'shape' corresponds to an observable, and the possible shape-value of 'being warped' is a possible value of that observable. The expected value of an observable of a composite system, is therefore a different property than the expected value of the subsystem.

Failure of property composition entails that properties of parts are different from properties of wholes. This, argues Calosi, means a possibility of *submergence*; there are properties of parts that properties of wholes cannot fully explain. The BDMI and SDMI entails failure of *both* property composition and decomposition, and so we have both emergent *and* submergent properties. To fully characterise a quantum system (such as the universe), we therefore need to look at both wholes and parts, and it is unclear which one has ontological priority.

If property composition and decomposition do not hold, then neither does Schaffer's asymmetry of supervenience. These interpretations do not seem to go well with a metaphysical argument based on the emergence/submergence distinction. Calosi's aim is not to prove that either emergence or submergence is necessarily the case, nor does he advocate for the BDMI or SDMI. Instead, what he shows is that the question is still very much up to debate, since different interpretations of QM yield widely different ontological outcomes.

## 1. Ontology without individuals

There seems to be two different ways of approaching quantum phenomena: we can either identify subsystems and how their interactions give rise to a phenomenon (a bottom-up approach), or we can look at the whole composite system and how its structure may explain it (a top-down approach) (Fortin and Lombardi, 2017). As becomes clear from Calosi's article, if property composition and decomposition fails, we need both approaches to make sure that all information is captured.

da Costa and Lombardi (2014) use this bottom-up/top-down framework to discuss the phenomenon of indistinguishability in QM, from which ontological conclusions are drawn. Particularly interesting about their article is that their approach to indistinguishability is from the perspective of *modal interpretations overall*. The ontological conclusions drawn are based on the modal distinction between the dynamic state and the value state, but do not require choosing a specific interpretation (like the BDMI or SDMI) (da Costa and Lombardi, 2014: 1247). This article therefore allows us to discuss property composition and decomposition in terms of top-down and bottom-up approaches, in the framework of modal interpretations as a whole.

In QM, there exist particles that are identical (such as electrons) where not even their positions can be measured so that we can tell them apart. According to *Leibniz's Principle of Identity of Indiscernibles*, identical entities are *indistinguishable* from one another (Loemker, 1969). The problem with indistinguishability is that the category of individuals does not fit very well in QM; if we consider quantum particles as being individuals, Leibniz' principle is violated (French and Krause, 2006). From this, da Costa and Lombardi argue that we should give up on individuality entirely, and instead focus exclusively on properties and the structures they are instantiated in. They propose an alternative ontology in which elements do not possess individuality. In previous works, da Costa, Lombardi and Lastiri (2013) present this ontology from the bottom up; namely, an account of the smallest elements of the theory (elemental quantum systems) and how they, in turn, combine into complex elements (composite quantum systems). Their more recent article, however, expands this explanation by showing that we can begin with considering the whole composite system and get the same result: an ontology without individuals.

Coming up, I will explain da Costa and Lombardi's ontology from a bottom-up and top-down approach respectively. I will then argue that these two approaches of characterising quantum systems can be connected to property composition and decomposition. My conclusion will be that if a bottom-up approach is necessary, we may have failure of property composition and, consequently, submergent properties. The same goes for the top-down method: if part of the explanation of how quantum systems work comes from considering composite systems first, we may have emergent properties.

## Bottom-up

The bottom-up building of da Costa and Lombardi's ontology starts with its atomic elements, which are referred to as *atomic bundles*. A bundle means "a collection of instances of universal type-properties" (da Costa and Lombardi 2014; 1248). There is no substratum according to this view, nothing that properties 'attach to'; there are only instances of type-properties so as to minimise any need for a notion of individuality. Note that instances of type-properties are not actual valued properties of the system, but representations of the set of observables that *can* be found in the system. They constitute the realm of *possibility* – the dynamical values of the system – which is why the theory is based on modal interpretations of QM.

When two bundles of instances of type-properties have the same dynamical values, they are indistinguishable. Da Costa and Lombardi argue that an ontology with non-individual elements is favourable in the quantum realm, since there is no need to account for what happens to singular bundles after they have gone through different processes. For example: if two bundles form a composite, what is relevant is no longer how they relate to each other, but what the composite system looks like – i.e. the properties of the whole.

When indistinguishable bundles combine, then, they form an aggregate which cannot be decomposed into the original bundles. Since they are indistinguishable, there is no particular order to the formation of the new bundle – it is commutative. This commutativity, in turn, makes it so that the instances of type-properties of the new bundle are governed by a structural property that is entirely symmetric. This explanation of indistinguishability is what da Costa and Lombardi call the *bottom-up approach*. We started with atomic bundles of type-properties as correlates to elementary particles, and ended up with symmetry properties of aggregated bundles. Indistinguishability is the result of non-individual bundles having identical instances of type-properties, which explains why composite systems sometimes cannot pick out components.

