Anti-Foundationalist Coherentism as an Ontology for Relational Quantum Mechanics

Abstract

There have been a number of recent attempts to identify the best metaphysical framework for capturing Rovelli's Relational Quantum Mechanics (RQM). All such accounts commit to some form of fundamentalia, whether they be traditional objects, physical relations, events or 'flashes', or the cosmos as a fundamental whole.

However, Rovelli's own recommendation is that 'a natural philosophical home for RQM is an anti-foundationalist perspective' (2018:10). This gives us some prima facie reason to explore options beyond these foundationalist frameworks, and take seriously a picture that lacks fundamentalia.

I construct an argument from elimination in favour of an anti-foundationalist interpretation of RQM. The argument notes that *priority monism* and *priority pluralism* are exhaustive foundationalist options, and then shows that there are reasons to reject their union with RQM. I finish by recommending *metaphysical coherentism* as a promising anti-foundationalist alternative, which captures the key characteristics of RQM through accepting symmetrical dependence, whilst avoiding challenges by jettisoning any commitment to fundamental entities.

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1. Introduction

Foundationalism, the idea that there must be some ultimate, fundamental elements of reality, is widely entrenched across Western metaphysical discourse. In this paper I defend the thesis that a metaphysical interpretation of Relational Quantum Mechanics pushes us to think beyond foundationalism.[1]

The current options for the metaphysical interpretations of RQM all involve commitment to some form of fundamentalia. In §2, I offer a survey of the existing suggestions, and note the form of fundamentalia they each commit to. I argue that an improvement can be made upon these by accepting anti-foundationalism. My argument from elimination is put forward in §3, and offers reasons to reject both exhaustive foundationalist options: monism and pluralism. I finish with a positive suggestion for what I consider to be a promising anti-foundationalist ontology for RQM: *anti-foundationalist coherentism* (§4).

Before embarking on the project, some preliminaries need to be addressed. First, I will briefly characterise RQM and its departure from textbook QM. I will also spend some time clarifying the notions of fundamentality and foundations that I use in my development of anti-foundationalist coherentism.

[1] The vast number of variations on textbook quantum mechanics demonstrate the difference in ways that quantum phenomena have been understood by physicists. Relational Quantum Mechanics (RQM) is one such variation. I do not motivate or defend RQM: my interest lies in exploring the proper metaphysical framework in which to situate RQM.

1.1 Introducing RQM

The measurement problem that pervades quantum mechanics involves the properties of a physical system being determined only upon measurement. Before being measured, the superposition states of such physical systems means that their properties, such as location or spin, remain undetermined. A superposition is when a quantum system exists in multiple (inconsistent) states simultaneously. Rovelli suggests that we should make sense of these phenomena found in quantum mechanics by understanding physical systems as having no[2] defined properties that are independent from their interactions with other systems. Thus, the key characteristic of Rovelli's *relational* understanding of QM is that, in addition to physical systems being the subjects of measurement that determine their properties, any physical system can also play the role of the measurer, or in physicists' language, the *observer*. The properties of the observer, too, are affected by the interaction of measurement.

Whilst textbook quantum mechanics takes an observer to be uninfluenced by any measurement it makes, relational quantum mechanics takes both the observer and the observed to be part of the interaction of measurement (Rovelli 2022: 47, 67-69). This interaction has an effect on both. Rovelli's revision suggests that observers do not hold any privileged or objective perspective. Their involvement in interactions mean that all contingent properties of physical systems are relational, and there are no absolute values of variables that are independent from interactions with other physical systems.

To illustrate, take the classic case of Schrödinger's cat. In terms of textbook QM, the puzzle is presented as a puzzle only about the determination of properties of the physical system that is to be observed: the cat. Prior to measurement, the superposition of the quantum state that is to determine the fate of the cat is problematic since its properties are undetermined. This means the cat's property of being alive or dead is also bizarrely undetermined. Given *relational* QM, the observers properties are also undetermined, prior to its measurement interaction with the cat.[3] As Rovelli puts it: "*All* variable aspects of an object exist only in relation to other objects. It is only in interactions that nature draws the world" (Rovelli, 2017: 115). RQM therefore implies that there are no parts of the world that are completely self-constituted, ontologically independent, and immune to external influences.

[2] I present Rovelli's view as claiming that prior to interaction, systems have *no* defined properties. Other presentations of his view might suggest that systems have *a multitude of inconsistent* defined properties prior to interaction, making the properties of undetermined systems glutty instead of gappy. Glutty indeterminacy is when a system possesses multiple inconsistent properties, whereas gappy indeterminacy is when a system lacks defined properties. Regardless of which characterisation of undetermined systems is more accurate, the key point that matter is that individual systems *are indeterminate* prior to interactions with others.

[3] An observer need not be conscious, as Rovelli emphasises, an observer can be any physical system. The interaction has both an effect on the observer and the observed, determining both of their properties. The interaction of observation between the physicist and cat has effect on both the physicist and the cat.

1.2 Introducing Fundamentality

For the purposes of the paper, I will follow the majority of the literature on fundamentality[4] in referring to any metaphysical position that commits to the existence of one or more fundamental entities as *foundationalist*. The antithesis then, is a metaphysical position that makes no such commitment to any fundamental entity: anti-foundationalism. As such, a clarification of what is meant by 'fundamental entity' is crucial before embarking on the current debate.

I adopt the view that fundamentality is intimately connected to an entity's position within the 'structure of reality', where 'structure' is thought of in terms of relations.[5] To then say that an entity is fundamental is to say that it occupies a specific position within that structure. Two further questions follow: what are these relations that structure reality? And what place within the structure does an entity need to occupy in order to qualify as an ultimately fundamental entity? I take each question in turn.

