Quantum Entanglement, Internality and Dependence

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Abstract

The metaphysics of quantum entanglement has been a subject of interest among philosophers of physics in recent decades. Entanglement is commonly described as a relation that does not depend on the intrinsic properties of its relata. This feature has led some authors to propose that the quantum reality is fundamentally relational and/or holistic. Moreover, it has been employed to support various influential metaphysical perspectives within the metaphysics of science, including structuralism, monism, and, recently, coherentism. This paper advocates a non-reductionist approach to internal relations, drawing on Fine's analysis of propositions involving essential properties. Assuming the pervasiveness of quantum entanglement, it is argued that treating it as an internal relation is the most compelling option. Under this interpretation, entanglement can be accommodated within different metaphysical frameworks: (1) as a fundamental internal relation, it aligns with structuralism; (2) as a derivative internal relation, it is compatible with monism; and (3) as a relation of dependence, it supports coherentism.

Keywords

Coherentism; Essential properties; Internal relations; Monism; Quantum entanglement; Structuralism.

1. Introduction

The metaphysical nature of quantum entanglement has attracted the attention of philosophers of physics over the past few decades. Generally, quantum entanglement has been characterized as a relation that does not supervene on the intrinsic properties of its relata. This feature has led some authors to propose that, according to quantum mechanics, physical reality is fundamentally relational and/or holistic (Teller, 1986; Howard, 1989; Healey, 1991; Esfeld, 2004). Moreover, entanglement has been invoked to support some innovative metaphysical frameworks, such as ontic structural realism (French, 2006, 2010; Ladyman et al., 2007), monism (Schaffer, 2010a, 2010b), and, recently, coherentism (Calosi and Morganti, 2021). From now on, the term 'structuralism' will be used to refer to ontic structural realism.

At first sight, the non-supervenience of entanglement prompts an analysis of its metaphysical nature in terms of external relations, understood as non-supervenient according to Lewis's (1986) standard characterization. The aim of this article is to show that such an analysis is neither the only possible nor the most appropriate one. Assuming that quantum entanglement is a widespread phenomenon, it will be proposed that analyzing entanglement in terms of internal relations better accounts for its metaphysics. To this end, a non-reductionist approach to internal relations is proposed, allowing them to be non-supervenient and interpreting internality in terms of essence. This approach is formalized using Fine's logic of essence (1995b). Finally, it is shown that quantum entanglement, as an internal relation, can naturally fit into various metaphysical frameworks: (1) as a fundamental internal relation, it aligns with structuralism; (2) as a derivative internal relation, it aligns with monism; (3) as an internal relation equivalent to symmetric dependence, it aligns with coherentism.

The structure of the article is as follows. In Section (2), some preliminary aspects of the physics and metaphysics of quantum entanglement are introduced. Section (3) is dedicated to the metaphysics of relations and ontological dependence. Subsection (3.1) discusses the ontological status of internal relations and proposes an analysis in terms of essence. Subsection (3.2) offers various analyses of the notion of ontological dependence. Section (4) addresses the metaphysical nature of quantum entanglement. Subsection (4.1) discusses the inadequacy of treating entanglement as an external relation. Subsection (4.2) argues in favor of entanglement as an internal relation, and after introducing some physical and mereological assumptions, it shows how entanglement as an internal relation aligns with structuralism, monism, and coherentism.

2. Preliminaries on Quantum Entanglement

We now turn to a preliminary examination of the physics and metaphysics of entanglement. Consider the simplest case of quantum entanglement: two fermions, x_1 and x_2 in the singlet state:

$$\left|0\right\rangle_{x_1x_2} = \tfrac{1}{\sqrt{2}}\left|\uparrow\right\rangle_{x_1} \otimes \left|\downarrow\right\rangle_{x_2} - \tfrac{1}{\sqrt{2}}\left|\downarrow\right\rangle_{x_1} \otimes \left|\uparrow\right\rangle_{x_2} \tag{1}$$

