Segmenting Ontology

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Abstract

Ontological universalism is widespread, but this paper argues that the validity of many ontological claims is bounded, and thus that segmented (though not *frag*mented) ontologies may represent the world more accurately. To be more specific, it criticizes the work of Karen Barad, and of James Ladyman and Don Ross. Both draw ontological conclusions from interpretations of quantum mechanics and then attempt to universalize the reach of those conclusions. By contrast, the paper adapts a loosely Bhaskarian critical realism to develop a segmented ontology. This identifies two boundaries between three related but also substantially different ontological segments. At the boundary between the quantum and material segments, quantum particles can become entangled with larger systems in ways that provide determinate relative locations for material objects. This enables the emergence of causal powers that depend on determinate spatial relations between the parts of material objects. At the boundary between the material and social segments, mental properties provide the possibility of human agents forming intentional relations and thus enable the emergence of social causal powers. Regardless of the merits of this particular ontological scheme, I argue that segmented ontologies are likely to fit better with the causal structure of our universe.

Keywords

Critical realism; agential realism; structural realism; quantum mechanics; social ontology.

Statements and Declarations

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1 Introduction

Scholars have often tended, whether explicitly or implicitly, to see ontological claims as universally valid. Some authors are quite explicit about this, such as Bruno Latour's insistence on treating everything as an actor-network or assemblage. Latour (at least prior to the introduction of *modes of existence* in his later work) explicitly effaces differences, for example, between humans and non-humans, or the social and the non-social (Latour, 2005). Or consider Elizabeth Bennett's new vitalism, extending life force all the way down to atoms and beyond (Bennett, 2010). Others perhaps adopt the assumption implicitly without considering it problematic, assuming that their arguments are universally applicable without considering the question of how wide their zone of validity might be.

This paper's most general thesis is that ontological universalism has led to a series of significant errors and that we should pay more attention to the boundaries of validity of our ontological claims. More specifically, I will argue that several otherwise quite different authors have erred by generalising universally from (often rather speculative) views of the ontological implications of quantum mechanics. These quantum imperialists, as I shall call them, have used this universalising strategy to attack more conventional metaphysical realisms. Meanwhile, some realists may have made themselves vulnerable to such attacks by their own tendency to universalise forms of realism without attending to the possibility that they cease to be valid in the quantum realm.

As an alternative, this paper offers the strategy of segmenting ontology: recognising that our ontological claims have validity boundaries and thus that more comprehensive ontologies will see the world as segmented into different areas or aspects in which different but mutually consistent ontological claims apply. This does not in itself entail accepting any specific set of ontological claims, but I will also argue that broadly realist claims can be sustained across all known domains of ontology even though they may have to take different forms in different areas.

While others have pointed to flaws arising from the universalising strategies of quantum imperialism, few have sought to develop an explicitly segmented ontology as an alternative. This paper, by contrast, attempts to construct a concrete segmented ontology based on clear principles. To do so, the paper will adapt a loosely Bhaskarian form of critical realism to show how a segmented realist ontology could function.

The first two parts of the paper will outline and challenge some examples of quantum imperialism, focusing on two influential works from quite different traditions: Karen Barad's *Meeting the Universe Halfway* (Barad, 2007), and James Ladyman and Don Ross's *Every Thing Must Go* (Ladyman et al., 2007). The third will begin to develop an alternative by giving a brief overview of critical realist ontology. The core concept here is *mechanisms*: processes that produce causal powers. The heart of the paper's argument is that different kinds of mechanism operate in the different segments it considers. The following two sections will propose segmenting ontology by partially differentiating the ontologies of the quantum and social realms from that of ordinary material objects, and the last will provide an overview of the resulting segmented ontology and the interfaces between its segments. In the proposed ontology, mechanisms in the ordinary material segment are essentially spatial, while those in the social segment are intentional. The spatial mechanisms of the material segment are made possible by entanglement with (typically) larger objects at the quantum level, while the intentional mechanisms of the social level are made possible by the development of mental properties from the material level.

2 Quantum imperialism

It has been known for much of the last century that quantum phenomena follow radically different patterns than we might expect from classical physics. In the well-known two-slit experiment, for example, when electrons or photons are fired through two narrowly separated slits the pattern that they make on a screen behind the slits does not form two parallel lines behind the two slits, but rather a diffraction or interference pattern. This implies that individual particles don't simply take a single path but are somehow influenced in the path they take by the possibility of passing through either slit. Rather than taking a determinate path they arrive in the places that we might expect if each individual particle took a mixture of the two paths (see, for example Al-Khalili, 2012, pp. 17–24). For many years physicists themselves tended to set aside the ontological challenges this raises, preferring to "shut up and calculate" (Becker, 2018, p. 226), and indeed marginalising those who raised questions about the proper 'interpretation' of quantum mechanics (Becker, 2018, p. 211). More recently, however, both philosophers and philosophically inclined physicists have taken more interest it the ontological implications of quantum mechanics. Many have argued that quantum phenomena call into question ontologies that were informed by earlier physics and other sciences. My concern in this paper, however, is with the increasing tendency to argue, not simply that we need to change our ontologies to accommodate the quantum realm, but that existing ontologies should be superseded entirely by new ontologies of universal scope derived from quantum phenomena. I will refer to this latter strategy as *quantum imperialism* (a term that was used in a similar sense by Cartwright, 1999, pp. 232–233).

Examples include the work of the international relations theorist Alexander Wendt (Wendt, 2015) and the physicist Carlo Rovelli (Rovelli, 2021), but I will focus on what are perhaps the two most prominent examples. The first is the book *Every Thing Must Go* by the analytical philosophers Ladyman and Ross (Ladyman et al., 2007), and the second *Meeting the Universe Halfway* by the physicist turned poststructuralist social theorist Karen Barad (Barad, 2007). All argue, in quite different ways, that we should derive our ontology from their understandings of the quantum space. They also claim that because quantum phenomena are foundational to all other material phenomena this means that our entire ontology must take a form drawn from quantum phenomena. In other words, they are all committed to the idea of a uniform universal foundationalist ontology.

Ladyman and Ross defend what they call "a radically naturalistic metaphysics," meaning "a metaphysics that is motivated exclusively by attempts to unify hypotheses and theories that are taken seriously by contemporary science" (Ladyman et al., 2007, loc. 73). On this basis, they dismiss vast swathes of recent metaphysics which, they claim, fail to take adequate account of fundamental physics. Yet, they are also dismissive of the ontological significance of all contemporary science other than quantum physics itself. They claim that scientists themselves recognise the "primacy of physics" (Ladyman et al., 2007, loc. 680), meaning that other sciences must give way to the implications of quantum physics but not vice-versa. They then advance a similar principle for ontology: any ontological implications of the special sciences must give way to those of fundamental (i.e. quantum) physics. In particular, as the title of their book suggests, they deny the metaphysical significance of things, entities, or individuals: “if the best current interpretation of fundamental physics says there are no self-subsistent individuals, then special sciences had better admit, for the sake of unification, of an ontological interpretation that is compatible with a non-atomistic metaphysics” (Ladyman et al., 2007, loc. 3166).

Having said that, they do allow a place for objects but claim that “they are not metaphysically fundamental” (Ladyman et al., 2007, loc. 2165). For them, things, events, and processes “lose all significance except purely practical, book-keeping, significance for human beings in certain sorts of special circumstances. From the metaphysical point of view, what exist are just real patterns” (Ladyman et al., 2007, p. 2009). Scientists beyond quantum physics, it seems, are to be allowed to work with these concepts, but they are really secondary to the core concept of their *ontic structural realism*: patterns of phenomena. This reflects the nature of quantum mechanics, which takes the form of wave or matrix equations that (remarkably successfully) predict the *probability* of certain outcomes, such as where on the screen at the back of the two-slit experiment an electron might strike. Those equations can also therefore predict the overall pattern that will be produced across many outcomes, but they have nothing to say about the causal processes or mechanisms that produce any given outcome. Ladyman and Ross think that this model of science, which is remarkably successful at predicting the probabilities of certain outcomes at the quantum level but remarkably limited in terms of its explanatory ambition, should provide the basis for a universal ontology that also applies to other sciences which can and do develop fuller causal explanations. This quantum ontology, they suggest, trumps whatever ontological conclusions we might draw from the other sciences.

Barad’s background and her reference literature are very different from Ladyman and Ross – she is a physicist who has engaged deeply with poststructuralist social theory. Yet her version of quantum imperialism shares several features with theirs: it is explicitly universalist, it is based largely on a single feature of quantum mechanics as she understands it, it denies the ontological significance of entities and conventional understandings of causation, and she argues that it should supplant all previous ontologies. Like them, she claims to base her ontology on “an empirically accurate understanding of scientific practice, one that is consonant with the latest scientific research” (Barad, 2007, p. 26) – and, again, only on one variety of scientific research, quantum mechanics.