Candidate relations commonly considered in the fundamentality literature include grounding, building (Bennett, 2017), and ontological dependence.[6] I consider the broadest of these to be ontological dependence. If an entity is grounded or built, then it must be dependent upon what grounds or builds it. However, this doesn't hold in the opposite direction- an entity being dependent does not necessarily mean it's grounded or built. This is because both grounding and building have stricter formal features, including irreflexivity and asymmetry. A putative reflexive ontological dependence relation could not be described as grounding or building (Tahko and Lowe 2020, Bennett 2017). With the view to keeping the rest of the paper as applicable and generalisable as possible, and to keeping the requirements for qualifying as a 'fundamental entity' as broad as possible, I thus opt for understanding the relations that structure reality as relations of *ontological dependence*.

It is important for the discussion that follows that the ontological dependence referred to is not just for dependence-for-existence, but also for identity. For example, a set could be considered as ontologically dependent for its existence on its members. Moreover, the identity of the set is fixed by the identity of its members (example taken from Tahko and Lowe 2020, for more see Lowe 1998 and Correia 2008). Thus, the dependence I will be referring to is of the kind that x depends on y for its existence *and the properties that are essential to its identity*.[7]

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[4] See, for example Schaffer 2010: 37, Tahko 2023: §3, Bliss and Priest 2018: 2, Oberle 2022: 97.

[5] For an alternative that takes fundamentality to be a primitive notion, see Wilson (2014) whose position can be captured by the slogan 'fundamentality is fundamental'. See Bennett (2017) for a response to such a position, who counterargues that it is only fundamental entities that are unanalysable, rather than 'fundamentality' itself. The unanalysability of fundamental entities amounts to the claim that what marks an entity as fundamental is its independence, which underpins the inability to be explained in terms of any other phenomenon.

[6] Other options are available. For example fundamentality has been tied to part-whole relations (for example, Schaffer 2010), constitution, and even explanatory relations (e.g. Thompson 2018).

[7] Lowe refers to this kind of relation as 'identity dependence' (x is dependent for its existence on y iff necessarily, the identity of x depends on the identity of y). Identity dependence is argued by Lowe to be a stronger form of dependence that encompasses identity dependence. Correia prefers 'essential

The second question concerns the position within the structure of ontological dependence an entity must occupy in order for it to be considered *ultimately fundamental*. It is often thought that foundationalism is marked by 'wellfoundedness', and anti-foundationalism is marked by 'non-wellfoundedness'. Wellfoundedness can be thought of as the presence of a lower bound to complete all chains of dependence that structure reality hierarchically.[8] This steers us towards something like:

Ontological independence: x is ontologically independent iff, for all ontological dependence relations, D, there is no y such that Dxy.[9]

Further, if something is ontologically independent, then there is no entity upon which it depends for its existence. Call any such ontologically independent entity fundamental. Thus:

Foundationalism: There exists some x, such that for all D, there is no y such that Dxy.

Anti-foundationalism: For all x, there is some y such that Dxy.

In sum then, I take foundationalism to be any metaphysical position that commits to the existence of at least one fundamental entity. X is a fundamental entity iff x does not ontologically depend for its existence or nature on any other entity, y. The position I intend to defend as most appropriate for capturing RQM is anti-foundationalism, on which every entity is ontologically dependent for its existence and nature on some other entity. For all entities that exist, there must be some other entity on which it is dependent for its nature and existence.

It is important to note, that I do not begin my enquiry from the point of accepting that the quantum domain is the fundamental domain, before enquiring into what RQM can tell us about the dependence structure of the fundamental quantum domain. Instead, I begin with no prior commitments as to whether a fundamental domain exists, before enquiring into what RQM can tell us about dependence structures, and what we can infer from these dependence structures about whether a fundamental domain exists.

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dependence' to capture this increased strength of the relation, beyond just dependence for existence, but also dependence for the essential properties of the entities in question, (x is essentially such that it exists only if y exists).

[8] Two caveats are worth noting. First, Bliss (2013) highlights that well-founded chains of dependence need not always be finite chains. Infinite well-founded chains are possible, if chains 'ascend' infinitely, possessing a lower bound, whilst lacking an upper bound. Second, Leunberger (2019) notes that what it is to be a lower bound might be thought of in two ways, that can come apart. What marks a lower bound may be its lack of dependence on anything else (ontological *independence*), or its role in providing the foundation for the rest of a dependence structure. Leuenberger frames this as an issue of whether being fundamental is being 'ungrounded' or being 'all-grounding'. As already indicated, I take the marker of fundamentality to be *ontological independence* (or *ungroundedness* in Leunberger's terminology). An entity is fundamental iff it does not depend on any other entity for it's existence or nature.

[9] I hold the important feature of making an entity fundamental is the lack of dependence on *any entity other than itself*. If an entity is purely reflexively dependent on itself, then I consider it and independent in the relevant sense, and hence fundamental. If there were to exist an entity such that Dxx, then this entity would be rendered fundamental, as it depends on no *other* entity.

2. Existing Ontologies for RQM

Let's now turn to how fundamentality and RQM have been treated together. The reader already familiar with this literature may wish to skip ahead to section 3. The core of my argument is that RQM should not be blended with either of priority monism (the view that exactly one entity is fundamental) or priority pluralism (the view that more than one entity is fundamental). The arguments themselves do not turn on the details of the specific positions taken within the literature. Nonetheless, I produce them here to give the reader a sense of the various ways in which the positions have been cashed out and how it has been suggested that they mesh with RQM.