## Top-down

da Costa and Lombardi argue that we can get the same explanation of indistinguishability from a top-down perspective: the same ontological elements can be obtained from considering the symmetry properties of composite wholes.

In the quantum realm, perfect symmetry is a postulate that cannot be violated without breaking general principles of QM (Dieks and Versteegh, 2008). This means that systems with perfect symmetry do not allow us to pick out individual subsystems, and so there are no distinguishable particles. For Leibniz's principle to allow individual particles, then, one must start assigning names to particles in order to distinguish them from one another. However, quantum particles cannot be labelled this way, because our means of distinguishing and naming particles are based on how they are already related in the symmetric structure. It involves a circularity (French and Krause, 2006). According to da Costa and Lombardi, the solution is to give up on individuality: two identical particles cannot be named nor distinguished.

So far we have arrived at the conclusion that individuality and QM do not go hand in hand by looking at the *symmetry properties of the entire system*. But if there are no individual particles, what does the symmetry structure consist of? da Costa and Lombardi argue that the solution can be found in their ontology of non-individual bundles of properties:

“In this ontology, quantum systems are bundles of instances of universal type-properties, and bundles are not individuals. Therefore, when component bundles combine, the new bundle is a non-individual whole without individual parts. This means that the structure whose symmetry-properties have to be studied is the composite bundle.” (da Costa and Lombardi, 2014: 1254)

There is no need to worry about identifying components of a composite system, what is relevant is the symmetry properties of the system as a whole. It is those symmetry properties which determine the system’s instances of type-properties. This top-down approach to the problem of indistinguishability is characterised by symmetry, but also holism: the composite bundle appears to be more than the sum of its parts (da Costa and Lombardi, 2014: 1255). More specifically, the composite system instantiates structural properties which are something over-and-beyond the sum of properties of the original systems. This idea ties neatly together with the holistic way of describing quantum entanglement. I will return to this connection shortly.

## Approaches in general

What da Costa and Lombardi’s article shows is that the problem of indistinguishability can be examined from two different starting points, both of which lead us to a quantum ontology without individuals. On the one hand, we have the bottom-up method which assumes da

Costa and Lombardi's ontology from the beginning. It explains how indistinguishability comes from identical atomic bundles that form a symmetrical aggregate. On the other hand, we have the top-down method where we begin with the symmetrical system from which we draw the conclusion that there are no individuals. After that, to make sense of what quantum systems are made out of, we introduce da Costa and Lombardi's ontology of non-individual elements: a system is a bundle of instances of type-properties.

In the bottom-up approach, indistinguishability is the result of non-individual bundles having identical instances of type-properties combining into a new system; in the top-down approach, indistinguishability comes from the symmetry structure of a non-individual and indivisible whole (da Costa and Lombardi, 2014: 1255). But, as I have previously mentioned, this distinction between a bottom-up and top-down approach is not limited to the problem of indistinguishability. Rather, it is an example of two general methods of approaching QM: explanations of quantum phenomena can, in general, either be approached from considering interactions between atomic quantum systems, or from looking at internal properties of a composite whole (Fortin and Lombardi, 2017).

## Possible relations between a top-down and bottom-up approach

What is the relationship between these two approaches? da Costa and Lombardi do not say much about which is preferable or how they relate to each other, but state that they may be seen as two sides of the same coin, hinting at some kind of symmetry between them (p. 1255). That is, a symmetry between interactions of atomic systems and the structural properties of composite systems. If this is true, we can characterise the structural properties of a composite by characterising the properties of its components, and vice versa.

A connection to property composition and decomposition can be drawn: if both hold, all properties of the whole express properties of its parts, and all properties of the components express properties of the whole. In the case of indistinguishability, for example, the symmetry property of the whole can, on the one hand, be expressed in terms of atomic systems being identical and therefore ordering themselves symmetrically. But on the other hand, the fact that the atomic systems are indistinguishable can be derived from the symmetry properties of the whole. In essence, if property composition and decomposition hold, these explanations contain the same information.

Since different modal interpretations entail different facts about property composition and decomposition, depending on what modal interpretation we choose to embrace there seems to be four different possible relations between the bottom-up and top-down approaches:

(1) The top-down and the bottom-up approaches are just two sides of the same coin; we do not have a failure of property composition or decomposition.

(2) The bottom-up approach can account for everything that the top-down approach can, and also some things that the top-down cannot; we have property decomposition but not always property composition.

