

# Emergent Realities: Diffracting Barad within a quantum-realist ontology of matter and politics

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## Abstract

One of the most influential contemporary authors of the new materialist turn in the social sciences is Karen Barad. Barad's work in *agential realism*, based on her interpretations of quantum physics, has been widely cited within a growing body of new materialist publications. However, in translating Barad's assertions into social domains, there has been increasing critical appraisal of the physics underlying her work and its relationship with non-quantum domains. In this paper, we contribute to this discussion by exploring aspects of agential realism through quantum decoherence and quantum Darwinism. We explore implications for Barad's metaphysics and the relationship of the social with the rest of the material world.

**Keywords:** Barad, agential realism, quantum Darwinism, quantum decoherence, new materialism

## Introduction

Karen Barad's *Meeting the universe halfway* (2007) has emerged as one of the foundational works in the developing field of new materialist philosophy. By the start of 2022, it had surpassed 13,000 citations. In the book, Barad develops a comprehensive theory of *agential realism* on the basis of her interpretations of quantum physics, making wide-reaching ontological claims on matter and meaning with the goal of bridging the social and natural sciences.

Interrogating the relationship between society and the more-than-human world – as is the goal of Barad and other new materialist scholars – has attracted significant attention for various reasons. Amongst these is the drive to establish a compelling foundation from which to speak truth to power as a political imperative (Demeritt, 2006). This can be related to pressing existential anthropogenic threats such as climate change and ecological decline, which necessitate meaningful engagement between the

natural and social sciences. New materialist onto-epistemological approaches are emerging to address these concerns, from education to policy development (i.e. Fox & Alldred, 2020; Verlie, 2017, 2022). While new materialist work traverses wide terrain in social and natural sciences, including biology, chemistry, poststructuralism, and feminism, unquestionably, citations of Barad (2007) have gained particular prominence in the new materialist literature. However, we join a growing group of scholars concerned about the uncritical application of Barad's theories in these fields, in particular in relation to the extrapolation of quantum mechanical indeterminacy at the human scale (see for example Hollin et al., 2017; Faye & Jaksland, 2021; Jaksland, 2021).

To contribute to this discussion, we explore Barad's agential realism in relation to quantum decoherence and quantum Darwinism (Schlosshauer, 2019; Zurek, 1994, 2003, 2009, 2018, 2021). We argue that these readings of quantum physics, which are themselves continually evolving, refocus new materialism away from quantum mechanics and on ontologies of matter and emergence at the social scale. We are not arguing *against* new materialism; we support it as a political and intellectual project, driven to engage with the world across disciplines, and extending beyond the limitations of other bodies of social theorising such as social constructivism. Rather, we propose that the physics underpinning Barad's (2007) agential realism be critically considered alongside developments in the field and the persistent challenges of *thinking through* Barad's theories in social domains.

In order to do this, the paper proceeds as follows. Firstly, we introduce new materialism. We then explore the metaphysics and politics of new materialism and agential realism, and we address recent critiques of Barad's work. As the main focus of our argument, we then discuss two key elements of Barad's theory with reference to decoherence and quantum Darwinism:

- the assertion that *relata* do not exist beyond specific intra-actions, and
- the insistence that the ways in which quantum phenomena operate in microscopic realms can be translated into the macroscopic realm of the social.

We ultimately argue that developments in physics, particularly in the work of Zurek, do not provide justification for an ontology of quantum indeterminacy extrapolated to social scales, and nor do they give license to deny or exclude the existence, history, and individuation of objects and subjects outside specific intra-actions. Indeed, we argue that emancipatory social theorising may be poorly directed by a turn to quantum physics at the microscopic scale.

### **From constructed realities to new materialisms**

To position Barad's contribution within the context of recent theorising about the role of science, the nature of reality and the role of human actions, we briefly address the prevalence of social constructivism preceding the recent turn to new materialism. While social constructivism is not the only

scholarly body of work to which new materialism responds, we have chosen to highlight it as it provides a useful illustration of the ways new materialism can respond to what Barad (2007) frames as follows:

Language has been granted too much power. The linguistic turn, the semiotic turn, the interpretative turn, the cultural turn: it seems that at every turn lately every “thing”—even materiality—is turned into a matter of language or some other form of cultural representation. [...] Language matters. Discourse matters. Culture matters. There is an important sense in which the only thing that doesn’t seem to matter anymore is matter. (p. 132)

Constructivism tends to sidestep ontology, laying the foundation for an emphasis on epistemology and for a relativistic approach to knowledge construction through interaction and experience. Radical constructivist theories even reject the notion of an objective reality as the basis for scientific explanations (Peschl & Riegler, 1999). Indeed, some have gone so far as to propose that a reality external to the human mind is “irrelevant” (Riegler 2001, p. 4). Riegler (2001) argues that humans are epistemologically capable only of knowing that we exist, but nothing beyond the ‘self’ is truly knowable.

These views contradict scientific realism, which is the dominant philosophy in the natural sciences. Hofer (2020) provides useful clarification in determining how scientific realism fits into this discussion. He defines scientific realism as “the family of philosophical views that assert that we have strong reasons to believe in the truth or approximate truth of much of the content of our best current scientific theories” (p. 19). Of importance to this definition are the *best current scientific theories*; as Hofer (2020) clarifies, this is not a claim to assert that everything that has ever been labelled ‘scientific’ or conducted under the banner of science establishes (approximate) truth. Rather, he claims that “a large proportion of our current scientific picture of the world is correct, and that we have ample reason to believe that it will never be overthrown and replaced in the way that important theories from earlier centuries ... were overthrown and replaced” (p. 19).