One thing common to all interpretations of RQM to date is a commitment to some fundamental, ontologically independent entity(ies). Hence, I regard the suggestions as to metaphysical structures that best fit with RQM, surveyed below as *foundationalist*.

Priority Monism

Morganti and Dorato (2022) argue that a natural connection might be made between RQM and priority monism, of the kind defended by Schaffer (2010). Given the characteristics of RQM, a monist ontological interpretation might emerge,

> 'according to which the truly fundamental physical entity is the universe as a whole, which however, is constituted by a plurality of systems that acquire a physical characterisation only in relation to one another' (2022: 5).

Schaffer's view postulates the priority of the universe as one single whole, over all physical systems taken as parts contained within, which he argues to be the best explanation for quantum phenomena like entanglement.

Schaffer's view is a universalisation of a more moderate *holism,* which holds that there are instances where wholes are ontologically prior to parts. According to Schaffer, cases that exhibit holism include a simple case of two entangled physical subsystems. The single overall system containing two subsystems is more fundamental than each subsystem, since the properties of both subsystems are dependent on one another, and hence neither can be described fully and accurately when described independently. The system as a whole contains all of the information relevant to the explanation of each subsystem, whereas some relevant information is lost when giving an explanation of a subsystem in isolation. Systems as wholes contain more information than subsystems taken as individual parts.

This idea could be thought to mesh with the upshots of RQM. The whole produced by two sub-systems and their interaction contains more information, *including determinate properties of the two subsystems*, than each of the subsystems taken individually, which possess indeterminate properties prior to interaction. A whole is only formed when two subsystems interact, and their properties get determined relative to one another. Parts of the system in isolation possess no such properties. Hence, it could be argued that the

priority of wholes over their parts can be used to account for systems (post interaction) containing more information than individual subsystems (prior to interaction) in RQM.

Schaffer extends holism universally, to produce an all-pervading monism, according to which all physical systems are derivative parts of one maximal, fundamental whole. Such a move is made through Schaffer's argument that the entire universe is in an entangled state, and all entangled states as wholes, are more fundamental than their parts (2010: 51-52). Hence, this entails that the universe as a whole is the only entity that is ontologically independent, and the one single fundamental foundation.

Monism can then be unified with RQM, by suggesting that the one fundamental whole is prior to all of its interacting parts. Within the whole, all parts must interact in order for their properties to be determined. It is only at the maximal level that all information about all interacting subsystems could be gathered. Therefore, the universe as a maximal whole is prior to all of its parts. Priority monism makes a commitment to a fundamental entity, albeit only one, which is enough for it to qualify as a form of foundationalism.

Ontic Structural Realism

Candiotto (2017) argues that Ladyman and Ross' (2007) *ontic structual realism* (OSR) provides the best metaphysical framework for understanding RQM. RQM's upshot is that quantum systems have no definite properties or absolute values that can be regarded as intrinsic to a system treated as an individual. OSR provides a way to account for such a lack of intrinsic features: according to OSR, all features of quantum systems are essentially relational or structural. OSR requires emphasising the ontological priority of relations over their relata, so that entities and their properties are derivative from the relational structure that holds between them.

The dependence of a quantum system's properties upon the interactions between that system and another (in RQM), is reflected in OSR by the dependence of entities and their properties upon physical, fundamental relations that hold between them. Strong forms of OSR take relations as physical, primitive or ontologically independent, demoting the entities they hold between to derivatives. Candiotto argues that the dependence of entities on the relational structure that holds between them can explain the inability to understand physical systems independently from their interactions on RQM. OSR is an alternative form of foundationalism, as (most of its forms) revise the view that traditional objects constitute fundamental foundations, to instead hold that *relations* constitute reality's fundamental foundations.

Processualism/ Event Ontology

Rovelli himself suggests an ontology on which events that occur when quantum systems interact, are to be considered as fundamental. It is within these relational quantum events that systems acquire their determinate properties, meaning entities and their properties could be considered to rely on such events, and events could be considered to rely on nothing else, making them fundamental.

Dorato (2015) addresses this suggestion from Rovelli, claiming that interactions are indescribable and require no explanation. 'According to RQM… attributing definite states to non-interactive physical systems has no meaning' (2015: 10). It is only possible to talk of *interactive phenomena* as definite states. It is worth noting that Dorato goes further to argue that fundamental events are an appropriate ontology for all physical interpretations of QM, of which RQM is just one: 'Events are *necessary* both in realistic and in antirealistic views of the wave function: in virtue of their interpretation-independence, events turn out to be a central ontological component of quantum mechanics' (2015: 12).

An ontology of events might be thought of as a kind of processualism, which holds that dynamic processes with temporal parts are fundamental. All entities such as individuals or universal are derivative from these dynamic fundamentalia. Proponents of processual interpretations of QM, like Barad (2007), recommend thinking past a world that is fundamentally made up of bits of matter that have determined properties and identities, and towards a world where such identities are dependent upon the activities that they are a part of. According to RQM, entities cannot be determined independent from their context amongst processes of interaction. The processualist would argue that this implies processes of interaction must be prior to entities with determined properties. According to processualism, events are the ultimate foundations of reality.