The vector $|0\rangle$ represents the singlet state of the composite system x_1x_2, while $|\uparrow\rangle$ and $|\downarrow\rangle$ are, respectively, the spin-up and spin-down eigenstates of fermions x_1 and x_2. The state $|0\rangle$ indicates that when a spin measurement is performed in a given direction (e.g., z), there is a 0.5 probability of finding x_1 spin-up and x_2 spin-down and a 0.5 probability of finding x_1 spin-down and x_2 spin-up. This state of the composite system is such that each fermion does not have an independent state vector; instead, the spin eigenstates of one fermion are correlated with those of the other. This arises from the fact that the state $|0\rangle$ is non-factorizable; that is, it is not a tensor product of two spin eigenstates but rather a superposition of two product states, namely $|\uparrow\rangle_{x_1} \otimes |\downarrow\rangle_{x_2}$ and $|\downarrow\rangle_{x_1} \otimes |\uparrow\rangle_{x_2}$. Thus, the singlet state is considered a non-separable or entangled state. This example illustrates that, when discussing cases of entanglement, the non-factorizability or non-separability of a state is typically regarded as a sufficient condition for it to be entangled. Some subtleties regarding this will be considered soon.

To move from the mere quantum formalism to metaphysical considerations, it is necessary to assume an interpretative postulate that assigns properties to the objects to which quantum mechanics refers. The so-called eigenstate-eigenvalue link (EEL) is the most popular in interpretations of quantum mechanics. By the way, this shows that the metaphysics of entanglement is a matter sensitive to the interpretation of quantum mechanics one chooses to adopt (Belousek, 2003). (EEL) establishes that the object corresponding to the system x has the property P, corresponding to the eigenvalue P, iff the state $|\psi\rangle$ of x is the eigenstate $|P\rangle$ corresponding to that eigenvalue. Formally:

$$\left(|\psi\rangle_x = |P\rangle_x\right) \leftrightarrow Px \tag{2}$$

In the case of two fermions in the singlet state, it follows from (EEL) that the composite system x_1x_2 has a property corresponding to the eigenstate $|0\rangle$ (total spin zero), whereas the fermions do not have properties corresponding to state-dependent observables. However, the fermions are related in such a way that it is possible to specify a set of connections between their possible properties, corresponding to the spin correlations. That is, the relation between the entangled fermions is such that, if a measurement is performed and one fermion is found to be spin-up then the other will necessarily be spin-down:

$$R^{\text{sym}}x_1x_2 \equiv \left(Ux_1 \leftrightarrow Dx_2\right) \wedge \left(Dx_1 \leftrightarrow Ux_2\right) \quad (3)$$

Here, $R^{\text{sym}}x_1x_2$ represents the relation between entangled fermions; U and D are predicates corresponding respectively to the spin-up and spin-down properties; and $Ux_1 \leftrightarrow Dx_2$, $Dx_1 \leftrightarrow Ux_2$ denote connections that could be given a modal character. At this point, the characterization of entanglement has shifted from being a property of the state of the composite system to a relation between its subsystems. The peculiarity of entanglement lies in the fact that if $R^{\text{sym}}x_1x_2$ is the case, then Ux_1, Dx_1, Ux_2 and Dx_2 cannot hold, at least as long as the subsystems involved remain entangled and (EEL) is assumed. Note that, in equation (3), $Ux_1 \leftrightarrow Dx_2$ and $Dx_1 \leftrightarrow Ux_2$ are just conditional statements, so $R^{\text{sym}}x_1x_2$ does not entail that Ux_1, Dx_1, Ux_2 and Dx_2 are the case. This corresponds to the fact that it is not possible to assign states to the subsystems from which the state of the composite system can be derived. Hence, duplicating each relatum along with all its non-relational properties and spatiotemporal relations is insufficient to reproduce the entanglement relation. That is, $R^{\text{sym}}x_1x_2$ cannot supervene on Ux_1, Dx_1, Ux_2 and Dx_2 nor on any other properties of the subsystems.

This surprising feature of quantum entanglement has led some authors in past decades to suggest that the reality referred to by quantum mechanics is fundamentally relational and/or holistic. Teller (1986) was likely the first to characterize entanglement as a non-supervenient relation. According to him, entanglement relations are inherent relations that give rise to a form of relational holism. Similarly, Esfeld (2004) points out that there are properties of the whole that indicate the way the parts are related to one another. In the example of two fermions in a singlet state presented above, Esfeld's insight means that the property of the composite system corresponding to the eigenstate $|0\rangle$ is somehow associated with the entanglement relation $R^{\text{sym}}x_1x_2$ that holds between the subsystems.