The exponential rise of anthropogenic impacts on the planetary systems, in particular over the last fifty years (Crutzen & Stoermer, 2000), has emphasised the necessity for dialogue between the social and the natural sciences. However, during the crucial decades since the 1980s, the social sciences were strongly influenced by radical constructivist theories which wielded considerable influence over, amongst other things, the early decades of the climate change debate (Hansson, 2020). Significant academic support was given to climate science denialism by a host of prominent authors from the science and technology studies (STS) field during these times (Hansson, 2020). The onto-epistemological relativism promoted by some within the field has often operated in tandem with particular political agendas built on the denial of climate science. Hansson (2020) comments on the culmination of postmodernist deconstruction of facts, objectivity and expertise in the post-truth world,

where truth is no longer *sought and found* but *made to suit* political and economic agendas. He cites Bruno Latour's (2004) concerns about the support of climate denial by such scholarship:

Why does it burn my tongue to say that global warming is a fact whether you like it or not? Why can't I simply say that the argument is closed for good? ... Or should we rather bring the sword of criticism to criticism itself and do a bit of soul-searching here: what were we really after when we were so intent on showing the social construction of scientific facts? (Latour, 2004, p. 227)

Extending on foundations in philosophy, STS, poststructuralism and feminism, new materialist work aims to deliberately *bridge* the social and natural sciences, to pay greater attention to the independent existence of the world beyond humanity, and to acknowledge non-human agency and matter (Cool & Frost, 2010). Positioning previous social theorising, including constructivism, as overly concerned with humans to the exclusion of everything and everyone else, new materialists deliberately problematise the separation of the social and natural worlds. According to Ferrando (2013), new materialist work

arose as a reaction to the representationalist and constructivist radicalizations of late postmodernity, which somehow lost track of the material realm. Such a loss postulated an inner dualism between what was perceived as manipulated by the act of observing and describing, as pursued by the observers, and an external reality, that would thus become unapproachable. (pp. 30-31)

MacLure (2017), in capturing a central refrain of new materialist work, states that “[d]iscourse does not discipline matter” (p. 7). Although humans and human theorising are part of reality, they do not determine what reality is. This is a deliberate step away from solipsism; indeed, part of the new materialist project is to attend to *interconnections* and *relations* between beings, things, and matter, while understanding that neither relations nor entities are necessarily ‘fixed’ or permanent in themselves. Although there is no single strand of new materialism work – the field may be better described as an interlinking project entailing some differences in theory and approach – some branches of work stand out prominently. Amongst these, the work of Karen Barad is of particular importance.

### **Meeting the Universe halfway: Barad's Agential Realism**

Barad's book *Meeting the Universe Halfway* (2007) introduces agential realism as a holistic ontology grounded in quantum physics. After completing a PhD in physics as well as producing various publications in quantum physics in the 1980s, Barad has articulated her quantum physics-inspired theory of agential realism over a number of publications (see Barad, 2003, 2007, 2010, 2012, 2014) drawing strongly on the work of philosopher-physicist Niels Bohr. Agential realism exemplifies the goal of new materialist theorising to cross the boundaries – and intentionally blur the distinctions –

between the social and natural sciences. Like other new materialist work, it is also explicitly underpinned by a feminist approach (Barad, 1998).

As stated in the preface to Barad's (2007) book, agential realism's central arguments address entanglements and the lack of "independent, self-contained existence" (p. ix) outside these. As the basis for agential realism, Barad (2007) provides a well-developed introduction to quantum mechanics and a discussion of its history as it applies to the microscopic world of quantum systems. However, Barad (2007) does not limit the application of quantum mechanics to the micro-realm but extends it to macro scales, where it is theorised that all *relata*, including human bodies, things and words, remain indeterminate outside specific agential intra-actions (p. 150).

Fundamental to Barad's agential realism are the quantum mechanical concepts of *superposition*, *entanglement* and *interference*. Before discussing Barad's (2007) work and our critique, we provide for readers a brief description of these terms as they are understood within physics with reference to Barad's (2007) useful introduction (pp. 247-353). For deeper engagement, we refer readers to the well-established literature on quantum physics, including Carroll (2019) and French (2018).

Certain properties of isolated quantum systems remain indeterminate and in a simultaneous superposition of different possible values. Among these indeterminate properties are spatial relationships, the directionality of spins, movement, energy and appearance in time. Quantum systems, such as elementary particles of matter and quanta of energy (photons), can propagate along a superposition of multiple paths simultaneously while their impulse and energy remain indeterminate within certain bounds, as long as they remain in isolation from the environment.

According to quantum mechanics, the superpositions of properties of quantum systems over time can be calculated using a wave function: the Schrödinger Equation. The alternative paths and the propagation of properties permitted by this function can interfere with each other and create diffraction patterns. The diffraction patterns that arise when light passes through multiple gaps in a screen are an example of such a superposition of multiple paths in action.

When quantum systems interact with each other, they can become *entangled*, and a new combined quantum system arises with a joined wave function that describes the superpositions of the many possible states of the now entangled parts. The original systems lose the independent determinability of their properties. Quantum systems can become entangled with many other systems and remain in a state of superposition of properties, as long as the collective of these systems remains isolated from *the environment*.