(3) The top-down approach can account for everything that the bottom-up approach can, and also some things that the bottom-up cannot; we have property composition but not always property decomposition.

(4) Both approaches are necessary to get a full explanation of QM; we have neither property composition nor property decomposition.

Connecting this to emergence and submergence, it becomes clear that submergent properties are possible in (2), emergent properties in (3), and both in (4). Calosi's argument comes from a modal interpretation that seems to entail (4).

# 2. Quantum holism

## The necessity of a top-down approach

Where we are: we have put the property composition/decomposition distinction in a framework that deals with more general methods of characterising quantum systems. The question has consequently moved from being about whether we have property composition or decomposition, to a question of whether to adopt a top-down or bottom-up approach. I will argue that a top-down approach is more general and can give a more nuanced overview of quantum phenomena than the bottom-up can. In other words, I will argue in favour of (3).

Let me begin by presenting some observations based on da Costa and Lombardi's ideas. First and foremost, it can be noted that the bottom-up approach starts with assuming an ontology based on non-individual elements, whereas in the top-down method, the elements of the ontology are derived from the systems in which indistinguishability occurs. The worry I have about the bottom-up approach is that it might yield correct, albeit *partial* explanations of quantum phenomena. Its way of approaching the problem of indistinguishability, for example, provides a solution that already assumes atomic elements that will combine symmetrically if they are identical. But where does the symmetry come from? My worry is that conclusions based on a bottom-up approach are already given, that is, we already know that we should propose a solution that is compatible with structure symmetry. This is connected to the possible circularity brought up by French and Krause (2006): we already assume an underlying structure based on symmetry. Compare this with the top-down approach, where symmetry is accounted for as a structure property of the system in which components cannot be picked out. From the symmetry of the system, one ontological conclusion we can draw is that systems might be bundles of instances of properties. The bottom-up approach, on the other hand, may not tell us the whole story, even though the results are correct. As a consequence, I believe there is pressure to view a top-down approach as at least a necessary ingredient when explaining quantum phenomena. I will come back to the risk of partial explanations when starting with subsystems. Before that, however, I will look more into the holism present in the explanation of indistinguishability.

## Indistinguishability and entanglement

As previously mentioned, when viewed from a top-down approach, holism is part of the solution to the indistinguishability problem. If this approach is necessary, then, holism is an ingredient in the explanation of indistinguishability (da Costa and Lombardi, 2014: 1255). Understanding quantum phenomena in terms of holism is not a new thing, and it has been suggested that holism might be the characteristic of quantum mechanics which separates the workings of the quantum realm from classical physics. The motivation for adopting a holistic position is mainly due to entanglement. Correlations between entangled particles make them appear non-separable, and a likely explanation is that they need to be defined from the perspective of the system they are part of (Healey, 2016). If holism is a necessary component in the explanation of indistinguishability, da Costa and Lombardi conclude that we have good reasons to embrace the holistic explanation of non-separability:

“This view immediately suggests the connection between quantum indistinguishability and quantum non-separability. In fact, if one of the ingredients in the explanation of indistinguishability is holism, the holistic interpretation of non-separability seems to be a necessary consequence.” (da Costa and Lombardi, 2014: 1256)

In other words, by adopting a top-down approach to indistinguishability, we also accept the explanation of entanglement based on holism. How exactly is the top-down explanation of indistinguishability and the holistic interpretation of entanglement connected? Remember that the top-down approach suggests that indistinguishability is the result of an internal symmetry of the system, and is therefore not a relationship between components. The same idea can be applied to entanglement: it is not a relationship between subsystems, but between sets of observables found in the structure of the quantum system (Harshman and Ranade, 2011; Fortin and Lombardi 2017). This suggests an immediate connection to holistic non-separability: particles are non-separable and need to be described in reference to one another; that is, they do not have pure quantum states and are therefore mere fragments of the system they are part of (Healey 2016). As stated in the background section, this explanation of entanglement is what Schaffer bases his argument from emergence on (Schaffer, 2010: 51).

Taking all this into consideration, (3) seems to be the intuitive choice to describe the relationship between the bottom-up and the top-down approach, namely that a top-down approach is more general. If it is the structural properties of the combined whole that needs to be considered, as da Costa and Lombardi suggests, then those properties are all we need to fully characterise a quantum system – no properties of components are left out because, in the combined system, the identity of those components are not retained.