Beyond this, however, their perspectives are quite different. Drawing on her own interpretation of the philosophy-physics of Niels Bohr (Barad, 2007, Chapter 3), perhaps the most influential figure in the history of quantum theory, Barad develops what she calls *agential realism* (Barad, 2007, Chapter 4). For her, “the primary ontological units are not ‘things’ but phenomena - dynamic topological reconfigurations/ entanglements/ relationalities/ (re)articulations of the world” (Barad, 2007, p. 141). Entities, she argues, do not pre-exist phenomena but rather come into being through processes of intra-action – not inter-action, which would imply the prior existence of the things that interact. Again, this approach builds on one key feature of quantum mechanics, or rather on one key feature of Bohr’s interpretation of quantum mechanics as she understands it. This is the idea that certain properties of quantum entities like electrons and photons are indeterminate before they are measured – not just unknown, but inherently not set to any value. If, for example, an experiment measures the position of an electron, then it is the intra-action between the measuring apparatus and the electron that brings its position into being. Such outcomes come about, according to Barad, through entanglements, but she does not understand entanglement as a relation between two previously existing individuals; on the contrary,

> To be entangled is not simply to be intertwined with another, as in the joining of separate entities, but to lack an independent, self-contained existence. Existence is not an individual affair. Individuals do not preexist their interactions; rather, individuals emerge through and as part of their entangled intra-relating (Barad, 2007, p. ix)

Like Ladyman and Ross, however, once she has drawn this conclusion for quantum existence, she then insists that it applies across the ontological spectrum.

3 Questioning quantum imperialism

While I will dispute some of the key points made by these authors, quantum mechanics itself is one of the most successful contemporary sciences. I can see no reason to doubt its strictly scientific conclusions or the fact that they cause problems for some of our established ways of thinking. Quantum behaviour clearly conflicts with the sorts of ontological models that we could draw from classical physics, and not just in the case of the two slits experiment – there are many other experiments that reveal equally puzzling quantum behaviour. Objects like electrons, photons and indeed all the subatomic particles that make up our universe behave in ways that seem incomprehensible in terms drawn from classical understandings of objects. One popular interpretation of what might be required to produce the kind of diffraction pattern produced in the two slits experiment is that the particles concerned don't have determinate spatial positions while they are travelling, but rather something like a probabilistic field of potential positions. Those probabilities can be calculated using an equation called a wave function. Wave functions appear to describe a state in which the particle exists in a *superposition* of different locations (or other properties), with different probabilities, at the same time. Physicists can specify these wave functions precisely and they produce exceptionally reliable empirical predictions (of patterns, not individual events). Despite this indeterminacy during the journey to the screen, however, when an electron reaches the screen its position is resolved at a specific point, hence the bands we see in the diffraction pattern. Often these moments of resolution are called measurements, although it is now clear that they also occur in many other circumstances when they are not provoked by measurement experiments (for fuller explanations, see, for example, Al-Khalili, 2012; Cox & Forshaw, 2011).

Alongside quantum science, however, there are also a great many *interpretations* of quantum science, including many by physicists, that are not logically entailed by it. The best known is the so-called Copenhagen interpretation on which Barad draws, developed by Niels Bohr, Werner Heisenberg, and other physicists from about the 1920s onwards. Perhaps the most problematic element of this approach is its empiricism. Its advocates essentially deny that anything unmeasured is meaningful. This encourages formulations like one I used in the previous paragraph: that particles do not have determinate positions until their positions are measured. But other interpretations are possible. Metaphysical realists are particularly fond of citing the work of David Bohm, who advocated a pilot wave theory in which the particles in two slit experiments always have determinate positions, but they are guided by a pilot wave that affects where they end up (see, for example, Al-Khalili, 2012, pp. 161–165; Lewis, 2016, pp. 55–59). Bohm's theory, however, appears to require nonlocal causation at the quantum level (Lewis, 2016, p. 111). This means that entangled particles can affect each other's properties instantaneously over extended distances, contradicting a long established belief, mandated by Einstein's Special Theory of Relativity, that causation can only operate locally – by direct contact, that is, between the entities that are taken to be causally affecting each other, which is limited temporally by communication at the speed of light (Lewis, 2016, pp. 110–111). The implication is that at least some part of traditional metaphysical realism must go when we are considering the quantum world. I will consider later how this might play out for the quantum space.

The concern of this paper, however, is the claim that these challenges must also affect the ontology of what we might call the classical domain: loosely speaking, the world of objects significantly larger than photons, quarks and atoms, often referred to in this literature as *macroscopic* objects. Even if it were true, for example, that electrons and all their properties do not pre-exist their intra-actions with macroscopic apparatuses (a claim I shall reject below), can we really say the same about macroscopic objects? Even if it is true that it is only patterns that are real in the quantum space (and again I will reject this), could we really say the same about the worlds of classical physics and everyday experience?

Both Barad and Ladyman and Ross argue that we must, on the grounds that quantum mechanics applies to macroscopic objects as well as those that are usually considered quantum particles. Ladyman and Ross deny that indeterminism "can be confined to the microscopic level" on the grounds that "if there is indeterminism among quantum events and there is any coupling of them to macroscopic events, as there surely is, then the indeterminism will infect the macroscopic". They illustrate the point with the example of "a physicist deciding that she'll go for lunch after exactly so many clicks of the Geiger counter" (Ladyman et al., 2007, loc. 473). Barad is more ambitious, arguing that the equations of quantum mechanics apply equally to microscopic and macroscopic objects, with the laws of classical physics merely providing a useful approximation to them for the macroscopic cases. ""As far as we know," she writes, "the universe is not broken up into two separate domains (i.e. the microscopic and the macroscopic) identified with different length scales with different sets of physical laws for each" (Barad, 2007, p. 85).

These arguments, however, do not entail we must accept quantum ontological imperialism. Consider three reasons.

First, the idea that we should extend arguments derived from quantum physics to all other domains of ontology rests on the claim that quantum physics is *fundamental*, as if there could be nothing below it. Yet all scientific claims that have been regarded as fundamental in the past have ended up being seen as secondary to the science of some new, more fundamental, level of reality. The logical expectation is that quantum science will cease to be seen as fundamental when we learn more about even more microscopic phenomena. Quantum theory, for example, might end up being understood as derivative from, or at least as less fundamental than, string theory. And then that pattern may repeat itself until we get to, not necessarily the real fundaments of reality, but the deepest level it is feasible for human science to discern or make sense of. Quantum imperialism rests on a failure to recognize that any ontological conclusions drawn from quantum mechanics are just as provisional, just as secondary, and just as pragmatic as the ontological conclusions we can draw from any other area of science or indeed of practical knowledge. There is therefore no grounds for deprecating ontology shaped by our understanding of higher levels of reality as inferior to quantum based ontology – as merely "parochial", "homely", or "folk" knowledge, as Ladyman and Ross position it (Ladyman et al., 2007, locs. 4056, 4545, 4598). As Peter Lewis has pointed out, if it were true that our ontology can only be based on the science of the most fundamental theory then we would have to "end up endorsing a kind of metaphysical skepticism: We can't know anything about physical ontology until the end of physics" (Lewis, 2016, p. xvii). And we may never know whether the end of physics has arrived.

Second, even if we could know that current quantum mechanics is in fact the final fundamental science of being, this would not entail that quantum science is the only science that matters, nor that quantum science is the only science that should inform our ontology. As Doug Porpora, for example, argues, as we move up through different levels of composition we find "varying causal logics" emerging, and mechanisms that can counteract forces at lower levels (Porpora, 2022, pp. 6–7). If that is so, and I shall develop that argument further below, then these forces cannot be left out of a comprehensive ontology. Nor can "thingness" be left out, if the causal powers of these higher level mechanisms rest on the persistent existence of individual objects.

Third, even if quantum mechanics were the final fundamental science and there was a convincing reason to believe that it should be the foundation for a single universal ontology, there would remain the question of what it is about quantum mechanics that could provide such a foundation. If the intention is to invoke the strongest scientific conclusions of quantum mechanics, the usual answer offered by physicists would seem to be the equations that predict the probabilities of quantum events and the empirical patterns that arise from those probabilities (Lewis, 2016, p. 1). Ladyman and Ross gesture strongly in this direction, with their talk of patterns and structures, but the further implication that they want to carry across to all ontology is the denial of the existence of things, of individuals, and there is no warrant for this in quantum mechanics itself – only in some of the speculative and controversial interpretations that have been made of it. Barad, similarly, wants to dispose of objects from our ontology on the grounds that in quantum mechanics there are no persistent objects but only intra-actions producing phenomena. Again, however, this is an interpretation, not a scientific finding. As Faye and Jaksland have argued, it is also an interpretation that is out of step with most others, including that of Bohr, whom she claims as her inspiration (Faye & Jaksland, 2021, pp. 8231, 8233). As they conclude, "agential realism is not entailed by quantum mechanics" (Faye & Jaksland, 2021, p. 8246).