However, when quantum systems entangle with a quasi-infinite number of others (the environment), something fundamentally new happens. The superpositions of the many possible states

of the systems' properties in question are destroyed almost instantaneously (Zurek, 1986, 2021), and the values of the properties that are entangled with the environment become determinate and settle into one of their physically possible states. Interactions of quantum systems with the environment are often referred to as *measurements* in quantum physics because macroscopic changes that could be evoked by this interaction can be conceptualised as perceptible changes using measurement instruments. The destruction of superpositions of quantum systems due to their interaction with the environment is referred to as *decoherence*. Through environment-induced decoherence, quantum systems settle into classical states, and classical reality emerges with macroscopic entities that exist separate from each other, have persistence and behave classically (Zurek, 2021). As we shall argue later in detail, decoherence and the resulting manifestation of the macroscopic perceptible properties of the world are central to the development of an ontology at the human scale and our critique of Barad's (2007) theory.

Introducing her agential realism, Barad (2007) contrasts the views of Bohr and Heisenberg, and sides with Bohr's interpretation that the indeterminacy of properties of quantum objects is a fundamental ontological constitution of quantum systems over Heisenberg's epistemic view of indeterminacy arising from the observers' limitations of what can be known in principle.

Barad argues that agential reality comprises material-discursive phenomena, which are continually reconstituted through the intra-actions of agents and apparatuses (Barad, 1998, 2007, 2010). Using the neologism *intra-action*, Barad seeks to capture the effects of agency in the constitution of phenomena. Barad (2007) explains:

A phenomenon is a specific intra-action of an "object" and the "measuring agencies"; the object and the measuring agencies emerge from, rather than precede, the intra-action that produces them. Crucially, then, we should understand phenomena not as objects-in-themselves, or as perceived objects (in the Kantian or phenomenological sense), but as specific intra-actions. (p. 128)

Barad (2007) argues that in intra-action, *agential cuts* are enacted. Contrasted with the Cartesian cut, which distinguishes between subject and object (or the knower and the known), the agential cut enacts a resolution *within* the world; however, as part of this, there is no *inherent* separation between the knower/known, observer/observed, and so on (Barad, 2007, 2014). Barad (2007) argues that these cuts are made by apparatuses that are themselves phenomena or "are open-ended practices" (p. 146); they are not located separately in or from the world but are reconfigurations *of* the world. However, Barad (2014) does not pose material monism. Rather, she makes use of the notion of *entanglement*: "Entanglements are not unities. They do not erase differences; on the contrary, entanglements entail differentiatings, differentiatings entail entanglings. One move – cutting together-apart" (Barad 2014, p.

176). For Barad, quantum effects are dominant at every scale and components and their differentiating and entangling are inseparable:

Phenomena are entanglements of spacetime-mattering, not in the colloquial sense of a connection or intertwining of individual entities, but rather in the technical sense of “quantum entanglements”, which are the (ontological) inseparability of agentially intra-acting “components”. (Barad, 2011, p. 125)

These assertions, read broadly, may speak to a relational ontology where observers and researchers are not separate from each other and the world they observe and research. However, agential realism takes seriously the notion that the nature and behaviour of quantum systems are *not* restricted to the quantum realm. Rather, quantum mechanical entanglement crosses from the micro to the macro – and from the quantum to the social – highlighting the “entangled structure of the changing and contingent ontology of the world, including the ontology of knowing” (Barad, 2007, p. 73). Importantly, the quantum is not used as a metaphor. The literal transposition of the indeterminacy of isolated microscopic quantum systems into the macro realm is part of Barad’s (2007) core hypothesis:

No evidence exists to support the belief that the physical world is divided into two separate domains, each with its own set of physical laws: a microscopic domain governed by the laws of quantum physics, and a macroscopic domain governed by the laws of Newtonian physics. (p. 110)

Barad (2007) applies these assertions to the social domain, arguing that “relata do not preexist relations; rather, relata-within-phenomena emerge through specific intra-actions” (p. 140), that “human bodies and human subjects do not preexist as such” (p. 150), and that “outside of particular agential intra-actions, ‘words’ and ‘things’ are indeterminate” (p. 150). To be clear, Barad does not equate these assertions with chaos or unpredictability; rather, as read by Hollin, Forsyth, Giraud, and Potts (2017), “the same particular diffraction apparatus will always produce the same diffraction pattern and, thus, scientific experiments that take a particular apparatus to the world are reproducible: same matter, same apparatus, same outcome” (p. 90).

The notion of causality is also significantly reworked through agential realism (Barad, 2003). Barad (2007) asserts that “separately determinate entities do not preexist their intra-action” (p. 175); rather, “[c]ause and effect emerge through intra-actions. Agential intra-actions are causal enactments” (p. 176). Causality is recast as *entangled*. Barad (2007) concludes that causality “is not about momentum transfer among individual events or beings. The future is not the end point of a set of branching chain reactions; it is a cascade experiment” (p. 394).

Barad's work explicitly problematises the separation of matter and discourse. Responding to a perceived overreliance on language and discourse in the social sciences, Barad (1998) turns to Bohr to navigate the interrelationships between humans and the more-than-human universe, descriptive concepts and material apparatuses, the agents and objects of observation, and the material conditions for knowledge. These are matters of both epistemology and ontology. Barad interrogates the nexus of what is known, how it is known, who claims to know, and on what basis this knowledge rests, resisting the poles that reality is unknowable or inaccessible *and* that it is completely knowable or constituted through language. As with other new materialist work, one core agenda of agential realism is to move beyond the binaries which have characterised social research debates, such as that between scientific realism and social constructivism, and positivism and postmodernism, which present irreconcilable positions in relation to the nature of realit(ies). Barad's work also extends agency beyond the human; "matter is not figured as a mere effect of discursive practices, but rather as an agentive factor in its iterative materialization" (Barad, 2012, p. 32).