Remember, however, that Calosi does not oppose the possibility of emergent properties. Rather, he argues that properties of the whole might not give us all possible information about the system, in which case the emergence/submergence distinction does not give away whether we have priority monism or pluralism. It is not my job to rule out interpretations of QM. My aim, however, is to show that if a top-down approach is required to get a full explanation of indistinguishability (as it appears to be), and if it entails quantum holism, then we have reasons to prefer (3) over (4), where a bottom-up approach is not necessary. In the following sections, I will explore the holistic interpretation of entanglement in more detail and describe how it might fit into a metaphysical grounding-framework.

## Holistic non-separability

When Einstein first came across entangled particles, he called the phenomenon "spooky action at distance" (Einstein, Podolsky, and Rosen, 1935). To make sense of this spooky action, one of the most prevalent explanations has been 'non-locality'. Non-locality has it so that when we perform a measurement on an entangled particle, it instantly causes the other particles to display certain properties. The explanation would be that there are so-called 'hidden variables' within the particles that allows for instant causation (Bell, 1964; Schaffer, 2018). But there is pressure from parsimony here: we shall avoid adding cloudy relations or properties if we can. We want the quantum state *by itself* to yield all successful predictions (Ismael and Schaffer, 2020), which, in modal interpretations, translates to a dynamical quantum state accounting for all possibilities and an actualization rule that predicts what possibilities become actual. Moreover, hidden-variables theories run into other problems, such as loss of unity in the pluralist explanation of how fundamental particles and relations make up the world (Schaffer, 2018). Therefore, there are reasons to prefer an explanation of quantum entanglement that does not rely on non-locality, and the holistic interpretation of non-separability is precisely such an explanation. If the entanglement relation is not a hidden variable of the particles themselves, the system they are part of hosts further information – it is something over-and-beyond its components (Healey, 2016).

Given that da Costa and Lombardi's solution to the problem of indistinguishability is connected to quantum holism, they conclude: "This means that the modal ontology of properties might supply a framework adequate also to give a response to the problem of non-separability that does not rely on non-locality." (da Costa and Lombardi, 2014: 1256)

## Common ground

Where we are: If we allow particles to be non-separable, entanglement can be explained as particles being mere fragments of the system they are part of, in which case they do not have pure quantum states but need to be defined in the state of the system they are part of. According to da Costa and Lombardi, this interpretation seems to be a necessary consequence if we adopt a top-down view.

In their article *Holism: nonseparability as common ground* (2020), Ismael and Schaffer put this in metaphysical terms by arguing that the particles share a *common ground*. The idea is that the common ground has ontological priority and, as the name suggests, grounds the properties of the particles. In da Costa and Lombardi's ontology, this translates to properties of a composite bundle grounding atomic bundles of instances of type-properties. Ismael and Schaffer's argument is based on the assumption that connected non-identical events are connected in virtue of either causation or grounding. In this case, the connected non-identical events are two entangled particles measuring correlated definite values. From this, Ismael and Schaffer develop 'Source Inference':

"*Source Inference*: If non-identical events *a* and *b* are modally connected, then either (1) *a* and *b* are grounding-connected (/non-distinct), in that either (i) *a* grounds *b*, or (ii) *b* grounds *a*, or (iii) *a* and *b* are joint results of some common ground *c*; or (2) *a* and *b* are (distinct but) causally connected, in that either (i) *a* causes *b*, or (ii) *b* causes *a*, or (iii) *a* and *b* are joint effects of some common cause *c*." (Ismael and Schaffer, 2020: 4139)

Particles' displaying entangled properties is instantaneous, and, as we have seen from non-locality, a causal connection between them is problematic. A causal explanation also entails that one event is 'the cause' and the other 'the result', but why should the properties of one particle be the cause and not the other? And, given that measurements are only performed on one particle at a time, what would a possible common cause look like? What seems to be the case here is some kind of grounding relation. Since there is no reason to believe that one particle grounds the other, Ismael and Schaffer argue that the common ground explanation of non-separability is the most plausible metaphysical relation.

Assuming that a top-down approach (and therefore likely quantum holism) is necessary, we have reasons to embrace the holistic interpretation of non-separability. Ismael and Schaffer's arguments point towards a metaphysical understanding of holistic non-separability in terms of common ground: entangled particles are connected in a bigger whole that grounds them. If the whole grounds its parts, then all relevant information can be found in the whole, and only a top-down approach to QM is necessary.

## Revisiting submergence

By embracing (3), we claim that the top-down approach can account for all information that is needed to fully characterise a quantum system. Quantum holism certainly points us in this direction, but I would like to spend some time exploring what emergent and submergent properties would look like if (4) was the case, as Calosi argues is a possibility.