Indeed, the most cursory examination of the two slits experiment reveals that quantum mechanics is built on the assumption that microscopic entities *do* exist and do persist from moment to moment. Those experiments make no sense whatsoever without the belief, which is baked into every description of them, that electrons can be fired at the two slits and then persist at least until the point at which they strike the screen behind them. Granted, it seems likely that not all the *properties* of these electrons exist continuously through the experiment, and it seems certain that electrons are nothing like classical notions of particles. However, there is still an individual object that is fired at the screen, that arrives there, and that has certain properties even if those properties themselves are not persistent. One consequence is that neither Barad's ontology nor Ladyman and Ross's is convincing even as an ontology of purely quantum phenomena.

If quantum mechanics cannot do without things, the same conclusion applies *a fortiori* to the macroscopic sciences and indeed our explanations of ordinary events. Take, for example, the creation of books and papers on the topic of ontology. Until such time as artificial intelligence progresses a little further, and with the possible exception of forms of intelligence on other planets of which we are unaware, their creation requires the contribution of at least one human being, the writer. As Bouzanis has argued, for an ontology to be coherent, it must be consistent with the conditions required for its own production (Bouzanis, 2023, pp. 42–43). And thus, any coherent ontology must accept that we ontologists exist; any *plausible* ontology, I suggest, must accept that human beings exist both before and continuously during the production of the book or paper concerned.

While these arguments may be enough for us dismiss quantum imperialism, quantum science nevertheless raises issues that any alternative ontology will have to confront. Quantum behaviour remains incomprehensible in the terms of classical physics and much conventional ontology, and so we must find a way to accommodate it in an ontology that can also make sense of macroscopic behaviour. That points towards the need for a segmented ontology, an ontology that recognises that entities in different segments or domains of reality behave in significantly different ways. That in turn raises new questions: What are the different domains? What criteria mark the boundaries between them? How can phenomena in these different domains relate to each other or interact? And (how) can the ontologies of different segments be compatible with each other despite being different in at least some respects? Ultimately, I will argue, we need a segmented ontology in which the segments fit together like the piece of a jigsaw - we need to be able to see how the join works in a way that is consistent with what lies on each side of it.

4 Critical realism

This paper argues that we can construct a segmented ontology from a version of critical realism, based on the work of Roy Bhaskar and other critical realists, including Margaret Archer, Tony Lawson, and myself (Archer, 1995; Bhaskar, 1975, 1979; Elder-Vass, 2010; Lawson, 2019). This section will describe what we could call the *classical* version of critical realism, both in the sense that I believe it is a reasonable representation of mainstream critical realist ontology and in the sense that it relates most clearly and consistently to the realm of classical physics: macroscopic material objects and their causal powers. Having said that, critical realism is already somewhat segmented, in two senses. First, all its advocates acknowledge significant differences between the ontology of the material and the social; and second, it distinguishes between general philosophical ontology and what Bhaskar calls *scientific ontologies*, which relate to the particular types of entity, mechanism and power present in the domains studied by particular scientific disciplines (Bhaskar, 1986, p. 36). Despite that, there is a tendency for critical realists to assume that it has a core philosophical ontology of universal applicability, and little attempt has been made to accommodate the challenges of quantum science. A few critical realists, however, have adopted Bohm's pilot wave theory, perhaps because it appears to provide a way to fit the quantum realm into critical realism's core ontology (Lawson, 2023; Norris, 2000).

This core was introduced by Bhaskar through a critique of Humean understandings of cause as constant conjunctions of empirical events: as laws describing exceptionless regularities of the form 'events of type A are always followed by events of type B' (Bhaskar, 1975, pp. 12, 33–35). Bhaskar argues that the logic of scientific experiments assumes that the causal forces they reveal continue to operate in the world beyond the lab, even when they do not produce the causal regularities that can be created in the closed systems of the lab. Experiments are conducted by eliminating factors that would otherwise interfere with the results obtained, in order to reveal the sorts of outcomes that the causal forces involved *tend* to produce even outside the lab but do not always succeed in producing when such interference is present (Bhaskar, 1975, p. 46). Such experiments would be pointless if they did not tell us something useful about causal forces in non-experimental contexts, and we routinely believe that they do so. This can only make sense if causal forces operate as tendencies that can be frustrated or indeed aided by the interference of other causal forces, rather than simply as exceptionless empirical regularities (Bhaskar, 1975, pp. 49–50).

This leads Bhaskar to adopt a causal powers theory, in which things (objects, individuals, or what I will call *entities*, using this term in a narrow sense that excludes, for example, events or phenomena) have emergent causal powers. Although Bhaskar is not particularly clear about how he understands emergence, at least some critical realists have argued that the basis of causal powers in this ontology is compositional (Elder-Vass, 2005). The powers of a whole, that is, depend on the nature of its parts, the relations in which they stand to each other when they are composed into this type of larger whole, and the ways in which those parts interact with each other as a consequence. Each causal power is taken to be the result of a particular mechanism: a particular process of interaction between the parts that is made possible by the whole's composition and structure (Elder-Vass, 2010, Chapter 2). Actual events are then produced by the interaction of the causal powers of whatever entities affect the case, which is known as multiple causation (from Mill) or multiple determination (Bhaskar, 1975, p. 72). Any given causal power, as a result, may or may not produce the outcome it tends towards in any given case, depending on how it interacts with the powers of other entities that are also acting in the case concerned.

This is a form of entity realism, and critical realists are committed to the view that entities and their powers exist independently of any given observer's beliefs about them (while social entities do depend on human beliefs, as we shall see in the next section, they are largely independent of any *particular* observer's beliefs). This ontological realism, however, implies that whatever beliefs we have about entities and their powers could be wrong, and so is accompanied by epistemological relativism, in the sense that our beliefs are seen to be influenced by the context of their formation. They are formed, in other words, through a series of multiply determined events, and are influenced both by our experience of their objects but also by other factors, including social factors. Having said that, because they are influenced by their objects and not *only* by social factors as radical social constructionists suggest, we may often have a reasonable basis for making judgements about them, which Bhaskar refers to as *judgemental rationality* (Bhaskar, 1986, p. 91).

Bhaskar's theory also entails (or the generalisation of conclusions from experiments to other cases could not hold) that entities fall into natural kinds, where all members of the kind (subject to the usual qualifications regarding fuzzy kinds) possess the same powers by virtue of possessing relevantly similar components, internal structures, and thus mechanisms. Because entities fall into natural kinds it is possible to develop causal explanations of both powers and events, which always rest on the characteristic capacities of entities of the kinds involved. We can also think of natural kinds as falling into larger groups where the members of the group have loosely common causal structures. For example, there are many kinds of molecules, but they are all composed of atoms held together by similar forces and this similarity of their composition and structure creates some parallels in the kinds of mechanisms that produce their causal powers. It is this that allows the segmentation within critical realist ontology alluded to above as the distinction between philosophical and scientific ontologies. So, for example, biology has a different scientific ontology then geology, because they deal with different kinds of objects, but both are taken to be sub-types of a more general philosophical ontology.

Still, that general philosophical ontology itself is generally assumed to be universal and unvariegated, and critical realism has occasionally been criticised for this (e.g. by Sarkia &

Kaidesoja, 2023). There is, arguably, a contrast here with the work of Nancy Cartwright, who also advocates a causal powers ontology but tends to be less systematic about what causal powers have in common with each other. She talks of “a patchwork, not a pyramid”, which might be taken as a critique of the kind of approach advocated in this paper, but it is *laws*, understood as exceptionless empirical regularities that she is commenting on here, not causal powers (Cartwright, 1999, p. 1). Her ‘dappled world’, I think, is less structured than the world as understood by critical realists and leaves more space for diversity in our understanding of the natures of things but may still be compatible with a segmented ontology.

This paper argues that critical realist ontology, because of its built-in sensitivity to the ontological diversity arising from different kinds of structures and different classes of kinds, provides an adaptable starting point well-suited to the development of a more segmented ontology. Indeed, the existing treatments of *social* reality in critical realism point towards just such a segmentation, although they were mostly developed *ad hoc,* as ways to provide ontological tools for the social sciences, rather than as part of a wider approach to ontological diversity. They do mean, however, that critical realism is well-placed to make sense of a partial ontological break between ordinary material reality and social reality: partial in the sense that significant parts of the core model also work for social reality, while others require modification. That, in turn, will provide us with a partial model for how we might be able to make sense of the break between classical material reality and quantum reality.