Now we mention some characteristics of quantum entanglement that must be taken into account in the following sections. First, entanglement is an irreflexive and symmetric relation. Since the properties of a single system are necessarily correlated, entanglement cannot be reflexive without becoming trivial, as everything would be entangled with itself. Therefore, entanglement should be regarded as an irreflexive relation. Additionally, entanglement is not a one-way relation but rather a symmetric one. If a quantum system x_1 is entangled with x_2, then x_2 must necessarily be entangled with x_1. This holds true not only when the quantum systems are indistinguishable but also in cases where they are not.

Second, what has been said about entanglement in bipartite systems (such as the case of two fermions in the singlet state considered earlier) can be extended to multipartite cases, with certain precautions. When dealing with multipartite cases, it is necessary to distinguish between genuine entanglement and entanglement resulting from the application of the symmetrization postulate (see Ghirardi et al., 2002). In other words, mere non-factorization of the state does not guarantee genuine entanglement. Here, genuine entanglement is defined as that which violates Bell inequalities. According to Bell's theorem (1964), statistical correlations must satisfy certain inequalities if there exist local hidden variables determining the outcomes. Empirical research has shown that these inequalities are not satisfied in cases of genuine quantum entanglement (Aspect et al., 1982). Moreover, it is possible to obtain non-separable states that satisfy Bell inequalities through the application of the symmetrization postulate, which is mandatory in the case of indistinguishable particles. While genuine entanglement usually presupposes prior interactions between entangled systems, indistinguishable particles may not have interacted yet still be in a non-separable state.

Third, a peculiarity arises even in the case of genuine entanglement. Bigaj (2012) provides an example where a composite system of three subsystems x_1, x_2, and x_3 is in a non-separable state, yet x_1 and x_3 are not entangled with each other.

$$|\psi\rangle_{x_1x_2x_3} = \frac{1}{2}\left(|0\rangle_{x_1}|1\rangle_{x_2}|2\rangle_{x_3} + |0\rangle_{x_1}|3\rangle_{x_2}|0\rangle_{x_3} + |1\rangle_{x_1}|0\rangle_{x_2}|2\rangle_{x_3} + |1\rangle_{x_1}|2\rangle_{x_2}|0\rangle_{x_3}\right) \tag{4}$$

Here, $|0\rangle$, $|1\rangle$, $|2\rangle$ and $|3\rangle$ span the state space of each subsystem (with $\otimes$ omitted for simplicity). As can be directly read from the state in equation (4), x_1 can only take values (0) and (1), x_3 can only take values (0) and (2), and x_2 can take any possible value (0), (1), (2), and (3). This state shows that:

(a) The value (0) of x_1 correlates with values (1) and (3) of x_2; and the value (1) of x_1 with (0) and (2) of x_2.

(b) The value (0) of x_3 correlates with values (2) and (3) of x_2; and the value (2) of x_3 with (0) and (1) of x_2.

(c) Among the possible values of x_1 and x_3, any combination is admissible.

Point (c) indicates that there are no statistical correlations between x_1 and x_3. Therefore, x_1 and x_3 are not entangled. A metaphysical lesson about entanglement can be drawn from this fact: if $Rx_1x_2 \wedge Rx_2x_3$ does not imply Rx_1x_3 (where R is the entanglement relation), then the entanglement relation is not transitive.

Fourth, while entanglement is relative to the partition or tensor product structure adopted (Earman, 2015), it is not relative to observables. If a state, expressed as a linear combination of eigenstates of a certain observable, is entangled, it is not possible to choose a basis corresponding to another observable and, keeping the partition fixed, rewrite the state as a tensor product. This follows from the fact that it is not possible to assign a state vector to an entangled subsystem (technically, its state is an improper mixture). As a result, quantum systems are not only entangled with respect to specific bases, such as the spin basis, but are entangled tout court. In a recent study, Cinti et al. (2022) show that entanglement cannot be reduced to a set of multiple relations relative to observables. For instance, if the systems have spin and position observables, entanglement cannot be decomposed, without loss of information, into an entanglement relation connecting the spins and another connecting the positions. From this study, it follows that entanglement must be considered a single multigrade relation. That is, it can involve any number of relata but cannot be decomposed into a series of relations of lower arity (since entanglement is not transitive) or into a set of relations indexed to observables. This point is important because it helps clarify a skeptical doubt raised by Calosi and Morganti (2021) against structuralism (a matter to be addressed in Section 4.2.2).