An implication for social theorists that can be read from Barad's work is that the formation, behaviour and constitution of material-discursive phenomena may *resemble* the behaviour of quantum systems in some ways. However, as Hollin et al. (2017) argue, "physics is not a metaphorical resource for Barad but, rather, underpins agential realism's articulation of how the material world is brought into being" (p. 921) – and further, that a corollary of these assertions is that "the rules that govern quantum realms must also be deemed applicable in macro contexts, and in socio-cultural contexts in particular" (p. 936). Barad (2011) confirms that it was her decision to not use physics "as a mirror metaphor for thinking about a variety of different issues. I am concerned about the temptation when thinking analogically to set up the mirror metaphor and find the same things/relations/patterns everywhere" (p. 445). She also discusses this in *Meeting the universe halfway*, claiming that "I am not interested in drawing analogies between particles and people, the micro and the macro, the scientific and the social, nature and culture; rather, I am interested in understanding the epistemological and ontological issues that quantum physics forces us to confront" (Barad, 2007, p. 24).

The politics of Barad's work are presented upfront. In a response to Pinch (2011), Barad (2011) underscores her position as a feminist practitioner of science studies. According to Barad (2011), feminist science studies practitioners insist on attending to "the mutual constitution of subjects and objects, nature and culture, humans and nonhumans, and science and society" (p. 445), avoid singular disciplinary analyses, and seek to engage with science up close through focusing on the materiality of practices and matter itself. She further argues that, from a feminist stance, "to do otherwise is to exclude in principle that which has been coded feminine – namely, nature as agent rather than as passive blank slate awaiting the imprint of culture" (p. 445). Barad (2011) also states powerfully the feminist science studies goals of pursuing a more ethical, responsible and just practice of science, reflecting that:



This issue is my passion, which is what drew me as a scientist into the discussion in the first place. It is no coincidence that so many feminist science studies scholars have been trained as scientists and that we have not shied away from expressing our deep love for science and this astonishingly remarkable, intricate, amazing world of which we are a part [...] The turn to ontology does not turn away from epistemology, when knowing is recognized as an activity the world engages in. And ethics, that is, matters of justice, are never secondary or derivative concerns (p. 450)

### **Critiques in the literature of Barad's interpretations and use of quantum physics**

In addition to its very positive reception, Barad's work has received its share of criticism, particularly in regard to its use of quantum mechanics. Hollin et al. (2017) raise concerns over Barad's scale-jumping and what is lost in the application of reading quantum mechanics into "macro-sociological concerns" (p. 921), which are the primary concern of social theorising. They further highlight Barad's assertion that apparatuses "do not measure but, rather, produce material realities" (p. 921) in the form of agential cuts. This, as Hollin et al. (2017) argue, constitutes the "radical potential of an ethics of exclusion" (p. 922), with consequences for those who use her work. Returning to the question of scale, they point to Barad's connection to the work of geographer Neil Smith (2008) and his notion that scale is a product of social processes (p. 924). However, this is a questionable axiom with regard to the transition from atomistic to macroscopic phenomena. Hollin et al. (2017) conclude with a note of caution against the uncritical application of Barad's approach (p. 936), but as Jakslund (2021) emphasises, the capacity for such critical appraisal requires a level of understanding of physics that is not available to many in Barad's audience.

Turning further to physics, Faye and Jakslund (2021) argue that agential realism is based on a substantial misreading of Bohr's philosophy. They also express concern for the fact that many theorists who are picking up on quantum physics but do not work in the field of physics per se – and who, understandably, do not have expertise in physics – are engaging with these ideas *through* Barad's interpretations, without necessarily understanding that quantum mechanics is an expansive field with its own internal debates. As such, "neither Bohr nor quantum mechanics as a whole proves Barad's agential realism to be true" (Faye & Jakslund, 2021, p. 5). As a particular case in point, the authors critique Barad's assertion that measuring instruments and observations are inseparable, asserting that a more accurate reading of Bohr is that "phenomena are most appropriately regarded as an *epistemological* integration of the object of study and measuring apparatus; however, in such a way that they retain their *ontological* separateness" (p. 11, emphasis added). Summarily, they argue, "Barad's strong notion of intra-actions enacting cuts within the ontologically primitive phenomena finds no counterpart in Bohr's interpretation of quantum mechanics" (Faye & Jakslund, 2021, p. 11).

In picking up on some of the core challenges in interdisciplinary work such as Barad's, Jaksland (2021) outlines the difficulties inherent in translating ideas across disciplinary boundaries. As interdisciplinary collaboration becomes more common, Jaksland (2021) calls for stricter epistemic norms to determine how truth or value are understood in different domains, particularly when concepts travel across domains that may normally require different forms of evidence to defend propositions. What he calls patterns of indirect borrowing – that is, reading work in a certain area (such as physics) through a particular theorist (such as Barad), rather than accessing source material directly – may lead to interpretations being presented as though they are undisputed, uncontested or factual. As bridging the social and natural sciences is one of the core aims of the new materialisms, a certain amount of epistemic uncertainty is to be expected, particularly as the field develops. However, Jaksland's (2021) recommendations to avoid mistranslation (or, applications across epistemic systems which are significantly different or even incommensurable) are that “all testimony in broad interdisciplinary [studies] must be neutral with respect to disputed issues within relevant disciplines”, and that deviation from this must be signalled clearly by authors (p. 58).