5 Social realism

Bhaskar turns to social reality in his second book, *The Possibility of Naturalism* (Bhaskar, 1979). The title already indicates that he believes the ontology of the social has something in common with that of the material world. As Ted Benton points out, however, the book could equally well have been called *The Impossibility of Naturalism*, since it pays at least as much attention to the ways that the social sciences, and the ontology of their subject matter, *differ* from the natural sciences (Benton, 1985). Bhaskar argues that social structures differ from natural structures in three significant ways: they are activity dependent, concept dependent, and less enduring (Bhaskar, 1979, p. 38). For our purposes the most important of these is concept dependence: social structures depend on what people believe. Perhaps the most familiar example is the case of money: money only exists when some group of people believes that some particular form of token is acceptable as a form of payment (Elder-Vass, 2022, pp. 102–106; Searle, 1995, pp. 37–46). They are activity dependent in the sense that their effects depend on people constantly reproducing them by acting on those beliefs. And they are less enduring because they can be modified through changes in those beliefs and actions.

Bhaskar also provides a simple model of the reproduction and change of social structures, in the form of his Transformational Model of Social Activity, although a similar model developed in parallel by Archer of the *morphogenetic cycle* is more influential among critical realists in the social sciences (Archer, 1995, pp. 154–161; Bhaskar, 1979, pp. 33–37). Both see social structural change as a cycle in which people are influenced in their actions by their previous experience and understanding of the structural conditions. Those actions, collectively, then lead to further reproduction or (usually gradual) transformation of the structures concerned. Both also see the resulting structures as emergent. Elder-Vass examines the nature of that emergence more closely, arguing that social structures, like material structures, have emergent properties that depend on their composition and the relations between their parts (Elder-Vass, 2010).

Distinctively, social structures include people among their parts, and their powers depend on the beliefs of those people and the processes of interaction between them (and often nonhuman material parts as well). Most recently, Tony Lawson's social positioning theory has stressed that individual members of social structures, which he calls communities, acquire some of their capacities through being positioned by those communities in particular roles (Lawson, 2019). The President of the United States, for example, has the capacity to speak as an emergent property of his or her material body, but they also have the capacity to act on behalf of the United States in a variety of contexts because they have been positioned in a role that has those rights and responsibilities. These capacities are therefore in effect powers of the structure, the state, but they are enacted by the President on its behalf. They are examples of what Silver has more recently called "*system-based social properties*" (Silver, 2021, p. 7870).

The basis of these emergent properties of social structures is somewhat different from that of the emergent properties of material objects. In general, I suggest, the emergent properties of macroscopic material objects depend on their parts and the *spatial* relations between their parts. While those spatial relations can take a variety of forms, they all entail that the parts concerned have specific (though often mobile) spatial positions relative to one another. The power of a watch to indicate the time depends on the spatial relationships between its cogs, springs and hands (or, these days, its battery, circuits and digital display); the power of an animal to propel itself along the ground depends on the spatial relationship between its limbs and body (among others); the power of a string of DNA to influence the structure of a body depends on the sequencing of the molecules that make it up. All these mechanisms depend on spatial relations, although in quite different ways. Although it is not possible to prove that *all* material mechanisms depend on spatial relations, I am not aware of any exceptions. By contrast, what is distinctive about social entities (I shall use the terms *social entity* and *social structure* interchangeably) is that their powers also depend on *intentional* relations between some of their parts, in other words on some of the mental properties of the people concerned (Elder-Vass, 2010, pp. 199–202). The President of the United States, for example, only possesses the powers of their role because, and only when, other members of the community believe (a) that they are the President; and (b) that as President they are entitled to those powers. The President need not be in any particular spatial relation with that community for this to be the case.

This has some radically different implications for the nature of social structures as compared to material structures. The most striking is that social structures can overlap profusely. The same wheel can only be part of one bicycle at a time. The same planet can only be part of one solar system at a time. But the same person can be part of many different organisations, and indeed many other kinds of social structures too, all at the same time, because they can have many different intentional relations at the same time (Elder-Vass, 2010, pp. 201–202). That in turn leads to new kinds of possibilities. At the level of the individual, it means that the same human being can occupy multiple different roles in different social structures at the same time (Lawson, 2023, p. 604). At the level of social structures, it means that structures can overlap and interleave profusely in ways that are impossible for ordinary material entities. Frankly, it is impossible to make sense of social reality without recognizing this. The behaviour and influence of any given President, for example, is not merely a function of their material body and their positioning as President, but also a consequence of the ways in which they are embedded in many other intersecting structures – a political party, for example, perhaps a business community, gender structures, racialized structures, and many more.

There are also interesting implications for the question of parthood. We are accustomed to assuming that material objects can be parts of larger wholes, but, other than further nesting that occurs when those wholes themselves become parts, in most cases any given object can only be part of one larger whole at any one time. This makes it natural to think of *all* of the part-object as being a part of the whole-object, and to think of the part-object as being *continuously* part of the whole-object until such time as the whole is broken up in some way. But what happens to these intuitions when someone is part of multiple social entities but only acts their part in each at particular times? If I am part of a rock band, for example, by virtue of the fact that I and the other members believe that to be true and get together occasionally to play loud music, am I still a member of the band when I am asleep or making dinner for my family? Does the rock band even exist when we are all off doing other things? To put it in Baradian terms, do social structures exist between their intra-actions? Wendt, for example, thinks that "social structures are continuously popping in and out of existence with the practices through which they are instantiated" (Wendt, 2015, p. 264). I would argue, on the contrary, that social structures do persist, because we have the dispositions, the tendencies to think and act in the ways that are produced by, and in turn reproduce, those social structures, in between those moments when they have their causal effects. I'm still a member of the band when I'm asleep because I, and the other members, are still disposed to think of me as one and we are all disposed to act in accordance with those beliefs even when we are not actually thinking those thoughts or acting on them. The band therefore exists in between our moments of enacting it.

Perhaps this also helps with some of the other challenges that have been made to social emergentism. Wendt, for example, thinks that the unobservability of social structures is a problem for existing approaches to social science (Wendt, 2015, pp. 23–25). But if the point of social structures is that they exert a causal influence on social events, and this is sustained by intentional relations between their members, then it should be no surprise that those relations are invisible, while the influence of the structures themselves is always enacted through their visible parts – the people that compose them.

I also wonder whether some of the commoner reductionist responses to social realism arise because it is not obvious how the emergentist part-whole model can be translated for social cases. That model may be more persuasive when we are clearer about the radical difference between emergence based on spatial relations and emergence based on intentional relations.

In *some* respects, then, critical realism's social ontology is very similar to its ontology of material entities – it is a compositional ontology of emergent causal powers. Yet there is also a significant ontological break between the two, a difference between the basis of causal powers at the material level and the basis of causal powers at the social level. The difference is that emergence works in different ways, based on spatial relations for material entities and intentional relations for social entities. This in turn explains some of the radical differences between the social world and the non-social parts of the material world. The critical realist accounts of the material and the social, in other words, are two different but complementary segments of a segmented ontology.

This may be contrasted with what we could call a *fragmented* ontology, in which the world is seen as divided into radically separated ontological domains. Some versions of mind-body dualism, for example, deny that there is any significant connection between the mind and the physical body, with the mental appearing to be effectively independent of the physical. The problems this creates can be seen as far back as the work of Descartes: if the mind is completely independent of the physical then it is hard to see how it could have an effect on the world beyond the individual, and so Descartes had to hypothesize a connection through the pineal gland (Lokhorst, 2021). Similarly, radical social constructionists have often argued as if the social was independent of the material. They have tended to evade the question of how the social could act back on the material by invoking the neo-Kantian argument that there is nothing we can know about the world beyond discourse and so our understandings of the world and our effects on it are themselves socially produced (Elder-Vass, 2012, Chapter 12). Yet we live in that world, we affect the material world, and it acts back on us, with little concern for our social constructions, as the developing global climate disaster reminds us. The advantage of a segmented ontology, by contrast with such fragmentations, is that it makes space for us to see that the different segments are interconnected despite their differences, and that we can develop coherent, scientifically-rooted explanations of how those differences themselves emerge.

6 Quantum realism

Can we take a similar approach to the relation between quantum ontology and the ontology of the macroscopic material world? If so, we will need to consider what they have in common, how they differ, and how they connect with one another.

The first commonality, despite the objections of Barad and of Ladyman and Ross, is that they are populated by real and often persistent entities. For the avoidance of doubt, let me make clear that it is the ‘particles’ themselves that I regard as real quantum entities, and not the various mathematical models of them, such as wave functions, that are deployed in quantum mechanics. As I’ve already pointed out, the experiments of quantum mechanics make no sense unless we accept that objects like electrons and photons are real and persist across at least the duration of the experiment. If we take causal impact as a criterion of reality, then the fact that a photon can leave a trace on a screen makes it real. If we take the manipulability of an object by scientists as a criterion of reality, as Ian Hacking suggests, then the fact that electrons can be fired at an apparatus makes them real. Scientists, he tells us, must be committed to the belief that electrons are real because they use them as tools (Hacking, 1983, p. 263; Navarrete, 2024). Granted, they are strange objects by our usual standards, which may not exist in the same sort of form as the objects of classical physics, but they do exist in *some* form. As Chakravartty has shown, subatomic particles in general meet all the standard criteria of realism extremely well (Chakravartty, 2017, p. 140).