In conclusion, this section arrives at a preliminary characterization of quantum entanglement as a non-supervenient, irreflexive, symmetric, non-transitive, multigrade, and single relation. These are metaphysical aspects of entanglement that can be considered determined by physics itself, with the sole addition of the eigenstate-eigenvalue link. In what follows, other aspects of the metaphysics of entanglement that admit adaptation to different metaphysical frameworks will be studied. This leads us to examine certain general conditions of the metaphysics of relations and ontological dependence.

3. Some Aspects of the Metaphysics of Relations and Ontological Dependence

3.1. Internal Relations as Essential Polyadic Features

Relations can be characterized and classified according to various criteria (see MacBride, 2020). For instance, relations may be assessed based on whether they are fundamental or derivative, or, in other words, whether they are non-supervenient or supervenient. According to Lewis (1986), a relation that supervenes on the intrinsic properties of its relata is considered internal, whereas a relation that does not supervene on them is considered external. Armstrong's (1978) definition is similar: a relation necessitated by the intrinsic natures of its relata is deemed internal. Cleland (1984) proposed a distinction between weakly non-supervenient relations and strongly non-supervenient relations. According to Cleland, a dyadic relation R between x_1 and x_2 is strongly supervenient on the intrinsic property P iff:

(1) It is not possible for Rx_1x_2 to hold without x_1 and x_2 instantiating P.

(2) From Rx_1x_2, it follows that x_1 and x_2 instantiate P, and from P_ix_1 and P_jx_2, it follows that Rx_1x_2.

Here, P_i and P_j represent distinct instances of P. According to Cleland, the relation R is strongly non-supervenient if both conditions (1) and (2) are unmet, whereas it is weakly non-supervenient if only condition (2) is unmet (see also French and Krause, 2006, 165). It is worth noting that while authors such as Teller (1986) and Esfeld (2004) have used Cleland's notion to explain the metaphysics of entanglement, Cleland originally proposed this notion to account for relations typically considered external, such as the relation of spatial distance.

As can be observed, internal relations have generally been regarded as supervenient and therefore reducible to non-relational properties, while only external relations are seen as non-supervenient or fundamental. This characterization likely stems from a prior commitment to a reductionist view of internal relations. This view aligns with metaphysical frameworks that can be described as particularist, which are based on particular facts or individual objects (what structuralists might term "object-oriented metaphysics"). In these frameworks, relations are rarely included in fundamental ontology, except for a minimal set of recognized external relations. For instance, in Humean supervenience (Lewis, 1986), only spatiotemporal relations are accepted as fundamental.

However, tracing further back in history, one finds alternative definitions of internal relations. For example, according to Moore (1919), a relation is internal if it follows from the existence of its relata. Notably, Moore's definition allows internal relations to be considered at least as fundamental as the non-relational properties of their relata, since internal relations here derive solely from the existence of the relata and not from their non-relational properties. Thus, the sense of internality in Moore's definition is not tied to its fundamental or derivative status but rather relates to the notion of essence. The difference between Moore's definition and those of Armstrong and Lewis lies in the latter belonging to a generation of metaphysicians for whom the debate on the status of internal relations in favor of reductionism had already been settled. By contrast, Moore's more moderate position reflects his belonging to a generation of metaphysicians for whom the debate between particularism and holism (or between particularism and monistic holism) and the fundamental or derivative status of internal relations was still ongoing.