Indeterminate Quantum Systems

A key upshot of RQM that any metaphysical interpretation must account for is indeterminacy. Systems only acquire determinate properties, or variables only acquire determinate values, relative to another system, meaning that 'value definiteness' and complete determinism in nature, fail. It is not the case that all entities or properties of a system have precise values at all times, contrary to the determinism of classical physics.[10]

Calosi and Mariani (2020) interpret this to mean that there could be metaphysical indeterminacy at the fundamental level, in the form of indeterminate quantum systems as fundamental entities. They suggest that accepting indeterminacy at the fundamental level may help solve the issue of properties of quantum systems before interaction with another system. This indeterminacy is not just at the level of derivatives, but is part of what we should consider as RQM's fundamental ontology. They argue that indeterminacy is due to non-interaction between quantum systems, therefore the fundamental constituents of indeterminacy, the non-interacting systems, mean that indeterminacy is fundamental. Their view holds that when we accept indeterminacy, quantum systems can be considered as fundamental, whether they interact or not. This discussion of RQM as indeterminate relies on another foundationalist metaphysical picture: one that commits to indeterminate quantum systems as the foundations of reality.

[10] It could be claimed that even if systems lack determinate values prior to interaction, the probabilities that can be calculated prior to interaction are determined and fixed. In response to this kind of claim, I highlight that dispositions and probabilities are not the kinds of phenomena that could be considered as candidates for fundamentalia. This is because they rely on the existence of systems of which they could be considered properties.

Each of the accounts mentioned in this brief survey of metaphysical interpretations of RQM commits to some form of fundamentalia, whether that be the cosmos as a whole, physical relations, events or processes, or indeterminate quantum systems. In the following section I will provide arguments in favour of an anti-foundationalist interpretation of RQM, which suggest that it is worthwhile developing a metaphysical account of RQM that commits to no fundamentalia at all.

3. An argument in favour of interpreting RQM as anti-foundationalist

The possibilities just surveyed fit into two categories of interpretation. Priority monism-foundationalism commits to exactly one fundamental entity, and priority pluralism-foundationalism commits to more than one fundamental entity. My reasoning for favouring anti-foundationalism involves discussing why both these foundationalist possibilities can be found wanting.[11] Thus:

1) Priority monism and priority pluralism are exclusive and exhaustive foundationalist positions.[12]
2) Priority monism does not provide a good interpretation of RQM.[13]
3) Priority pluralism does not provide a good interpretation of RQM.
4) (If neither foundationalist interpretation can provide a good interpretation of RQM, then we should adopt an anti-foundationalist interpretation). [14]

Therefore,
C) We should adopt an anti-foundationalist interpretation of RQM.

Premises 1 and 4 seem relatively uncontroversial. That being so, I'll turn my attention to premises 2 and 3. 3.1 defends premise 2; 3.2 defends premise 3.

3.1 Against monism

We should reject the union of monism and RQM. In outline, the problem is this: RQM rejects the existence of absolute states with independent properties; monisms posit an absolute state which is the totality of the universe and which itself has independent properties. Thus, RQM and PM are incompatible.

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[11] To clarify, the argument presented here is not intended to *rule out* the possibilities presented in Section 2. The criticisms of monist and pluralist positions are intended to motivate thet suggestion looking in the coherentist direction.
[12] It may be objected, that this premise relies on Schaffer's controversial *tiling constraint* (2010: 38–39, 2015: 24–25). However, in the simple ways that I characterise foundationalism's commitment to at least one fundamental entity, monism: commitment to exactly one fundamental entity, and pluralism: commitment to more than one fundamental entity, it follows that monism and pluralism are exhaustive foundationalist positions. The issue of exclusivity, challenged by objections made to the tiling constraint, is not important for the sake of my argument- monist and pluralist positions may overlap. What is important is that, overlapping or not, they exhaust all the ways in which one might be foundationalist.
[13] It is important to note that these premises are not strong claims of logical inconsistency between both forms of foundationalism and RQM. They are weaker claims of best explanation or interpretation.
[14] Of course, at this stage one might want to opt for rejecting RQM. Since RQM is an assumption at the heart of the investigation, this option is ruled out here.

Drawing upon work by Dorato (2016) and Morganti and Dorato (2022), there are at least three ways of cashing out this problem. I take each in turn.

1. Determinate properties from fundamental indeterminacy

According to RQM, a single physical system can only have indeterminate properties, prior to interaction. According to priority monism, there is only one single fundamental physical system.[15] This means that if we conjoin RQM and priority monism, then the single fundamental system must have only indeterminate properties. Since we do not think that the actual world has only indeterminate properties (at least, not at the level of the non-fundamental), we should reject the union of RQM and priority monism.

The only obvious defence of this union would require us to locate a means of spelling out how the actual world's *non-fundamental* determinate properties can arise from a world that, at the fundamental level, is fully indeterminate. Since we lack any such account—we cannot give a systematic story about how determinacy arises from indeterminacy—so we lack any means of unifying RQM and priority monism. This is also a problem for any interpretation of RQM that accepts physical indeterminate quantum systems as fundamental, like that described in the final part of §2.[16]

2. (A)symmetry of dependence relations

Priority monism is defined as the view that the whole is fundamental and that the parts of the whole depend upon it for their existence (Schaffer, 2010). There is an asymmetry of existence, here. The one whole exists and the parts depend upon it. The whole does not depend upon its parts. As Schaffer notes (2010: 37) this requires a relation of asymmetry between the fundamental and the derivative.

In contrast, RQM requires symmetrical dependence relations between parts of the universe-for reasons I'll explain in a moment. This difference in properties of dependence relations between PM and RQM could be a second reason to doubt a connection between them (Morganti and Dorato, 2022: 11).