Furthermore, some important properties of these particles, such as their mass and electric charge, are determinate, predictable, and in no way subject to the sort of uncertainty revealed by the two slit experiment (Al-Khalili, 2012, p. 139). Indeed, on the basis of these properties and causal regularities in their interactions, physicists have taxonomised subatomic particles into a set of types described in the Standard Model, a centrepiece of contemporary physics (Al-Khalili, 2012, pp. 190–213; Chakravartty, 2017, p. 133). Quantum particles, in other words, fall into natural kinds just as classical objects do.

Thirdly, the reality of quantum particles and their properties, just like macroscopic material objects, is independent of what humans think about them, and this is true even of those properties (like position) that are sometimes indeterminate. It helps, here, to consider what happens when an indeterminate property is resolved to a determinate value. This resolution is sometimes known as the collapse of the wave function, but this terminology is confusing. The wave function is not a real thing, but a mathematical representation of the indeterminacy of the property before the ‘collapse’. What collapses, in the model, is the uncertainty over what the value of the property will be. Having said that, the term *collapse* is used ambivalently in the literature, sometimes to refer to a change in the mathematical model representing the state of the particle, sometimes to refer to a change in the particle itself and sometimes seeming to conflate the two. The implicit physical correlate of this collapse of uncertainty may vary depending on our interpretation of quantum mechanics. I shall assume that it means that a related real change has taken place in the particle, so that a superposition of possible values of the property has been resolved to a specific determinate value. Let me also be clear what I mean by *determinate*: a property is determinate when it takes a single value, which we could find out (i.e. measure) if we have the necessary tools and techniques. It does not mean that there is any causal inevitability to the property taking that value before it does so; it does not mean that the property is necessarily fixed before it is measured; and it does not necessarily mean that there is a *deterministic* process that produces that specific value. No one knows what, if anything, determines the values that these properties resolve to, and the mathematical models give us no help here either except that they give us a reliable set of probabilities for the different possible outcomes.

This absence has contributed to the growing popularity of the *multiple worlds* interpretation, according to which every possible value of a property is realised at such moments, with the universe effectively branching into many different universes, one for each possible value (Lewis, 2016, pp. 59–64). According to this interpretation, it only seems to us that the property has been resolved to a single value because that is what happened in the universe from which we are observing the result, and we have no access to what happened in the others. At every moment of time, of course, there is an unthinkably large number of such property resolutions occurring in any given universe, and at every subsequent moment that would lead to a similarly large number in every one of the new branches. Unthinkability squared, and squared again at every moment of time. No doubt this is a logical possibility, and it seems unlikely we could ever disprove it. But for me there is far simpler and more plausible alternative than this extravagant proliferation of universes: property indeterminacy really is resolved to determinate values in the one universe we inhabit, but we just don’t understand (yet?) how that comes about.

Although we cannot say what determines these values, we can say some things about the circumstances in which they are resolved. At one time, it was suggested that only measurements by scientists brought about the determination of a previously indeterminate property, and even that human observation of the measurement was required to achieve this. However, it is now widely accepted that human measurement is not essential to the resolution of indeterminate property values (Al-Khalili, 2012, Chapter 5; for an exception, see French, 2023). Rather, the measurements in which such resolution occurs are examples of a broader class of configurations that lead to property resolution. It's not that they resolve a property to a determinate value because they are measurements: rather, it is because they resolve a property to a determinate value that they are useful for measurement. True, when scientists conduct measurement experiments, they contribute to the resolution of the property concerned by provoking the collapse of the indeterminacy, but that does not mean that they determine the outcome, the value that the property takes, by their actions. Still less is there any reason to believe that the semantic contents of scientists’ belief might determine any such result. I believe we can therefore reject the sense of mind dependence that could be considered a threat to quantum realism – the radical social constructionist version, in which we have a performative effect on quantum reality when we change how we think or talk about it.

Quantum ontology, then, like macroscopic ontology, must surely include real entities with real properties and causal heft, many of which exist independently of human belief or activity, and which fall into natural kinds. But it seems likely that there are other respects in which it will have to differ from macroscopic ontology.

The most striking distinctions relate to those properties of quantum entities, such as their position, that are not clearly determinate prior to the so-called collapse of the wave function. One option, which has been favoured by some other realists, is to resist the assumption that these properties are indeterminate by adopting Bohm's pilot wave theory, mentioned earlier (Lawson, 2023; Norris, 2000). Perhaps Bohm is right that quantum entities always have determinate positions, and it seems that there is no empirical basis yet on which to judge that. But it also seems that most physicists are unconvinced by his argument and interpret the otherwise puzzling results of quantum experiments to mean that these properties are inherently indeterminate until resolved: that a particle, for example does not have a definite location until the resolution of its location is forced on it by an interaction with some other, typically larger, system (Al-Khalili, 2012, p. 70). For the purposes of this paper, therefore, I will assume that these physicists are right and ask what quantum ontology would look like if indeterminacy is true.

On the one hand, it would seem perverse to call an indeterminate property real. On the other, there are mathematically determinable wave functions that can be used to accurately predict the probability of such properties taking a given value, and these mathematical models would seem to represent or describe *something* real about the particle concerned. One way of thinking about this would be to see the wave function as a description of a quantifiable set of *potentials* that the corresponding real particle possesses. Such potentials would appear to fit with Bhaskar's understanding of non-actual elements of the real and thus with critical realist ontology, although this initial impression would require further examination (Bhaskar, 1975, pp. 56–57; Elder-Vass et al., 2023).

For a segmented ontology that distinguishes separate segments for quantum and macroscopic mechanisms, a second challenge is the question of how the two segments are related to each other. To be more specific, I have argued that causal mechanisms in the macroscopic segment depend on spatial relations between the parts of the entities concerned, and yet at the quantum level the location of a particle (and thus its spatial relations with other entities) can be indeterminate. The moment at which the particle's position is resolved (corresponding to the collapse of the wave function) is therefore crucial to this relationship. Purely instrumentalist accounts are silent at best on the question of how this might occur, but it is possible to provide realist interpretations of this process.

One of the best known is the GRW spontaneous collapse theory, named after Giancarlo Ghirardi, Alberto Rimini, and Tullio Weber, the physicists who proposed it (Ghirardi et al., 1986; for an overview see Lewis, 2016, pp. 50–54). GRW propose an addition to the enormously successful Schrödinger model of quantum systems. Their addition entails that at each moment the wave function of every quantum particle has a very small probability of spontaneously collapsing to a determinate state, with the corresponding property of the particle resolving to a determinate value. The probability is so small that it may be something of the order of a billion years before any given particle's wave function collapses (Becker, 2018, p. 236). But when it does, it also brings about a larger collapse of the wave function for any macroscopic object with which it is entangled (to be discussed below), and a corresponding localization of the whole object (I draw the term 'localization' from Wendt, 2015, p. 76). The GRW hypothesis appears to rest on the existence of a real (although thoroughly random) mechanism that brings about these spontaneous collapses. It may or may not be true, but it does illustrate one possible way in which the positionality of macroscopic objects could emerge from the positional indeterminacy that is described by quantum physics.

Recently these questions have often been approached using the concept of *decoherence*. The core concept is very close to the idea of collapse of the wave function. *Decoherence* also refers to the change that occurs when the wave function for an individual particle is resolved to a specific value, and thus, like collapse, it refers to a feature of the mathematical models used to predict such events. And like *collapse* the term is employed somewhat ambivalently in the literature, sometimes seeming to refer to a corresponding change in the particle itself (Schlosshauer, 2019 seems to use it to refer to both, for example). However, the literature around decoherence has developed the argument further. Here, the core argument is that decoherence occurs when a particle becomes entangled with a (usually) larger system (again both *entanglement* and *system* are used ambivalently in the literature; here I am using *entanglement* to refer to a real relationship between two particles rather than a mathematical model of such a relationship, and *system* to refer to a complex of real particles rather than a mathematical model). Entanglement can occur when two or more quantum particles interact with each other, and has the consequence that "they can become correlated in the sense that their fates will be intertwined for ever, however far apart they get – until, that is, one of them interacts with a measuring device" (Al-Khalili, 2012, p. 106) (or indeed with any system that prompts a resolution of property indeterminacy). So, for example, the initial interaction may lead two particles to be synchronised in the sense that the spin of one particle, if measured, will always turn out to be opposite to the spin of the other, even though neither spin is yet determinate (Lewis, 2016, p. 8). Experimental work has shown that when the spin of the first particle is resolved by interaction with a suitable device, the spin of the second particle will always be found to be set to the opposite value even when they are separated by large distances (Barad, 2007, pp. 289–292).