In (4), we need to consider the elemental subsystems, in addition to looking at the composite system as a whole. I have argued that the bottom-up approach might involve a degree of partiality in its explanation of indistinguishability, since it appears to assume a symmetry structure without explaining where it comes from. (4) agrees that a bottom-up approach alone does not suffice, but that the top-down approach faces the same problem. By looking solely at the properties of a whole system, information about its components is lost. This is because, according to (4), where there is no property composition, properties of subsystems do not correspond to properties of the composite. In the ontology without individuals, this translates to a difference between instances of type-properties that make up the component bundles, and structural properties of the composite bundle. Properties of components are submergent, while properties of the composite are emergent.

The bottom-up and top-down approaches therefore contain different information. For example, the explanation of indistinguishability that is due to two atomic systems being identical, contains different information from the explanation based on properties of a symmetric whole. To get the full picture of a quantum phenomenon, one must approach it from both top and bottom. Even though the *method* of approaching a phenomenon from top to bottom might yield the correct results, there is a difference in what *information* these approaches contain.[2] This entails that what is fundamental may as well be a set of elemental quantum systems (or atomic bundles of properties), as it may be a single whole. Quantum holism is only part of the story; properties of elemental quantum systems is the other.

*Source Inference* may not be applicable to this scenario, because there is a risk that a common ground explanation does not account for all properties. There is a risk that the link between quantum holism and common ground is not a straightforward one. The question of whether elemental quantum systems or composite systems have ontological priority, boils down to whether a top-down or a bottom-up approach can account for all information that can be found in a quantum system. As we have seen, (4) does not provide an answer here, urging us to look for answers elsewhere.

## 3. Objectivity and partiality

Opposed to (4), I will argue that we can, in fact, draw conclusions about grounding from the bottom-up/top-down distinction (and, consequently, the emergence/submergence distinction).

[2] See Healey (2016) and the difference between 'methodological holism' and 'metaphysical holism'.

First and foremost, in da Costa and Lombardi's ontology, none of the elements are individuals; all that exist are instances of type-properties bundled together in different ways. In essence: there are no proper parts. There is no indistinguishability relation between identical atomic bundles because once they are in the same system, only the system itself is relevant. This is easy to see with indistinguishability since there are, by definition, no distinguishable proper parts, but the same goes for other quantum phenomena as well; the non-individual nature of quantum systems makes it so that their identity is lost in the composite system. Or, rather, their identity is no longer relevant once they have combined into the new system. That means that even though the bottom-up explanation of indistinguishability centres around interactions between the component bundles, the end result is holistic – what is relevant is the properties of the new bundle.

## Ontic structural realism

When presenting the top-down approach to indistinguishability, da Costa and Lombardi draw some connections to ontic structural realism. Ontic structural realism proposes a metaphysical shift from objects to structures when talking about basic entities. In line with this position is the idea that particles are not individuals, but mere 'intersections' between relations present in a structure: "physical objects are "reduced to mere 'nodes' of the structure, or 'intersections' of the relevant relations." (French, 2006: 173)

According to da Costa and Lombardi, their theory generates the missing pieces of ontic structural realism from a quantum perspective: a complete ontological inventory of elements which constitute the overarching structures of the quantum realm. Most importantly, this means that the structure of a composite bundle is, in fact, prior to the atomic bundles (French and Ladyman, 2003; da Costa and Lombardi, 2014). If elemental particles (or atomic bundles of properties) are mere intersections of some structure, then apparently they are to be derived from a bigger whole and cannot exist by themselves.

This explains why the relevant properties in da Costa and Lombardi's text are those of the combined system. I have previously suggested that the top-down approach to indistinguishability is more general because we were able to derive the same ontological conclusions *without assuming anything about the elemental systems*. When starting with the atomic bundles, however, the symmetry under which they order themselves had to be assumed in order to get the correct result. In the framework of ontic structural realism, this might be because intersections cannot be taken entirely out of the context of their structure.

A system may be decomposed into subsystems, but as we soon will see, this might involve an unavoidable partiality. This is because there are many different ways in which a quantum system can be decomposed, and so the complete objective picture comes from the structure of the quantum system as a whole. The final discussion coming up completes the picture of the top-down approach being more general, and the keywords are *partiality* and the *priority of closed systems*.

## Closed systems

The position that a top-down approach is more objective, while a bottom-up is partial is argued for in the article *A top-down view of the classical limit of quantum mechanics* (Fortin and Lombardi, 2017). Fortin and Lombardi also use the distinction between a bottom-up and a top-down approach, but instead of discussing the problem of indistinguishability, they deal with a different problem in QM: the problem of the classical limit – i.e. the question of what is involved in the connection between the quantum world and the classical world. They argue that a top-down method of understanding the classical limit resolves conceptual issues that the most common method, environment-induced decoherence (EID), which is bottom-up, faces. When examining a composite quantum system, we should, according to Fortin and Lombardi, start with considering the whole composite system and identify what parts of the structure might behave classically. The bottom-up method, by contrast, assumes that the classical realm emerges from interactions between subsystems and their nearby environment. It is the environment's degree of freedom to behave classically that affects the subsystems and in turn gives them a degree of possibility to behave classically themselves.