Why think a simple case can be made from RQM to the existence of symmetrical dependence relations? On RQM, a system requires interaction with another for the determination of its properties. If this is the case, then such a system is dependent for the properties that determine its identity on the system it interacts with. Per RQM, *every* system depends for its identity on its interactions with other systems. Thus, every system

[15] My characterisation of monism takes the prior fundamental whole to be *a physical fundamental whole*. This is the only way I have come across monism presented, so it is the account of monism I address. It may be possible that if the prior whole is not a physical prior whole, then determinate properties need not come from an indeterminate physical quantum state. However, I put this issue aside until such an account of non-physical priority monism is developed.

[16] Calosi and Mariani (2020) give two examples to illustrate how indeterminate quantum states could be thought of as fundamental. Both of these cases involve some interaction with a second quantum system. Neither example gives an explanation of how a completely isolated, independent fundamental indeterminate system might give rise to determinate states. Rejecting the possibility of indeterminate quantum systems as fundamental does *not* require rejecting an understanding of RQM that features indeterminacy.

depends upon another for its identity. When interaction occurs, both systems involved acquire determinate properties. Therefore, when an interaction occurs, both systems involved become symmetrically dependent upon each other for their existence and identity.

3. Locality and Holism

RQM posits symmetrical local dependence connections between subsystems *within* the universe. PM posits asymmetric dependence between parts of the universe and the universe itself. If we are to assume RQM, then there can only be dependence between the parts of the universe, since interactions happen at a local level. Conversely, if we assume PM to be true and the universe is more fundamental than its parts, then all parts must depend on the totality, and the totality must not depend on any of its parts.

As Dorato puts it: 'Failure of ontic priority of the One [whole] follows from the fact that there is no consistent sum of all possible perspectives yielded by the parts, so that there is no definite One whose identity is non-relational or non-structural' (2016: 23).[17]

3.2 Against Pluralism

The remaining suggestions set out in §2 are forms of priority pluralism, characterised by their commitment to more than one fundamental entity. Due to the concerns already addressed with the idea of indeterminate quantum systems as fundamentalia (argument 1, in 3.1), I will spend this section focussing on raising worries with the two current most popular priority pluralist options for interpreting RQM: relations as fundamental, and events as fundamental.

According to the preliminaries outlined in §1, what sets fundamentalia apart from all other phenomena is their ontological independence. Accordingly, if relations/events are fundamental, they must be treated as ontologically independent. In this section, I will explore two strategies to show that, given the constraints of RQM, neither relations nor events can be considered as ontologically independent. If these strategies succeed, then we should reject the union of RQM and priority pluralism.

Challenge 1: Spatiotemporal Location Argument

The most popular account of relations as fundamental discussed in the context of RQM is Ladyman and Ross' ontic structural realism. OSR is clear in its commitment to *physical* fundamental relations. According to OSR, dependencies between physical systems must be reified and considered as *physical* irreflexive symmetrical relations.[18] Similarly, all accounts

[17] A further illustration of this point comes from Morganti and Dorato's analogy between RQM and Leibnizian Monads: a Monad will 'reflect' other Monads or parts of the universe from its particular perspective. However, there is no 'Monad of Monads', because Monads can only 'reflect' from within- and each system can only have partial information about the universe as a whole from their particular internal perspective. (2022: 8)

[18] In cases of entanglement, dependencies between systems may be understood as physical relations of 'having the opposite spin to…'. In such cases, Morganti and Calosi discuss the issue of whether these dependencies should be considered as genuine physical relations.

of dynamic events classified by Meyer (2013:14)[19] presuppose the existence of spatiotemporal regions, lending them to being understood as *physical.*

A tension can be highlighted between the putative physicality of both fundamental relations and fundamental events, and their ontological independence, given RQM. This tension is shown through the conjunction of the following principles:

Physicality (P):
$Px \rightarrow STLx$ (if x is physical, then x possesses a spatiotemporal location)

Independence (I):
$Fx \leftrightarrow OIx$ (x is fundamental iff x is ontologically independent)

Determinate properties principle (DPP):
$RQM \rightarrow (STLx \rightarrow \neg OIx)$ (Given RQM, then if x has a spatiotemporal location, then x is not ontologically independent).

Principles (P)[20] and (I)[21] come from commonly used understandings of physicality and fundamentality. I won't spend time offering further support of them here. The third principle, (DPP), is more interesting and controversial. Nonetheless, I argue that RQM implies that any entity that has a spatiotemporal location cannot be ontologically independent.

RQM's central move is to interpret all physical variables as relationally *dependent*. In Rovelli's words, 'there are no properties outside of interactions' (2022: 70). According to (P), all physical things possess at least one property- the property of a spatiotemporal location.

Given RQM, possessing a property like spatiotemporal location means that an entity must be interacting with some other system. Rovelli himself discusses such a case. The example he gives is that of the orbit of an electron. To enquire of the orbit of an electron when it is not interacting with anything is to ask an empty question. 'When the electron does not interact with anything, it has *no physical properties. It has no position; it has no velocity'* (2022: 71, my emphasis added). Thus, nothing that possesses a spatiotemporal location can be ontologically independent.[22]

For this reason, DPP must be correct: given the core commitments of RQM, if x has a spatiotemporal location, then x is not ontologically independent. If relations or events are considered as our best candidates for x, and relations or events are thought of to be physical, then this creates a problem regarding our ability to accept relations or events as ontologically independent. To see this by way of reductio, assume that our putative

[19] Summarised by Dorato (forthcoming)
[20] See Markosian (2000)
[21] See Tahko (2018)
[22] Physical properties require interactions between physical systems according to RQM. Any physical system with properties must be dependent upon the existence and nature of second system that it interacts with.

fundamental relation or event R, is physical and hold on to the above theses. Semi-formally, suppose that R is fundamental and that R is physical.