Echoing the concerns of these scholars, physicist Holzhey (2021) argues for a more general critique of the use of physics as a tool to generate politically relevant ontologies of matter. In fact, Holzhey (2021) argues that a sound understanding of physics can be helpful to articulate “its own irrelevance [for politics at the human scale] and at the same time inspire strategies to deactivate the normativity of ontologies of matter” (p. 253). Holzhey (2021) claims that even radically different ontologies at the cosmological scale as well as at the microcosm of the quantum scale do *not* produce measurable differences at the human and the political scale and are therefore politically irrelevant. Turning to Barad (2007), and mirroring concerns raised also by Hollin et al. (2017), Holzhey (2021) is concerned that agential realism risks “short-circuiting different levels, registers, and scales” (p. 259), in which a clear sense of what “emerges and comes to matter in between” (p. 259) is lost. Holzhey (2021) recognises that Barad engages in “top-down constructions, from social discourse all the way down to the sub-atomic scale” (p. 259) as part of the development of her performative theories. While this may successfully affirm Barad's ontology of indeterminacy inspired by feminist and queer theorising, the proposed theories are problematic with respect to emergence and the notions of discontinuity through agential cuts. Theories developed for domains of a particular scale cease to matter at different scales (Holzhey, 2021). Failing to acknowledge that these ideas may not apply equally across all scales may lead to undue extrapolation and the assertion that “everything *is* indeterminate and queer, and *should* and can be recognized and destabilized as such” (Holzhey, 2021, p. 260, emphasis in original).

Responding to and extending on these emerging critical arguments and drawing on the work of Zurek and others on decoherence, quantum Darwinism and the emergence of the *classical reality*, we

focus in the subsequent sections of this paper, as stated in the introduction, on two crucial aspects of Barad's agential realism and their consequences for social theorising:

- the assertion that *relata* do not exist beyond specific intra-actions, and
- the insistence that the ways in which quantum phenomena operate in microscopic realms can be translated into the macroscopic realm of the social.

For the avoidance of doubt, by *classical reality*, we refer to the objective, relativistic space-time continuum and the macroscopic assemblages of matter and energy that are perceptible to us.

The aims of this discussion are not to dismiss the focus of agential realism or the relational nature of reality; like Barad, we see domains of reality as deeply interconnected, and we appreciate the politics that underpin her work. In fact, as we will argue with reference to decoherence theory, the pervasive agential *connectedness* of the world is generative of the classical reality we perceive, and the quasi-stability of this classical reality *predicates* evolutionary emergence. We agree that the 'natural' and the 'social' can function as heuristics to categorise parts of a more-than-human world that do not necessarily attend to the ostensible separation between them. We also agree that work that attempts interdisciplinarity is a worthwhile endeavour and a necessary step towards problematising the anthropocentrism that has characterised the social sciences for some time. However, we would proceed cautiously with respect to both the evolving field of quantum mechanics and its application to the social domain.

### **Quantum Decoherence, Quantum Darwinism and the emergence of classical reality**

The interpretation of quantum mechanics has been a contested matter since the inception of quantum theory over a century ago, in particular, the question of how the perception of classical reality can be reconciled with the predictions of quantum theory. According to the mathematical formalism of quantum mechanics, we should be living in a world of bizarre multiplicities and macroscopic superpositions of simultaneous states such as the infamous Schrödinger's cat that is simultaneously dead and alive (Barad, 2007, p. 275). However, the world we perceive, including human bodies and things, appears classical and relatively predictable, without macroscopic superpositions of states and with properties that trace past interactions and permit the evolution of emerging systems. Contrary to Barad's (2007) assertions, *relata* in the macro-world appear to exist separately from each other before and after interacting, together with the marks or mutations they may have acquired in their interactions.

The question of how classical reality at the macroscopic scale emerges from the quantum realm has therefore been of "immense importance" (Schlosshauer, 2019, p. 2). Key insights into the explanation of this problem were proposed by Zeh (1970) and later Zurek (1994, 2003, 2009, 2018, 2021) in a theory of *decoherence* and *quantum Darwinism* that describes how classical reality emerges

from the quantum realm due to the pervasive entanglement of microscopic quantum systems with the quasi-infinite multitude of others – *the environment*, which ultimately includes the entire universe.

In the history of quantum theory, environment-induced decoherence is a relatively recent advancement. Joos (2007) states that “[i]t seems to be a historical accident, that the importance of the interaction with the natural environment was overlooked for such a long time” (p. 20). We can only provide a brief overview of the implications of decoherence theory for our critique of Barad (2007). For a deeper engagement, besides Zurek’s (2021) recent summary, we recommend Schlosshauer’s (2019) comprehensive review of quantum decoherence in the *Memorial of Zeh*, Camilleri’s (2009) recount of the history of the interpretation problem of quantum mechanics and the establishment of Zeh’s and Zurek’s theory, and, in particular, the excellent introductions to decoherence theory by Joos (2002, 2006, 2007) and Joos et al. (2013).

Decoherence is induced when quantum systems come into contact and irreversibly entangle with the quasi-infinite number of degrees of freedom of the environment. In the process of this entanglement, superpositions of states in which the system may have been prior to this interaction vanish from observable sub-systems of the universe such as the macroscopic objects around us. Decoherence reduces quantum systems to a mixture of classical states, previously indeterminate properties assume determinate values based on probabilities (Joos, 2007, p. 4), and macroscopic objects become localised in space (Joos, 2007, p. 6). This has similarities to the measurement of a quantum system with an apparatus. Decoherence also affects further entanglements of the quantum systems with the environment. In fact, as Zurek (2021) argues, superpositions of environmentally-induced (einselected) classical pointer states do not entangle with the environment due to decoherence (p. 12).