Decoherence is associated with cases where a quantum entity becomes entangled with some element of its environment, often with a macroscopic entity. In such cases, the corresponding wave functions can decohere exceptionally rapidly (although not instantaneously) (Zurek, 2003). While the mechanism at work is unknown (though GRW collapse could be a candidate for at least part of the explanation) the outcome is that the relevant property (e.g. position) of the quantum entity becomes determinate with respect to the macroscopic entity. From the point of view of the mathematical model, the wave function for the position of the quantum entity collapses. As Wojciech Zurek puts it, "many (perhaps all) of the symptoms of classicality can be induced in quantum systems by their environments" (Zurek, 2003, p. 715).

Decoherence has assumed particular prominence in recent work on quantum computing. Quantum computing employs quantum particles in a superposed state which allows them to be used as *qubits* (the quantum computing equivalent of *bits*, the binary digits used in conventional computing). Because superposition allows them to assume a broad range of complex values, qubits can represent much more information than conventional bits and quantum computers can (at least in principle) perform radically more complex calculations (Mitchem, 2025). But qubits are vulnerable to decoherence events in which the superposition is destroyed and the qubit instead takes on a determinate ('classical') state, and this eliminates their value for quantum computing. Hence a large part of the development of quantum computing has been concerned with how to maintain qubits in a superposed state, and this has led to considerable learning about what kinds of interactions with other entities lead to entanglement and decoherence (Mitchem, 2025).

From an ontological perspective, the implication of such work is that the transition from a superposed state to a determinate value of a property of a quantum particle is a real change, since (a) it has real consequences for quantum calculations; and (b) it can be manipulated by changes to the set up. Hence, although the term *decoherence* has mathematical origins, it refers to a change that has a real physical basis. Let me refer to that kind of change as *real decoherence*. Now I believe we can argue that real decoherence provides the positionality of macroscopic objects that is required for them to have spatial relationships with each other, and thus the basis for macroscopic or material causal mechanisms as I understand them. While the mathematical models suggest that other indeterminacies may remain at a higher level after real decoherence events, this need not be an obstacle to the argument as long as decoherence resolves positionality with respect to the other components of the system concerned. In that case, as long as the parts of an entity are entangled with each other, they could have determinate spatial relations with each other.

Some authors suggest on the basis of entanglement and decoherence theory that the positions of macroscopic objects should be seen as emergent properties (Everth & Gurney, 2022, p. 14; Joos, 2006). I will agree, but some care is required here. On the model of emergence presented earlier, properties are emergent when they are properties of a whole that depend on the nature and relations between its parts. But consider the entanglement relations that appear to lead to the relative position of a quantum particle being resolved. These are not relations between the parts of the particle, if indeed it has parts at all. Rather, they are relations (possibly including nonlocal relations) between the particle and other entities, and in particular its relations with a macroscopic object that may be playing the part of a measuring device.

There are at least two other, closely related, models of emergence that may be of assistance here. First we have the concept of *intrastructuration*, introduced fleetingly by Bhaskar (Bhaskar, 1993, p. 599; and expanded a little in Elder-Vass, 2010, pp. 26–28). This is the idea that a property of a *part* is emergent if it depends on the entity concerned being a part of a larger whole (for a similar point see Bunge, 1996, p. 20). It refers to properties that derive from an entity's place in a larger system. For a simple example, consider the case of a bicycle pedal's capacity to be used to propel the bicycle (an affordance). This capacity is clearly emergent – that same lump of rubber and metal would not have it unless it was part of the larger system formed by the bicycle – and yet the internal parts and relations of the pedal itself are not enough to confer it. This property of the pedal also depends on the way that the pedal is related to the other parts of the bicycle. Intrastructural properties should probably best be understood as properties of the whole system (here, the bicycle), that are in effect delegated to, or localised in, the part (here, the pedal). Lawson's social positioning theory rests on a similar form of emergence, with the causal powers of the President, for example, derived from his or her position in a larger community. Perhaps the location of a particle after it has been measured, or at least its relative location, is an intrastructural emergent property of a larger decohered system composed of itself and the measuring device.

The concept of *contextual emergence* provides a second model. This was developed at least partly in response to the issues arising from quantum mechanics and entanglement (Bishop & Ellis, 2020; Navarrete & Fryer, 2024, p. 175; Silberstein, 2017). The core intuition is that "what we take to be basic parts and their dynamics get constrained/ determined/ overridden by contextual features allegedly outside the system, often at different interacting scales, and then new and stable patterns arise" (Silberstein, 2017, p. 166). To put it in terms that align with this paper's, some properties of some entities may depend not only on their own composition and structure, nor even on the composition and structure of clearly identifiable systems of which they are parts, but also or instead on a diverse range of external influences from their wider context. Silberstein conceives of contextual emergence as opposed to compositional accounts of emergence (Silberstein, 2017, p. 162), but there is no reason to think of the two models as necessarily mutually exclusive: perhaps some properties are compositionally emergent (including some that are intrastructural) and others are contextually emergent.

Decoherence may provide good examples of contextually emergent properties. According to Joos, for example, the position of macroscopic objects becomes classical (i.e. determinate) because they "are always under 'continuous observation' through their natural environment" (Joos, 2006, p. 59) – where observation means simply that they are constantly interacting with their environment, for example by scattering photons that strike them. If every photon that strikes an object, and indeed every other particle with which it interacts, potentially including distant particles with which it is entangled, contributes to making its position determinate, then it becomes difficult to see its position as an emergent property of a specific larger system – other than the entire universe. If so, this would seem like a case of contextual emergence.

The question at hand, however, is how far the critical realist model of causation in macroscopic systems applies to quantum properties and phenomena. On the one hand, there is very little we can say about whether even determinate properties of quantum entities (such as mass or charge) are compositionally emergent from lower level forces, since we do not yet understand their lower level composition or even if the concept of composition makes sense for them. If, despite this, it were to turn out that quantum entities have compositionally emergent properties, it would seem that they must work differently than the familiar critical realist model because the emergent properties of ordinary macroscopic objects depend on determinate spatial relations between their parts and it is hard to see how the parts of quantum objects, which appear to lack determinate locations as wholes unless and until they become entangled with their environment, could have such relations. On the other hand, it seems initially plausible that some of their properties, such as positionality after decoherence, may be contextually or even intrastructurally emergent. The latter is already a (neglected) feature of critical realism but the former would need to be added to critical realism's existing understanding of emergence (as proposed by Navarrete & Fryer, 2024).

Despite these difficulties, however, it does seem viable to regard quantum interaction mechanisms as producing emergent properties of higher level particles, particularly their determinate locations. This offers us a solution to the third part of the challenge to quantum realism: what is the connection between quantum ontology and the ontology of the macroscopic physical world? Rather than quantum indeterminacy overwhelming casual processes at a higher level, it seems that there is a mechanism, though as yet there is little understanding of how that mechanism works, that gives us determinate positional relations for the parts of macroscopic objects and thus the possibility of emergent causal powers at the macroscopic level that are based on spatial relations between parts.

7 Segments and boundaries

We are now in a position to assemble the pieces into a picture of the whole segmented ontology proposed here, including how the segments fit together. Figure 1 provides a visual representation of the differences and relations between the three segments that have been discussed in the last three sections.