The problem with this bottom-up approach (EID) comes from not considering quantum systems as *closed*; the composite system is open, and its subsystems are free to interact with the environment around them. It is the evolution of the subsystems that explains different quantum phenomena such as the emergence of the classical realm. But if this is the case, where do we draw the line between a system and its environment? What counts as a proper system? If a bottom-up approach considers composite systems to be open and changing depending on the interactions of its subsystems, how can it account for systems that are known to be closed, such as the universe as a whole? The emergence of classicality has been explained through a process called 'decoherence', but this process only applies to open systems. Fortin and Lombardi therefore ask: "If decoherence explains the emergence of classicality, but only open systems can decohere, the question is: what about closed systems, in particular, the universe as a whole?" (Fortin and Lombardi, 2017: 3)

## Objectivity

When it comes to defining what counts as a system and what counts as environment, the EID is argued to not be predictive but merely a confirmation of what is already assumed:

"/…/ the approach does not supply a general criterion to discriminate between system and environment. In general, the classically behaving degrees of freedom are assumed in advance:

the application of the EID formalism does not predict which observables will show a classical behavior but only confirms a previous assumption.” (Fortin and Lombardi, 2017: 6)

The main issue with the EID is that it does not provide a general explanation for the classical limit. It describes rather than predicts outcomes of measurements, and is based on the observer’s viewpoint. This is because a quantum system can be partitioned in many different ways, and so placing a ‘cut’ between an open system and its environment is the same as choosing a field of relevant observables of the closed system.[3] In other words, all we have done is pick one of many ways to partition the same system.

“But there is no privileged or “essential” decomposition; therefore, there is no need of an unequivocal criterion for deciding where to place the cut between “the” system and “the” environment.” (Fortin and Lombardi ,2017: 16)

A quantum system, that we know is objective and operates independently from us, is, when approached from interactions of so-called ‘open systems’, explained from a subjective perspective.

While their notion of bottom-up and top-down approaches stems from the problem of the classical limit, they also claim that they can be applicable to QM as a whole: quantum phenomena can either be described through a bottom-up or top-down method. I have already used bottom-up and top-down in this way by talking about how they are methods for fully characterising quantum systems. Characterising a system from a bottom-up perspective starts with picking out subsystems and considering their interactions afterwards. From a top-down perspective, though, the probabilities of subsystems behaving in different ways can be traced

[3] Compare this with previous discussions about the circularity involved when naming indistinguishable particles, as well as when choosing the elements of da Costa and Lombardi’s ontology.

back to the internal structure of a *closed* system. Interactions between subsystems take place relative to a specific partition of the system as a whole. We do not define subsystems and *then* look at their interactions, but are well aware that how subsystems and interactions appear is due to how we choose to part the closed system. The conclusion Fortin and Lombardi draw is that proper quantum systems are always closed:

"This top-down view of decoherence and the classical limit fits into the general framework of a top-down view of quantum mechanics, according to which the only legitimate quantum systems are the unitary evolving closed systems." (Fortin and Lombardi, 2017: 19)

Any system that appears to be open is, by contrast, merely a relevant partition of a bigger, *closed* system. To get a full explanation of a quantum system, we need to adopt a top-down approach in which we consider the system as a whole, or else we cannot be completely objective in our observations. This entails that to fully characterise the universe, which is likely a closed system, nothing short of considering the whole universe suffices.

Fortin and Lombardi's proposal confirms previous worries about the bottom-up approach: it may involve partiality. This is because it treats subsystems as open systems that are free to interact, while they should be seen as fragments of a bigger structure. Connecting this to ontic structural realism, it appears that an overall structure cannot be derived from its intersections; we would end up with the same subjective problems that an open-system view of QM faces when trying to account for the classical limit. That is, when dividing a structure into a set of intersections, information is lost and we become unavoidably partial.

The closed-system view also proposes that entangled particles are not proper systems, but mere partitions of a closed system. This, in turn, supports holistic interpretations of non-separability. Further, there is no reason to suspect that the bottom-up approach contains information that is not defined in the top-down approach, because any explanation from the bottom-up is just a partial version of one that comes from considering the closed system as a whole. Therefore, we have no problem applying *Source Inference* to entangled particles: quantum holism can, and probably should, be understood in terms of common ground.