Formally, decoherence can be viewed as a dynamical filter on the space of quantum states, singling out those states that, for a given system, can be stably prepared and maintained, while effectively excluding most other states, in particular, nonclassical superposition states of the kind epitomized by Schrödinger’s cat. (Schlosshauer, 2019, p. 2)

The universe is filled with an all-encompassing thermal bath of photons (quanta of light) that can act as entangling links between quantum systems and the environment and cause decoherence. Decoherence happens virtually instantaneously and continuously for systems that are well coupled with the environment (Zurek, 1986, 2021, p. 11). With respect to the human brain, Tegmark (2000) calculated that decoherence in the brain happens in  $10^{-20}$  to  $10^{-13}$  seconds, many orders of magnitude faster than characteristic processes in neuron activity in human brains, which are in the order of  $10^{-3}$  to  $10^{-1}$  seconds. Therefore, quantum superpositions in the brain dissipate much faster than any sensory activity would be able to detect them.

Decoherence enacts an ontological cut that produces the emergence of classical reality in a well-connected universe. Zurek (2021) states that due to decoherence “objects acquire effective classicality because they are in effect monitored by their environments” (p. 12). According to decoherence theory, macroscopic reality emerges with the classical properties and behaviours we are accustomed to as a direct consequence of the laws of quantum mechanics in a deeply connected universe (Schlosshauer, 2019; Zurek, 2021). Joos (2006) concurs with Zeh, Zurek, Schlosshauer and many other physicists that the notions of classical reality “can be *derived* from quantum concepts” (p. 54) through decoherence theory. Joos (2006) concludes “we do not need classical notions as the starting point for physics. Instead, these emerge through the dynamical process of decoherence from the quantum substrate” (p. 77). Joos (2007) further states that “typical classical properties, such as localization in space, *are created by the environment in an irreversible process*, and are therefore not inherent attributes of macroscopic objects” (p. 21, emphasis ours).

Decoherence theory explains how quantum systems, through their contact with the environment, become localised in space and settle into one of their possible classical states. What remained to be resolved was the question of how objective perceptions by multiple observers within classical reality arise. The resolution of this question was developed by Zurek (2003; 2021) and others through the realisation that human observers rely on indirect information gained by observing small fragments of the environment rather than observing quantum systems directly. However, only information about stable classical states of quantum systems that can be pervasively and consistently copied and propagated in the environment survives. Zurek (2003) coined the term *quantum Darwinism* for this process by which only specific *pointer states* of quantum systems survive the pervasive interaction with the environment and are einselected, with the information about their state rapidly and redundantly copied in the environment, thereby providing the basis of objective observations of phenomena.

The environment, as Zurek (2009) argues, becomes a “witness to the state of the system” (p. 182), and the proliferation of copies of the original information in the environment provides access to many observers, each accessing a fragment of the environment. As Zurek (2009) realised, “only states that produce multiple informational offspring – multiple imprints in the environment – can be found out from small fragments of [the environment]” (p. 182), which explains the Darwinism concept he introduced to the decoherence theory. Zurek (2021) states that “Quantum Darwinism is not really ‘hypothetical’ it is a ‘fact of life’. Its central tenet - the indirect acquisition of information by observers - is what actually happens in our quantum Universe” (p. 3). It shows, as Zurek (2021) summarises, “how the perception of classical reality arises via selective amplification and spreading of information in our fundamentally quantum Universe” (p. 3). Zurek (2021) confirms the ontological cut that decoherence enacts and states that the environment has the function of decohering the quantum states and

determining the state in which “the objects out there can exist, and it delivers to us information about the preferred states of the very objects it has decohered” (p. 3). The classical reality we perceive emerges through this process. Quantum Darwinism has been further developed by Blume-Kohout and Zurek (2006), Brandão et al. (2015) and consecutive works by Zurek up to his latest summary (Zurek, 2021).

Decoherence and quantum Darwinism are directly linked to the problem of *measurement* in quantum mechanics. The measurement problem refers to the question of how a quantum system’s wave function decoheres and settles into one of its possible states when it is *measured* – in other words, interacts with a macroscopic apparatus – and a perceptible macroscopic state change occurs, such as the positioning of a pointer on an instrument. The mathematics of the wave function according to which the quantum system should evolve in contact with the apparatus gives no answer. In fact, according to the mathematics of the wave function, collapse into a defined state should not occur. Instead, ever-larger networks of entangled states should lead to macroscopic indeterminacy of the apparatus, such as the infamous Schrödinger’s cat that finds itself in a superposition of being dead and alive. However, macroscopic measurement apparatuses are part of the environment. The advances of Zurek and others on quantum decoherence and quantum Darwinism, therefore, refocus the measurement problem on the environmentally induced decoherence of the observed system. In fact, as Bacciagaluppi (2020) argues, decoherence theory shifts the measurement problem from a discussion about a particular system and a measurement apparatus to the discussion of the continuous measurement of all systems by the environment whereby the effects observed by measurements are just part of the wider classical reality as emergent through decoherence. However, while decoherence explains why macroscopic superpositions of states are suppressed it does not resolve the question of how one particular measurement outcome is selected from the mixture of the observed system’s state instead of alternative possibilities. Why do we find ourselves in a universe where the cat is alive instead of dead? Is there a mechanism to be found that forces one choice over another, or do both outcomes of the cat paradox happen but in different branches of a multiverse (Joos, 2006, p. 75)? Physicists agree that decoherence theory must be augmented with a foundational theory and interpretation of quantum mechanics in order to either solve or dissolve the remaining questions of the measurement problem (Bacciagaluppi, 2020; Joos, 2007, p. 23). Nevertheless, Zurek (2021) cautiously asks “Will - in view of these advances - the measurement problem be regarded as ‘solved’?” (p. 13), and hopes that it might be, but he remains sceptical. As he states, many other physicists are still “rooting for it to remain a problem” (p. 14).