This historical issue was reintroduced in recent discussions by Schaffer (2010a, 2010b), who is recognized for his defense of a moderate form of monism that will be considered in Section (4.2.3). Schaffer's reflections on the late 19th and early 20th-century debate between neo-Hegelians (advocates of monistic holism) and early analytic philosophers (advocates of particularism) help clarify why a reductionist stance toward internal relations was adopted. Indeed, if internal relations as essential relations are merely derivative and not fundamental, then particularist metaphysics prevails over holistic metaphysical frameworks: there is nothing fundamental that essentially ties one object to another. However, if internal relations, as essential relations, are allowed to be at least as fundamental as the non-relational properties of their relata, then internally related objects would be fundamentally integrated wholes, thereby blurring the particularist view (more details on this line of reasoning are provided in Section 4.2.3).

Taking into account these conceptual and historical underpinnings, we define internal relations in this paper as those that are essential to the relata, meaning that their existence and identity depend on these relations. This definition allows us to regard internal relations as essential polyadic features of the relata, which could be either fundamental or, as typically considered, supervenient upon their intrinsic properties. This contrasts with external relations, which cannot be considered essential. This approach to assessing relations—focusing on their essential or non-essential character rather than their fundamental or derivative status—allows fundamental internal relations to exist, thus resolving the tension between entanglement's non-supervenience and internality. Clearly, this challenges the "reductionist view of internal relations" assumed in particularist metaphysical frameworks, while precisely enabling the characterization of entanglement—and other families of relations—as both internal and non-supervenient.

In what follows, we present our non-reductionist analysis of internal relations as essential polyadic features. As proposed, the focus shifts away from whether internal relations are fundamental or supervenient and instead centers on their essential character. Traditionally, the essential properties of an individual have been interpreted as those necessarily following from its existence. However, according to Fine, propositions involving essential predicates cannot be reduced to merely modal propositions. Nonetheless, modal propositions are necessary conditions for essential ones. Thus, the fact that a certain property is part of the essence of *x* can be expressed in modal-existential terms as follows (Fine, 1994):

$$P^{\text{ess}}x \rightarrow \Box\big(Ex \rightarrow \exists P\left(Px\right)\big) \tag{5}$$

Here, P^{ess} is an essential monadic predicate, and E is the existential predicate, which can be defined in terms of the existential quantifier and identity as $Ex \equiv \exists z(z = x)$. Equation (5) indicates that if P is an essential property of x, then it is necessary that, if x exists, there exists a property P such that Px. To define $P^{\text{ess}}x$ by establishing equivalence, it is necessary to use Fine's indexed modal operator $(\Box_x)$, introduced in his logic of essence (1995b), which signifies "it is true in virtue of the essence of *x* that"

$$P^{\text{ess}}x \equiv \Box_x\left(Ex \to \exists P\left(Px\right)\right) \tag{6}$$

Equation (6) means that *P* is an essential property of *x* iff it is true in virtue of the essence of *x* that, if *x* exists, then there exists a property *P* such that Px. The expression $\Box_x\left(Ex \to \exists P\left(Px\right)\right)$ in equation (6) can be simplified as $\Box_x Px$, which should be read as: "it is true in virtue of the essence of *x* that Px." Thus, $P^{\text{ess}}x$ meaning "*x* is essentially *P*," or "*P* is an essential property of *x*," can be formalized simply as $\Box_x Px$. That is:

$$P^{\text{ess}}x \equiv \Box_x Px \tag{7}$$

Following this line of reasoning, for an essential dyadic predicate, that is, for an internal relation R^{int}, we propose the following analysis:

$$R^{\text{int}}x_1x_2 \equiv \Box_{x_1} Rx_1x_2 \equiv \Box_{x_1}\left(Ex_1 \to \exists R\left(Rx_1x_2\right)\right) \tag{8}$$

That is, x_1 is internally *R*-related with x_2 iff it is true, in virtue of the essence of x_1, that if x_1 exists then there exists a relation *R* such that Rx_1x_2. *R* on the right cannot be just any relation but must be one that holds in virtue of the essence of x_1; otherwise, the condition would be trivially met. Of course, we are assuming here that x_1 and x_2 are distinct entities, so *R* cannot be identity. If we allowed identity to take the place of *R*, then everything would be internally related to itself, which is not the intended meaning of an internal relation. Clearly this is not the case for entanglement, which is an irreflexive relation, as discussed in Section (2).