[1] Given Physicality, it follows that R is Spatiotemporally Located.
[2] Given Independence, it follows that R is ontologically independent.
[3] From DPP and [1] it follows that it is not the case that R is ontologically independent.

As is clear, between them [2] and [3] yield a contradiction. If R is physical (if our event or relation is physical) and RQM is true, then R both is and is not ontologically independent. Thus we have our reductio. Assuming that we wish to hold on to RQM (and in this paper we are exploring how to best interpret RQM, so this is non-negotiable), we should not posit physical events or relations as fundamental. And since events and relations in this context are taken to be paradigmatically physical[23], we should reject fundamental events and relations.

Challenge 2: Ontological Dependence Argument

The second challenge to priority pluralist accounts of RQM is intended to cast doubt about whether any candidates for fundamentalia can be successful, given only the requirement that fundamentalia must be ontologically independent. The challenge involves an enquiry into the ways that pluralist candidates for fundamentalia (relations and events) are connected to other ontological categories, like objects or physical systems.

In outline, my argument is that given pluralist candidates for fundamentalia given RQM (relations and events), the only way to make sense of the existence of physical objects is to posit a symmetrical relation of dependence between physical objects and our pluralist candidates for fundamentalia. Since Pluralist Foundationalism presupposes asymmetric dependence, this result rules out Pluralist Foundationalism.

To generate this conclusion, let us start from the fact that either physical objects and relations/events are totally distinct from one another, or they are connected. It seems implausible that they are totally distinct from one another.

For example, there can be no event of tumbleweed movement without the object, the tumbleweed, moving. There can be no relation of distance between the tumbleweed and the rock without there being a tumbleweed and a rock. That being so, relations/events and physical objects must be connected.

If they are connected, then how? Nolan (2011) suggests that we should understand objects as reducible[24] to dynamic processes because the two are simply identical: objects *are*

[23] It is possible to explore non-physical relations/ events as potential fundamentalia, however this would be an odd route to pursue, especially given the background of interpreting QM. Given RQM, any relation that could be considered as fundamental must be one which relates physical systems, ensuring that they acquire determinate properties upon interaction. Non-physical relations such as functions, linguistic, logical or mathematical relations are not the kinds of relations that could play this role.
[24] In logic, reduction is thought of as asymmetric. If facts about tables reduce to facts about spacetime points, then facts about spacetime points do not reduce to facts about tables. However, in metaphysics, reduction implies that whatever is reducible is identical to what it is reduced to. If tables are reducible to

processes. Similarly, ontic structural realists who adopt a strong form of their position might argue that objects are reducible to a complex set of relations. Objects *are* a complex set of relations. If either of these positions are defensible, and the best way of understanding the relationship between these putative ontological categories is through identity, then this relationship is reflexive, transitive, and most importantly *symmetrical*. If that is correct then we do not have the kind of asymmetry that pluralist foundationalism requires.

A final option is that they are connected through dependence, but not reducible. The dependence of events on objects can be established through the internal complexity of events. An event, such as an interaction, must be temporally extended. By definition, it must possess dynamic change that requires change in the properties or physical systems that constitute the event. This means events cannot be ontologically simple- they must possess complexity. It is plausible to assume that complex events depend on their constituents, including physical systems[25]. Any given interaction between two physical systems requires those systems as parts of that event, in a way that means the individual event is dependent for its existence and nature on those physical systems. Events cannot be ontologically independent.

A particular instance of a relation can only be individuated by reference to the relata between which it holds. For example, to refer to a distance relation, we must refer to the two spatiotemporal locations or objects that the distance exists between. Even in cases of causation or grounding, the relata must be referenced in order to reference the particular occurrence of the relation. For instance, a propelled ball and a smashed window in the case of the causation, or arguably, H^2O and water in the case of the grounding. Physical relations must depend on physical systems for their identity, nature and individuation. Consequently, relations cannot be ontologically independent either.

Neither relations nor events can be understood completely independently from objects or physical systems. There must be some dependence that holds in at least one direction between the ontological categories. Given on RQM, that objects cannot possess determinate properties in isolation, they must also be dependent. Therefore, we must accept either that RQM should be understood in terms of symmetrical dependence between relations and objects, or symmetrical dependence between events and objects. For example, there cannot be the event without its constituents, and the constituents have no definite properties without the event. Physical systems rely on relations with other physical systems for their determined properties, and relations rely on physical systems for their existence, identity and individuation. The final section will defend *coherentism,* the idea that there is a vast web of interdependence that both relations and events are a part of.

Perhaps there are other options that will help us to preserve the asymmetry required for pluralist foundationalism. However, if that's right, then we should be told what they are and the options should be evaluated. In the absence of that, we should conclude that neither

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spacetime points, then tables are identical to those spacetime points. They are two descriptions of the same phenomenon. If they are the same phenomenon, neither has any metaphysical priority of the kind that would imply asymmetry.

[25] For examples of this sort of dependence, see Fine's (1995) essentialist notion of dependence, and the generic essential dependence formulated in Tahko and Lowe (2015).

pluralist foundationalism or monist foundationalism is viable. And since pluralism and monism are exhaustive categories of foundationalism, we should reject foundationalism, and explore anti-foundationalist alternatives, like *coherentism*.