## Property composition

Where we are: we have reasons to think that quantum systems are closed, which advocates for an overall top-down approach to QM. By starting with the quantum system as a whole, we ensure that all information is captured, as opposed to the bottom-up approach which appears to be limited to the perspective of the observer, and therefore lacks general accuracy. In the following paragraphs, I will show how Fortin and Lombardi's position assumes property composition.

There are two possible types of subsystems that can appear in a closed system. On the one hand, we have subsystems that are due to the partition of the closed system; such systems are not objective but mere reflections of the viewpoint from which the closed system is considered. On the other hand, we have subsystems that are closed and, therefore, exist objectively apart from the system they appear in (Lombardi and Castagnino, 2008). In the first scenario, properties of open systems correspond to properties of a partition of the closed system; they are properties of the whole regarded from a specific viewpoint. Information found in these kinds of subsystems can always be derived from the closed system through different ways of decomposition (Lombardi and Castagnino, 2008; Fortin and Lombardi, 2017).

In the second scenario, however, subsystems are actual proper parts whose properties do not necessarily have to be thought of as properties of the composite system. In order to explore what happens in this situation, we must choose an interpretation of QM; more specifically, one that endows a top-down closed-system view. An interpretation that does just that is the ‘Modal Hamiltonian Interpretation’ of QM (the MHI) (Fortin and Lombardi, 2017: 19-20). In this interpretation, systems can be decomposed in many different ways, but not any decomposition leads to proper quantum systems. Proper subsystems are correlated, but do not interact with one another. This correlation makes it so that the quantum state of the composite is an entangled state which is more than the sum of the quantum states of its subsystems. Entanglement between subsystems is a different relation compared to entanglement between ‘open systems’. Most importantly, the system composition and decomposition postulates of the MHI has it so that all properties of proper subsystems corresponds to a property of the composite, which means that property composition holds:

“The interpretational postulate IP4 expresses the usual quantum assumption according to which the observable $A1$ of a subsystem $S1$ and the observable A=A1⊗I2 of the composite system S=S1 ∪ S2 represent the same property.” (Lombardi and Castagnino, 2008: 391)[4]

The MHI has been proven successful in its predictions, corresponds well with empirical evidence, and avoids problems that other modal interpretations face. Perhaps most notably, it can give an account of the so-called measurement problem, both in its ideal and non-ideal versions. The non-ideal version of the measurement problem is troublesome for the BDMI and SDMI, which are the modal interpretations that Calosi bases his argument on. To get around this problem, BDMI and SDMI explain non-ideal measurements through environment-induced decoherence (EID), which is the open-system view that Fortin and Lombardi argue against (Lombardi and Dieks, 2021).

[4] ‘I2’ is the identity operator in S2.

The closed-system view is ultimately about viewing the whole proper system with ontological priority:

"All these works show that the view that endows closed system with ontological priority is gaining ground in the quantum foundations community. The top-down view of decoherence is one of its different manifestations" (Fortin and Lombardi, 2017: 20)

But even with this, one can ask whether property composition necessarily follows from the closed-system view. Is a closed-system interpretation without property composition possible? If we accept that closed systems have ontological priority, it seems necessary that composite systems are something over-and-beyond the sum of its subsystems. The reason being that if subsystems do not interact – which they, since they are closed systems, do not – something needs to account for how they are connected. That something is likely to be found from the viewpoint of the composite, which can be seen as a common ground that the subsystems share. As a consequence, decomposition into subsystems leaves out information about the composite.

On the other hand, if the viewpoint of the closed system is prior, decomposition of a composite lets us identify and fully characterise its proper subsystems. The idea of the bottom-up approach was to identify quantum systems and thereafter look at how they interact and form composites. But in the closed-system view, a bottom-up approach appears to be neither applicable nor necessary. That is because subsystems are derived from a bigger whole, they do not interact as long as they are closed, and their correlations cannot be explained through their respective properties alone.[5]

[5] It is not my place to say that it is *impossible* for a closed-system interpretation to be compatible with failure of property composition. But as we can see, it seems highly unlikely.

The previous reasoning certainly makes a case for property composition. Most of all, it shows how tightly connected the closed-system view and property composition are: if we want to avoid open-system views of QM (which we seem to have good reasons for), then property composition is a very likely consequence of the solution. When discussing what grounds what in the quantum realm, then, the question is about the ways a quantum system can be decomposed, and not what is making it up.