For the critique of Barad (2007), it is important to point out that environment-induced decoherence happens for macroscopic objects *independent from each other* and gives objects a separate, historised and individual classical existence within the environment. A drinking glass and a table are independently invoked and maintained as classical objects due to their pervasive individual contact with the environment regardless of being in proximity or some form of macroscopic intra-action with each

other. When the glass is placed on the table, the agential relationship between the glass being supported by the table and the table supporting the glass is a classical relationship between independently existing classical objects that have their own individual histories. This realisation directly contradicts Barad's (2007) view that *relata*, including human bodies and words, do not pre-exist independently from each other but are invoked as phenomena in the *intra-action between them*. Barad's (2007) interpretation of quantum mechanics, therefore, sidesteps the intra-action with the environment as the cause of the emergence of classical *relata*. Intra-actions between macroscopic *relata* do not reinstate quantum indeterminacy or undo individual historised existence. The quantum mechanics that Barad invokes are not at work between macroscopic *relata* in the way her theory suggests. Instead, ample processes or entanglements – other than those at the quantum mechanical scale – can be seen that point to agency and the production of phenomena at scales recognisable by humans. Decoherence theory explains classicality as a *consequence* of quantum mechanics, but quantum mechanics *per se* offers little explicatory value in understanding life at human scales.

It could be argued that the process by which classical reality is said to emerge from the quantum indeterminacy of isolated quantum systems through the pervasive entanglement with the environment has *similarities* with Barad's agential realism. Indeed, one could label the way in which indeterminate properties become determinate through the intra-actions between quantum objects and the environment as an example of agential realism in action. The significant difference, however, is that this pervasive network of constant and extensive intra-actions *at the micro-level* between quantum systems and the environment is generative of something *qualitatively very different at the macroscopic level*: the emergence of the macroscopic domain of classicality with independently established and maintained classical objects which then interact classically with each other at the human scale (Clayton & Davies, 2006; Joos, 2006). We argue that this emergence of the classical domain fulfils El-Hani and Pereira's (2000) definition of emergence with genuinely new and, from the perspective of quantum mechanics, unpredictable and novel properties:

1. Ontological physicalism: All that exists in the space-time world are the basic particles recognised by physics and their aggregates.
2. Property emergence: When aggregates of material particles attain an appropriate level of organizational complexity, genuinely novel properties emerge in these complex systems.
3. The irreducibility of the emergence: Emergent properties are irreducible to, and unpredictable from, the lower-level phenomena from which they emerge.
4. Downward causation: Higher-level entities causally affect their lower-level constituents.

(as cited in Clayton & Davies, 2006, p. 2)

Decoherence theory accepts quantum systems as the basic ontological primitives and understands classical reality as an emergent system based on the behaviour and physics of quantum systems. However, together with the classical reality, novel properties emerge; these include macroscopic entities that can exist and persist in defined states, the observer-independent objective measurability of properties, and the ability of entities to form persistent complex arrangements capable of representing information. While the emergence of classical reality is predicted by the theory of decoherence and quantum Darwinism, the emergent properties *of that which emerges within the classical domain* are unpredictable from the lower-level quantum phenomena. Emergence theory is closely linked to causality and troubles Barad's (2007) theories on causation by reinstating the existence of independent entities within emergent levels of reality. Cause and effect relationships are not limited to actions between entities within emergent levels or reducible to lower-level behaviour. Higher-level phenomena can cause lower-level behaviour through *downward causation* (see Clayton & David, 2006; Ellis, 2016; Voosholz & Gabriel, 2021, for detailed discussion).

Our critique of Barad's application of quantum mechanics to human scales does not claim to settle the remaining discourses in physics about the interpretation of quantum mechanics in a wider sense. It is widely acknowledged that decoherence theory has made a significant contribution to the understanding of quantum physics, but the metaphysics of quantum mechanics remains a field of active discussion. Decoherence through the entanglement of quantum systems with the environment leads to the understanding of the universe in its entirety as a quantum system with yet unresolved interpretational questions. Camilleri (2009) and Joos (2002) discuss how decoherence theory corresponds to wider interpretations of quantum physics, in particular, Everett's multiverse theory and Bohr's 'Copenhagen Interpretation'. Bacciagaluppi's (2020) entry on decoherence theory in the Stanford Encyclopedia of Philosophy provides a basis for further discussions.