4. Coherentism as the most promising form of anti-foundationalism

4.1 Introducing Anti-foundationalist Coherentism

Coherentist metaphysical structure is most often presented as an alternative to a foundationalist structure. It is an alternative that is receiving more attention from philosophers in recent years, especially since Bliss and Priest's 2018 volume which contained a series of essays giving it serious metaphysical treatment (see for example Barnes 2018, Nolan 2018, Thompson 2018, Priest 2018). The core characteristic of a coherentist picture is the acceptance of the possibility of *symmetrical* ontological dependence relations.

Everyday examples of symmetrical dependence have been defended by Barnes 2018 and Thompson 2018. These include the dependence of the fact A = <B is true> on the fact B = <A is true>. In a case where we assume that both propositions are true, then the fact that A is true depends on the fact that B is true *and vice versa*. Barnes argues that there are examples of events that are symmetrically dependent, the example she gives being the event of WW2 and the event of the evacuation of Dunkirk. Without the wider context of WW2, the evacuation of Dunkirk would not have happened in the way that it did, meanwhile, without the evacuation of Dunkirk, arguably, the entire event of WW2 would have been very different. My own favourite example of a simple case of symmetrical dependence, offered by Bliss and Priest 2018: 14, is the bi-directional dependence between the north and south poles of a magnet: "without the north pole, the south pole would not exist and without the south pole, the north pole would not exist".

Giving up on asymmetry, one of the traditional features of ontological dependence, opens up the possibility that reality need not be structured in linear chains of priority that together form a hierarchy. Instead, entities can be connected by vast webs of mutual dependence relations. Once this move is made, it is natural to suggest that coherentism is anti-foundationalist: webs of symmetrical dependence require no ultimate support from any ontologically independent entity. Linear chains of dependence, on the other hand, seem to demand a choice between being well-founded or non-well-founded. They either 'bottom' out in some foundational, independent entity, or they do not. If they do not, then worries of vicious infinite regress naturally arise. Coherentism may offer the anti-foundationalist a way out of such worries.

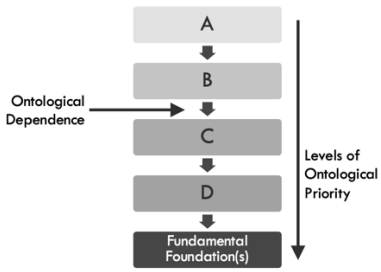

Figure 1. Standard Foundationalism

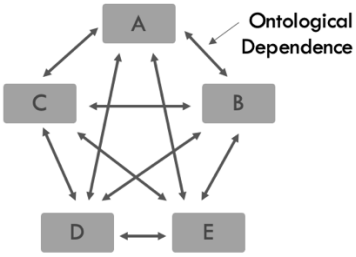

Figure 2. Standard Coherentism

Coherentism can come in different variations (Swiderski 2022), including its most extreme form, where all entities are dependent upon all other entities (Figure 2 above). Other less radical alternatives include structures that contain both asymmetric and symmetrical dependence, where for example, there are multiple layers of reality each structured as webs of mutual dependence. Each layer is connected to another through asymmetric dependence, and that creates a difference in ontological priority between layers (Figure 3)[26]. What is important for an account to be characterised as coherentist, is the lack of any ontologically independent entities (every entity depends on some other entity), and the presence of at least one symmetrical dependence relation.

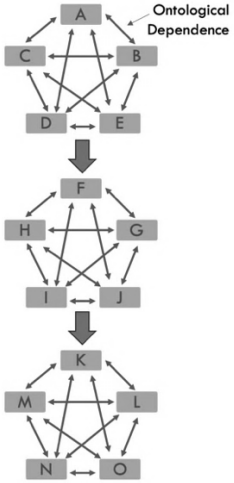

Figure 3. An example of coherentism that involves both symmetric and asymmetric dependence relations.

These two core commitments are captured by Swiderski's (2022) *Coherentist Canon: "*(i) For any x, there is some y such that y grounds x, and (ii) there is some z and some w such that z (perhaps indirectly) grounds w and vice versa" (2022: 1864).[27] Usually, commitment (i) which ensures the lack of any ontologically independent entities, is taken as the coherentist's rejection of foundationalism (given the popular understanding of the fundamental as whatever is ontologically independent, outlined in §1.2). This typical

[26] Variations of coherentist structures such as this are explored by Swiderski (2022). He refers to this structure as 'hierarchist' coherentism (2022: 14).

[27] For the sake of simplicity, the accept that grounding terminology used here can be translated into terminology of ontological dependence .

understanding, shared by Bliss and Priest (2018), and Swiderski (2022), renders coherentism an anti-foundationalist position.

4.2 Morganti and Dorato's *foundationalist* coherentist proposal

Morganti and Dorato (2022) offer a coherentist account *in the context of providing an ontology for RQM,* which is to be understood as *foundationalist*. Their proposal commits to both of Swiderski's criteria (the lack of any ontologically independent entity, and the presence of some symmetrical dependence).

However, their foundationalist understanding of coherentism is made possible by their rejection of a characterisation of fundamentalia in terms of ontological independence. The crux of their position is that RQM is best accounted for in terms of a network of symmetrical dependence, whilst the dependent nature of each entity in the network does not prevent them from being considered as fundamental. The ontology for RQM that they propose involves symmetrical dependence relations between all physical systems that rely on each other for their determined properties. According to their understanding, these dependent physical systems can still be considered as fundamental, despite relying on others.