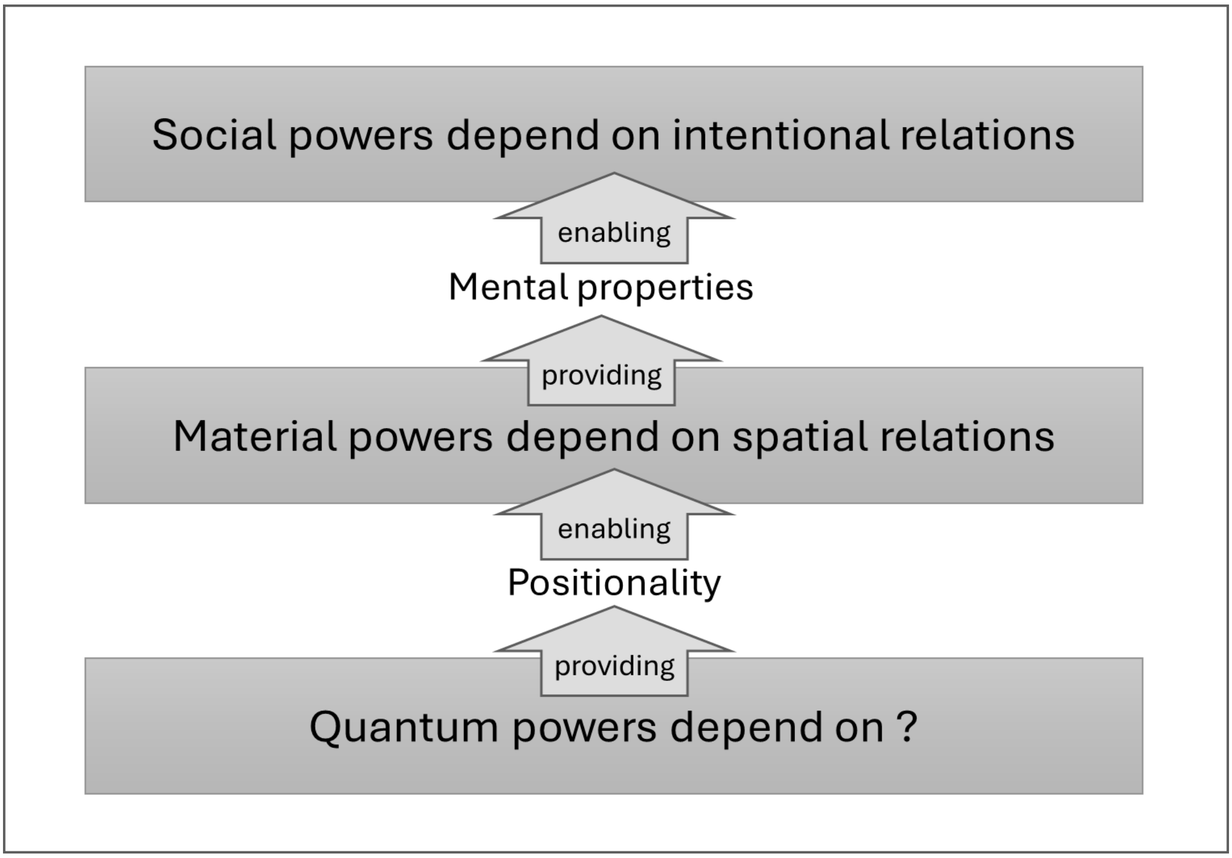

Figure 1 A segmented ontology

At the lowest level, we have the **quantum** segment, populated by a variety of subatomic particles that fall into natural kinds, with some real determinate properties and some other potential properties, including their location, that seem to be indeterminate until resolved in a decoherence event. These particles have causal powers, but we know too little about the physics of their structure to say what the basis of those powers might be. However, we do know that these particles can become entangled with each other, and with larger systems, and one result of this can be to decohere the wave functions that represent their potentials, resolve their relative positions, and bind them into larger systems – macroscopic or material entities.

This makes it possible for the parts of those **material** entities (unlike coherent quantum entities) to establish determinate spatial relations with each other. This in turn enables the parts to interact in ways that provide the mechanisms driving emergent causal powers, which differ between different natural kinds of material entity. These macroscopic material entities, with their mechanisms and powers, are just as much a part of the causal-ontological furniture of the universe as whatever exists in the quantum segment.

Material entities of some kinds have developed **mental properties**: most obviously human beings, to a lesser extent some other higher animals, and potentially others of which we are currently unaware. Those mental properties are emergent properties of the beings concerned, depending on the possession of neurons organised into interacting networks, linked to perceptual equipment. Let me stress that this is not the same model of mental emergence that has often been rejected in the philosophy of mind because of the causal exclusion thesis. On the model I advocate, mental properties, such as beliefs, depend on the neural networks of the individual holding them, but they cannot be reduced to properties of the neurons themselves because they depend on the particular complex of relationships between those neurons that form them into the particular neural network that constitutes the brain of the individual. I cannot do justice to this whole debate here but let me just point out that even Jaegwon Kim, the primary advocate of the causal exclusion thesis, points out that it does not apply to what he calls macro properties and thus to the model advocated here: "the fact that we can micro-structurally explain why a micro-based property has a certain set of causal powers does not mean that these causal powers are identical with the causal powers of its micro-constituents. Micro-reductively explainable causal powers may be new causal powers, net additions to the causal structure of the world" (Kim, 1998, p. 117 and also see his p. 7) (for further explanation see Elder-Vass, 2014).

Once we have such mental properties we can form a new kind of relationship with each other: intentional relations, which depend on the content of our beliefs about, for example, the status of other individuals, our obligations towards them, and their obligations to us and each other. Groups of people (and sometimes other objects) interrelated in this way can form **social** structures, with emergent causal powers of their own (for a detailed supporting argument see Elder-Vass, 2010).

The entities of at least the top two segments possess emergent causal powers. The relations between their parts that underpin these emergent powers, however, differ radically between the two segments. In both cases, the type of relation involved depends on properties of the parts that emerge from the segment below. The powers of material objects depend on the determinate spatiality of their parts, which emerges from decoherence, while the powers of social structures depend on intentional relations between people, which emerge as mental properties from the material structures of brains.

What is segmented in this picture is entities, or types of entities, along with their mechanisms and powers. What is *not* segmented is actual events. As per Bhaskar's original argument, actual events are determined by the interaction of many different causal powers. Those can originate from many different entities, including entities from different segments of the ontology outlined here. Thus, for example, in the two slits experiment, the causal potentials of the quantum particles being fired at the apparatus interact with those of the material apparatus itself to produce the interference patterns on the screen. Or, when the President of the United States orders government departments to mobilise to provide flood relief, social and material powers interact to produce the outcome. Of course, material powers always depend on quantum powers, and social powers always depend on material powers, but they arise from new mechanisms, new causal configurations at the higher level, which cannot be explained entirely by those lower level powers.

This argument does not seal off the macroscopic world from quantum influences. It *adds* macroscopic and social mechanisms to the mechanisms (if that is the right word) arising from quantum processes. Those macroscopic and social mechanisms are built on top of quantum processes and depend on them. They interact with them, as in cases like the two slits experiment, or indeed in more devastating cases like the explosion of a hydrogen bomb where quantum dynamics are deliberately amplified through macroscopic mechanisms. And it is not scale as such that puts us in the realm of the macroscopic. There are macro-scale phenomena with quantum explanations, such as superconductivity in certain systems (Bacciagaluppi, 2025, sec. 1.1). There may even be aspects of phenomena we are accustomed to thinking of in macroscopic terms that will turn out to be driven by quantum processes that are amplified naturally rather than artificially – such as navigation by birds, for example, or human cognition (Cai et al., 2010; Wendt, 2015, p. 135). There is a substantial literature, in particular, that argues that the logic of some human decision making is equivalent to the logic of quantum systems, although it is not at all clear whether that logic is driven by quantum mechanisms or homologous macroscopic ones (Busemeyer & Bruza, 2024; Pothos & Busemeyer, 2022). But there are also countless macro phenomena that we cannot make sense of without appealing to the macroscopic and indeed social mechanisms that I have discussed here. The quantum is not absent from those cases, but for many explanatory purposes it can be ignored because the proximate causes are powers that depend on macroscopic and/or social mechanisms. If and when science progresses below the quantum level, we may have to say the same sort of thing about quantum processes themselves.

I hope it is also clear that ontological segmentation need not come at the expense of the ontological unity of the universe. Ontological unity does not require that our ontologies of different segments must be *the same*, only that they must be *consistent with each other*. They need, as a minimum, to fit together in a way that reflects the unity of nature. They need to fit together like the piece of a jigsaw puzzle or the two sides of a river - we need to be able to see how the join works in a way that is consistent with what lies on each side of it. Relative positionality and mental properties provide the bridges, as it were, between the segments of the ontology outlined here.

8 Conclusion

This paper has argued:

First, that we should be suspicious of universalizing ontological claims. Our knowledge of the world has limits and we should be cautious about how far we extend reasoning based on it. Furthermore, the knowledge that we do have suggests some radical discontinuities in the causal structure of the world and our ontology should reflect that.

Second, that there is no warrant for dismissing realist ontology about the material world because of claims derived from interpretations of quantum mechanics. Quantum mechanics does imply that the ontology of the quantum space must differ significantly from realist ontologies of the macroscopic material world, but that does not entail – because of my previous point – that those ontologies are wrong. Specifically, denials of the existence or the metaphysical significance of real entities cannot be sustained on the basis of quantum mechanics.

Third, that the rational response to this situation is to replace universalized ontologies with segmented ontologies, which examine significant differences between segments of the world and identify the boundaries and relationships between them. This does not entail that the ontologies of different segments need to be *entirely* distinct. Some elements may be valid across multiple segments. Ultimately it is an empirical question which ontological claims are valid in which spaces.

Fourth, that critical realism, subject to some adaptation, provides us with a suitable basis for constructing a segmented realist ontology, partly because it already makes some provision for ontological segmentation. This paper has proposed a more systematic and wider ranging segmentation of critical realist ontology which takes explicit account of the characteristics of quantum phenomena, in addition to expanding and clarifying previous work on the relationship between the material and social segments.