### **Barad's discussion of decoherence**

Barad (2007) acknowledges the influence of the environment on quantum systems and introduces decoherence as an environment-induced *randomisation process*. However, for Barad (2007), decoherence is merely a disturbance of our ability to observe quantum behaviour because of the difficulty of keeping an object isolated from the environment (p. 279). According to Barad (2007), decoherence randomises the superposition of states of a quantum system into a mixture of classical states "'for all practical purposes' (but *not* in principle)" (p. 279, emphasis in original). However, Barad (2007) does not address the fundamental conflict that this juxtaposition of 'all practical purposes' and 'in principle' hints at for her theory about the macroscopic world we live in. Yet this is the central argument that decoherence and quantum Darwinism theory addresses. According to decoherence theory, macroscopic objects acquire classicality *in principle and irreversibly* (Joos, 2007, p. 21). However, Barad (2007) maintains that macroscopic relata are instantiated *by each other* in their intra-



actions and remain indeterminate and non-existent outside such intra-actions. This is Barad's (2007) key argument for her extension of quantum ideas to social theories. Barad's (2007) only citations of Zurek are a paper by Wothers and Zurek (1979) on the double-slit experiment and Bohr's complementarity principle and Wheeler and Zurek's (1983) book on quantum theory and measurement. However, Barad (2007) makes no reference to the extensive work on decoherence produced by Zurek and others in the 1990s and 2000s. Barad (2007) does provide a well-developed discussion of the measurement problem (p. 280), but without the important context that decoherence and quantum Darwinism theory provide. More fundamentally, Barad's (2007) avoidance of a deeper engagement with decoherence theory avoids the implications of the emergence of classical reality for agential realism and for her elevation of quantum phenomena to the macroscopic level.

### **On Barad's *relata*, persistence and the elevation of phenomena to ontological primitives**

Barad (2007) frequently refers to the term *relata* in her writing, maintaining that *relata* do not pre-exist their relations but themselves emerge within *phenomena* through specific intra-actions at all scales, including the human scale (p. 140). Further, Barad (2007) discusses the production of phenomena in intra-actions between objects and apparatuses and describes apparatuses as "specific material reconfigurings of the world" (p. 142). Barad (2007) elevates phenomena to the ontological primitives of her theory and asserts that:

Phenomena are ontological primitives (i.e., they are relations without *relata*). In a sense, phenomena are the new atoms where atoms are not individual objects but rather practices/doings distributed in space and time. (p. 444)

Yet Barad (2007) consistently asserts that phenomena are *constituted* (pp. 315-316), and that at least some phenomena are *reproducibly* generated by apparatuses intra-acting with objects (p. 329). This leaves the reader wondering how something that is constituted by something else and can be reproduced by specifically configured apparatuses, can be the ontological primitive. Barad's (2007) theorising about *relata*, existence, and ontological primitives remains opaque with respect to the observable properties of the macroscopic classical reality and in what ontological state macroscopic *relata* find themselves before and after specific intra-actions between them.

Barad's (2007) insistence on the non-existence of *relata* outside of specific intra-actions between them seems irreconcilable with the historised and individualised existence of macroscopic objects and subjects in the classical world we perceive as explained by decoherence theory. A key property of the classical domain is the temporal persistence of macroscopic objects and the information their arrangements represent. Entities in the macroscopic domain have deep histories of emergence, existence and transformation, as evidenced in the development of the universe over billions of years. The world we perceive is like a record book; this is pertinent for the geology of our planet and even the

history of Earth's climate with respect to the climate emergency (Hansen et al., 2016). The relative stability of the classical domain is in turn a requirement for evolutionary processes of emergence of complex systems, self-organisation and ultimately the evolution of living structures, conscious neural networks and the emergence of the social domain. As an example, Clayton and Davis (2006) cite the work of Michael Polanyi on the emergence of information-carrying structures in biology. Due to the biological processes of replication of RNA and DNA molecules, the morphogenetic information encoded by these molecules can persist for millions of years and provides the framework for the evolution of life (Jheeta, 2017; Orgel, 1994). Maturana and Varela (2012) argue that the evolutionary development of life is a "historical network" (p. 104) in which a succession of identities is predicated by both the stability and inheritance of pre-existing configurations and information, as well as a constant opportunity for change and the emergence of novel configurations. Like genetic traits, cultural traits are also undergoing emergent evolutionary processes based on existence, persistence and modification throughout history (Ostrom, 2000; Taborsky, 2021). In the social domain, persistence emanates from, and underpins, social practices at all levels; social analysis in both prescriptive and descriptive forms needs the capacity to grapple with persistence *and* novelty and to analyse the relationship between power, change and stability.

## **Conclusion**

Barad's focus on the entangled nature of reality is certainly well placed. However, we argue that the entanglements that matter at the human scale are not quantum mechanical in nature, but are enacted within the emergent classical reality that decoherence and quantum Darwinism theories explain. The elevation of quantum indeterminacy into the macro-scale of human existence contradicts the physics relevant to this scale, and it also risks deflecting the responsibility for the deconstruction of socially and politically oppressive determinisms to the ontology of quantum indeterminacy. While this may appear to be emancipatory, it leaves theorists with few stable foundations on which to build. New materialist theories may find more productive connections with emergence, evolution, and the organisation of complex systems and heterogeneous assemblages of subjects, matter and meaning. Explanations of the emergence of life, and of the interactions between the social and the material world(s), become productive once the classicality of the physical world we perceive is accepted.

This is also in line with arguments made by Holzhey (2021) in his call for an end to discussing fundamental physics in domains in which its relevance is not apparent. That is not to say that we believe physics to have no place in contemporary politics. In fact, we emphatically argue that physics and related sciences play a crucial role in contemporary governance - for example, with respect to the climate systems of our planet, the consequences of transgressing thresholds, and the possibilities and limitations of technological responses. The path to meeting the universe further requires a constructive dialogue between the social and natural sciences that acknowledges our interconnectedness and

dependence on the more-than-human world. To achieve this, new materialist philosophies may be well directed away from a focus on quantum-mechanical ontologies of the microcosm, to an ontology *at the scales that matter*.

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