4.3 Differences between the coherentist proposals, and reasons for preferring anti-foundationalist coherentism

The key difference between these competing accounts of foundationalism, is that Morganti and Dorato are willing to give up Hume's dictum, the idea that there can be no necessary connections between distinct, fundamental entities. The idea that fundamental entities must be absolutely independent can be attributed to Hume and Lewis. Morganti and Dorato contend that it is straightforwardly falsified by RQM. They hold that there must exist fundamental physical systems that are dependent for their determined properties on other physical systems, producing necessary connections between distinct fundamental entities.

'On the one hand, at least some of the physical systems described by quantum theory are arguably fundamental. On the other, RQM clearly describes physical systems as necessarily connected to other physical systems.' (2022: 16).

This I contend, is a move that need not be made, if we are ready to accept that there are no fundamental entities, and embrace anti-foundationalism. In the absence of further argument, the burden of proof lies on Morganti and Dorato to show why there must exist some fundamental entity. In order to justify giving up the idea that fundamentality is marked by ontological independence, Morganti and Dorato must either give some reasoning as to why some physical systems must be fundamental, or give some reasoning in favour of an alternative way of characterising fundamentality. Without some convincing reasons to this effect, we need not give up commitment to the view that fundamental entities are ontologically independent, and we should accept that if RQM is best interpreted using coherentism, then RQM is best interpreted as anti-foundationalist.

Another reason for preferring anti-foundationalist coherentism over foundationalist coherentism is because of the additional benefits it provides over competing interpretations

of RQM, like priority monism and ontic structural realism. I argue that Morganti and Dorato's critiques of these competing interpretations capture important ideas, but don't go far enough. They highlight coherentism's ability to avoid untenably strong claims made by both PM and OSR, that cannot be read directly from RQM. Consider the following statements:

'The proposed coherentist construal is more plausible than priority monism because the postulation of a symmetric dependence between proper parts of the universe by no means entails that the whole is (asymmetrically!) prior to the parts' (2022: 18).

'Also, the proposed coherentist construal is more plausible than structuralism because hypothesising ontological dependence relations between physical systems by no means entails that those physical relations are more fundamental than objects with their monadic properties' (2022: 18).

'While OS(R) reifies the explanans, since (interactions are literally fundamental constituents of reality) coherentism takes the empirical evidence to urge a change in the form of explanation since interactions are essential for a complete description of the way in which the fundamental constituents give rise to reality' (2022: 18).

The upshot of the first two statements is that RQM does not suggest a difference in priority between parts and wholes, or between relations and objects. Whilst I am in agreement that these are reasons for preferring coherentism, which does not involve such differences in metaphysical priority, over PM and OSR which do commit to such differences, I argue that these critiques don't go far enough. A coherentist interpretation of RQM is preferable to interpretations in terms of PM and OSR, not only because it avoids committing to differences in metaphysical priority, but also because it can avoid committing to an understanding of phenomena like wholes or relations as fundamentalia altogether. Not only is there no difference in relative fundamentality between these categories, coherentism can avoid positing anything ultimately fundamental.

Aside from the reasons already explored about why RQM struggles to be meshed with either monistic foundationalism nor pluralistic foundationalism, there are independent reasons for why an interpretation of RQM should avoid positing fundamentalia. The most compelling I consider to be, the problematic nature of fundamental entities. The commonly accepted tie between fundamentality and explanation (Schaffer 2016, Jenkins 2013, Thompson 2016, 2018) means that anything ultimately fundamental must lack a metaphysical explanation in terms of anything other. Such a brute, unexplainable entity violates the principle of sufficient reason. Whilst this is a price commonly paid by those who assume foundationalism, or accept foundationalism on pain of infinite regress, coherentism offers a way out of paying the price of committing to unexplainable entities. Assuming a close connection between metaphysical explanation and ontological dependence, the coherentist web of mutual dependence suggests there to be a virtuous holistic system of explanation. Within this system, all things are partially explained by all other things that they depend on, with no entity or physical system lacking a metaphysical explanation.

The final quotation listed above further highlights where Morganti and Dorato's coherentism, and anti-foundationalist coherentism differ from each other. Whilst interactions need not be reified nor considered to be fundamental as a result of their explanatory role, I hold that physical systems need not be considered as fundamental either. If we picture a coherentist network as a graph contain nodes, and connections between the nodes, then neither the nodes nor the connections must be fundamental, contrary to what Moranti and Dorato seem to assume. It seems that Morganti and Dorato consider some commitment to fundamentalia as essential. However, I follow recent work by Swiderski (2022), Thompson (2018) and Bliss (2014) in suggesting that coherentism can provide a consistent account of reality's structure without any need for commitment to fundamentalia or foundations.

The existence and properties of all entities are dependent on the entity's position in a vast network of dependence relations. Neither the relations, events of interaction, nor the entities between which they occur, are metaphysically prior according to this picture. This is made possible due to the acceptance of symmetrical dependence. There is no requirement for any foundational, independent entity, or metaphysical category, to do the work of giving rise to the rest of reality.[28] It is possible for all that exists to be dependent on something other.

Dispensing with commitment to ontologically independent foundations addresses RQM's central perplexing feature of the indeterminacy of all properties of physical systems prior to interaction. It ensures that these physical systems are always regarded as ontologically dependent for their nature, and hence, non-fundamental. Each element of the system is dependent on another element- as is suggested by Rovelli's description of interaction. It also avoids the problems that occur if we regard other ontological categories like relations or events as fundamental. For instance, it avoids the problem of how we are able to understand these categories independently of the physical systems they involve. Rovelli himself warns that accepting RQM will mean accepting novel metaphysical consequences. I hope to have shown that foundationalism might be a commitment that must be dispensed with in order to provide a metaphysics for interpreting RQM.

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