I do not claim, however, that the scheme introduced here is complete or final. On the contrary, the more important message is that we need to be sensitive to the possible need for ontological segmentation, and thus that we should be open to the possibility that there will be further boundaries and further segments to be recognised and accommodated. It is possible, for example, that progress in physics will reveal further levels below the quantum level that require not only different physics but also different ontologies. Or there may be other kinds of boundaries we will need to recognize, perhaps in the ontology of substance, for example, as well as in the ontology of cause, if these are different.

One strength of this approach is that it does not leave our ontologies entirely hostage to whatever future developments may arise in fundamental physics. If macroscopic material ontology is largely independent of many of the features of quantum ontology, then we may well be able to flex the lower segments of our ontology without affecting the continuing validity of the higher segments. By recognizing that our ontologies have boundaries of validity, we may make them more robust to scientific progress, though they will always be subject to revision, whether minor or major, as we learn more about the universe.

My hope is that this paper has shown, first, that we need to discard the common assumption that ontologies have universal scope and attend instead to the boundaries of applicability of each ontological claim; and second, that it is within our reach to construct segmented ontologies that are better adapted to the real causal structure of the world than universalised alternatives.

Reference list

Al-Khalili, J. (2012). *Quantum: A Guide For The Perplexed*. Weidenfeld & Nicolson.

Archer, M. S. (1995). *Realist Social Theory: The Morphogenetic Approach*. Cambridge University Press.

Bacciagaluppi, G. (2025). The Role of Decoherence in Quantum Mechanics. In E. N. Zalta & U. Nodelman (Eds.), *The Stanford Encyclopedia of Philosophy*. Metaphysics Research Lab, Stanford University. https://plato.stanford.edu/archives/spr2025/entries/qm-decoherence/

Barad, K. (2007). *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning*. Duke University Press.

Becker, A. (2018). *What is Real?: The Unfinished Quest for the Meaning of Quantum Physics*. John Murray.

Bennett, R. J. (2010). *Vibrant Matter: A Political Ecology of Things*. Duke UP.

Benton, T. (1985). Realism and Social Science. In R. Edgley & R. Osborne (Eds.), *Radical Philosophy Reader* (pp. 174–192). Verso.

Bhaskar, R. (1975). *A realist theory of science*. Leeds Books.

Bhaskar, R. (1979). *The Possibility of Naturalism*. Harvester.

Bhaskar, R. (1986). *Scientific realism and human emancipation*. Verso.

Bhaskar, R. (1993). *Dialectic: the pulse of freedom*. Verso.

Bishop, R. C., & Ellis, G. F. R. (2020). Contextual Emergence of Physical Properties. *Foundations of Physics*, *50*(5), 481–510. https://doi.org/10.1007/s10701-020-00333-9

Bouzanis, C. (2023). *Social Imaginary and the Metaphysical Discourse: On the Fundamental Predicament of Contemporary Philosophy and Social Sciences*. Routledge.

Bunge, M. (1996). *Finding philosophy in social science*. Yale University Press.

Busemeyer, J. R., & Bruza, P. D. (2024). *Quantum Models of Cognition and Decision: Principles and Applications*. Cambridge University Press.

Cai, J., Guerreschi, G. G., & Briegel, H. J. (2010). Quantum Control and Entanglement in a Chemical Compass. *Physical Review Letters*, *104*(22), 220502. https://doi.org/10.1103/PhysRevLett.104.220502

Cartwright, N. (1999). *The dappled world : a study of the boundaries of science*. Cambridge University Press. http://lcweb.loc.gov/catdir/toc/98032176.html

Chakravartty, A. (2017). *Scientific Ontology: Integrating Naturalized Metaphysics and Voluntarist Epistemology*. Oxford University Press.

Cox, B., & Forshaw, J. (2011). *The Quantum Universe: Everything that can happen does happen*. Penguin.

Elder-Vass, D. (2005). Emergence and the realist account of cause. *Journal of Critical Realism*, *4*(2), 315–338.

Elder-Vass, D. (2010). *The Causal Power of Social Structures*. Cambridge University Press.

Elder-Vass, D. (2012). *The Reality of Social Construction*. Cambridge University Press.

Elder-Vass, D. (2014). Social entities and the basis of their powers. In J. Zahle & F. Colin (Eds.), *Rethinking the Individualism-Holism Debate* (pp. 39–54). Springer.

Elder-Vass, D. (2022). *Inventing Value: The Social Construction of Monetary Worth*. Cambridge University Press.

Elder-Vass, D., Fryer, T., Groff, R. P., Navarrete, C., & Nellhaus, T. (2023). Does critical realism need the concept of three domains of reality? A roundtable. *Journal of Critical Realism*, *22*(2), 222–239. https://doi.org/10.1080/14767430.2023.2180965

Everth, T., & Gurney, L. (2022). Emergent Realities: Diffracting Barad within a quantum-realist ontology of matter and politics. *European Journal for Philosophy of Science*, *12*(3), 51. https://doi.org/10.1007/s13194-022-00476-8

Faye, J., & Jaksland, R. (2021). Barad, Bohr, and quantum mechanics. *Synthese*, *199*(3), 8231–8255. https://doi.org/10.1007/s11229-021-03160-1

French, S. (2023). *A Phenomenological Approach to Quantum Mechanics: Cutting the Chain of Correlations*. OUP Oxford.

Ghirardi, G. C., Rimini, A., & Weber, T. (1986). Unified dynamics for microscopic and macroscopic systems. *Physical Review D*, *34*(2), 470–491. https://doi.org/10.1103/PhysRevD.34.470

Hacking, I. (1983). *Representing and Intervening: Introductory Topics in the Philosophy of Natural Science*. Cambridge University Press.

Joos, E. (2006). The emergence of classicality from quantum theory. In P. Clayton & P. S. Davies (Eds.), *The Re-emergence of Emergence* (pp. 53–78). Oxford UP.

Ladyman, J., Ross, D., & Collier, J. (2007). *Every Thing Must Go: Metaphysics Naturalized*. OUP UK.

Latour, B. (2005). *Reassembling the social*. Oxford University Press.

Lawson, T. (2019). *The Nature of Social Reality: Issues in Social Ontology*. Routledge.

Lawson, T. (2023). Social positioning theory and quantum mechanics. *Journal for the Theory of Social Behaviour*, *53*(4), 583–619. https://doi.org/10.1111/jtsb.12390

Lewis, P. J. (2016). *Quantum Ontology: A Guide to the Metaphysics of Quantum Mechanics*. Oxford University Press.

Lokhorst, G.-J. (2021). Descartes and the Pineal Gland. In E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy*. Metaphysics Research Lab, Stanford University. https://plato.stanford.edu/archives/win2021/entries/pineal-gland/

Mitchem, S. (2025). *What is quantum coherence?* (Phys.Org). Argonne National Laboratory. https://phys.org/news/2025-02-quantum-coherence.html

Navarrete, C. (2024). Rearticulating Realism: Chains of Reference and Epistemic Success in the Sciences. *Sociological Theory*, *42*(4), 354–379. https://doi.org/10.1177/07352751241291831

Navarrete, C., & Fryer, T. (2024). Redefining emergence: Making the case for contextual emergence in critical realism. *Journal for the Theory of Social Behaviour*, *54*(2), 167–184. https://doi.org/10.1111/jtsb.12414

Norris, C. (2000). *Quantum Theory and the Flight From Realism: Philosophical Responses to Quantum Mechanics*. Routledge.

Porpora, D. V. (2022). The Metaphysical Issues in the Social Sciences and How Social Scientists Debate Them. *Synthese*, *200*(6), 1–20. https://doi.org/10.1007/s11229-022-03978-3

Pothos, E. M., & Busemeyer, J. R. (2022). Quantum Cognition. *Annual Review of Psychology*, *73*(Volume 73, 2022), 749–778. https://doi.org/10.1146/annurev-psych-033020-123501

Rovelli, C. (2021). *Helgoland* (E. Segre & S. Carnell, Trans.). Penguin.

Sarkia, M., & Kaidesoja, T. (2023). Two approaches to naturalistic social ontology. *Synthese*, *201*(3), 104. https://doi.org/10.1007/s11229-023-04105-6

Schlosshauer, M. (2019). Quantum decoherence. *Physics Reports*, *831*, 1–57. https://doi.org/10.1016/j.physrep.2019.10.001

Searle, J. R. (1995). *The construction of social reality*. Allen Lane.

Silberstein, M. (2017). Strong emergence no, contextual emergence yes. *Philosophica*, *91*(1), Article 1. https://doi.org/10.21825/philosophica.82119

Silver, K. (2021). Emergence within social systems. *Synthese*. https://doi.org/10.1007/s11229-021-03143-2

Wendt, A. (2015). *Quantum Mind and Social Science: Unifying Physical and Social Ontology*. Cambridge University Press.

Zurek, W. H. (2003). Decoherence, einselection, and the quantum origins of the classical. *Reviews of Modern Physics*, *75*(3), 715–775. https://doi.org/10.1103/RevModPhys.75.715