## Conclusions

I have examined the role of property composition in quantum mechanics through a framework of bottom-up and top-down approaches to quantum phenomena. I have argued that a top-down approach to characterising a quantum system is necessary, which, in turn, can be connected to holistic interpretations of non-separability and ontic structural realism; both of which push for an asymmetry of supervenience where properties of parts depend on properties of the whole, but not the other way around.

Further, there is interpretational pressure to only consider the closed system as a proper quantum system. Systems that appear to be open are, by contrast, merely partitions of a bigger closed system, similar to what holistic non-separability and ontic structural realism suggests. As a consequence, the whole closed system has ontological priority. Since *proper* subsystems are closed and do not interact, their correlation is a property of the composite alone, entailing failure of property decomposition. Property composition holds because, since closed systems have ontological priority, the composite possesses all information that can be found in its subsystems; subsystems can be fully derived through decomposition of the composite.

Summing up, I have argued that there is good reason to approach QM from a top-down closed-system perspective, where property composition but not always property decomposition holds. In other words, an ontology with emergent but not submergent properties.

## References


- Bell, John S. "On the einstein podolsky rosen paradox." *Physics Physique Fizika* 1.3 (1964): 195.
- Claudio Calosi, On the possibility of submergence, *Analysis*, Volume 77, Issue 3, July 2017, Pages 501–511.
- Da Costa, Newton, Olimpia Lombardi, and Mariano Lastiri. "A modal ontology of properties for quantum mechanics." *Synthese* 190.17 (2013): 3671-3693.
- di Francia, Giuliano Toraldo. "A world of individual objects." (1998).
- Dieks, Dennis, and Marijn AM Versteegh. "Identical quantum particles and weak discernibility." *Foundations of Physics* 38.10 (2008): 923-934.
- Einstein, Albert, Boris Podolsky, and Nathan Rosen. "Can quantum-mechanical description of physical reality be considered complete?." Physical review 47.10 (1935): 777.
- Fortin, Sebastian, and Olimpia Lombardi. "A top-down view of the classical limit of quantum mechanics." *Quantum structural studies: Classical emergence from the quantum level*. 2017. 435-468.
- French, Steven, and James Ladyman. "Remodelling structural realism: Quantum physics and the metaphysics of structure." *Synthese* 136.1 (2003): 31-56.
- French, Steven, and Décio Krause. *Identity in physics: A historical, philosophical, and formal analysis*. Oxford University Press, 2006.

- French, Steven. "Vi*—structure as a weapon of the realist 1." Proceedings of the Aristotelian Society (Hardback). Vol. 106. No. 1. Oxford, UK: Blackwell Publishing Ltd, 2006.
- Healey, Richard, "Holism and Nonseparability in Physics", *The Stanford Encyclopedia of Philosophy* (Spring 2016 Edition), Edward N. Zalta (ed.)
- Ismael, Jenann, "Quantum Mechanics", *The Stanford Encyclopedia of Philosophy* (Fall 2021 Edition), Edward N. Zalta (ed.)
- Loemker, Leroy E. "Gottfried Wilhelm Leibniz. Philosophical Papers and Letters." *Philosophical Quarterly* 8.32 (1958).
- Lombardi, Olimpia, and Mario Castagnino. "A modal-Hamiltonian interpretation of quantum mechanics." *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics* 39.2 (2008): 380-443.
- Lombardi, Olimpia and Dennis Dieks, "Modal Interpretations of Quantum Mechanics", *The Stanford Encyclopedia of Philosophy* (Winter 2021 Edition), Edward N. Zalta (ed.)
- Schaffer, Jonathan. "Monism: The Priority of the Whole." *The Philosophical Review*, vol. 119, no. 1, [Duke University Press, Philosophical Review], 2010, pp. 31–76
- Schaffer, Jonathan, "Monism", *The Stanford Encyclopedia of Philosophy* (Winter 2018 Edition), Edward N. Zalta (ed.)
- van Fraassen, B. C., 1972, "A formal approach to the philosophy of science," in *Paradigms and Paradoxes: The Philosophical Challenge of the Quantum Domain*, R. Colodny (ed.), Pittsburgh: University of Pittsburgh Press, pp. 303–366.
- Van Fraassen, Bas C. "The Einstein-Podolsky-Rosen paradox." *Logic and Probability in Quantum Mechanics*. Springer, Dordrecht, 1976. 283-301.

- Van, Fraassen, and Bas C. Van Fraassen. *Quantum mechanics: An empiricist view*. Oxford University Press, 1991.
- Vermaas, P., 1998, "The pros and cons of the Kochen-Dieks and the atomic modal interpretation," in *The Modal Interpretation of Quantum Mechanics*, D. Dieks and P. Vermaas (eds.), Dordrecht: Kluwer Academic Publishers, pp. 103–148.