For a symmetric internal relation, the proposed analysis is:

$$R^{\text{int,sym}}x_1x_2 \equiv \Box_{x_1x_2} Rx_1x_2 \equiv \Box_{x_1x_2}\left(Ex_1 \wedge Ex_2 \to \exists R^{\text{sym}}\left(Rx_1x_2\right)\right) \tag{9}$$

That is, x_1 and x_2 are internally R-related iff it is true, in virtue of the essences of x_1 and x_2, that if x_1 and x_2 exist then there exists a symmetric relation R such that Rx_1x_2. In equation (9), as can be observed, the existence of R follows, in virtue of the essences of both x_1 and x_2, from the existence of its two relata. Henceforth, $\Box_{x_1x_2} Rx_1x_2$ will be taken as the simplest formal expression to represent the fact that x_1 and x_2 are internally related by the symmetric relation R.

In this way, a non-reductionist analysis of internal relations is achieved, where internality is associated not with a supposed supervenient character but with its essential character, as we proposed in the above definition. As will be shown in Section (4), this analysis will prove useful for arguing in favor of considering entanglement as an internal relation within structuralism, monism and coherentism. With this foundation in place, we now turn to the notion of ontological dependence.

3.2. The Notion of Ontological Dependence

The metaphysical frameworks mentioned earlier are crucially distinguished by the structure of ontological dependence relations they posit. In structuralism, the fundamental entities are relations, and particular objects depend on them; in monism, the fundamental entity is the whole, and particular objects depend on it; in coherentism, particular objects symmetrically depend on one another. In particularist or object-oriented metaphysics, particular objects are the fundamental entities, with their internal relations and the whole they constitute being dependent entities.

Now, we outline several characteristics of this notion. First, ontological dependence is a relation whose relata are typically concrete particular objects. Nonetheless, it has also been proposed that the relata may belong to different ontological categories—for example, particulars and the relations between them. This is the case in structuralism, where concrete particulars ontologically depend on the relations between them. Conversely, in particularism, internal relations depend on the concrete particulars they relate. Second, most metaphysicians regard ontological dependence as an asymmetric relation. This is the case in structuralism, monism, and particularism. However, ontological dependence can also be conceived as a symmetric relation, as in coherentism.

Another assumption generally associated with the notion of ontological dependence is metaphysical foundationalism or well-foundedness (WF). Asymmetric dependence, by its irreflexive and transitive character, induces a partial order among particular objects. If dependence is well-founded, there exists a domain of basic objects that are considered absolutely fundamental, where chains of dependence end. Calosi (2014) formalizes (WF) as follows:

$$Bx \vee \exists y \left(By \wedge Dxy \right) \tag{10}$$

Here, B is the property of being a basic object, and D is a binary predicate corresponding to ontological dependence. Equation (10) signifies: object x is basic, or there exists an object y that is basic such that x ontologically depends on y. These basic objects can be located at any level of the mereological hierarchy. If they are at the lowest level, (WF) aligns with a form of atomistic particularism. If the basic object is at the highest level, the single whole, then (WF) aligns with a form of monistic holism. Recall that ontological dependence can also have relata belonging to different ontological categories. Therefore, it is possible for chains of dependence to terminate in a basic structure, as in structuralism. If (WF) is rejected, the chains of dependence may extend indefinitely (infinitism). If (WF) is rejected and reciprocal or symmetric dependence is admitted, the chains of dependence can loop back on themselves, as in the case of coherentism.

Although some metaphysicians consider the notion of ontological dependence to be primitive and therefore unanalyzable—merely a binary predicate D (see Schaffer, 2009)—there are several proposals for analyzing it. First, the modal-existential analysis of ontological dependence is mentioned (see Tahko & Lowe, 2020):

$$D^{\mathrm{mod}} x_1 x_2 \equiv \Box \left(Ex_1 \to Ex_2 \right) \tag{11}$$

Equation (11) tells us that x_1 depends on x_2 iff, necessarily, if x_1 exists, then x_2 exists. According to Fine, in his paper on ontological dependence (1995a), the modal-existential analysis is too weak to account for the notion of ontological dependence and is consequently vulnerable to counterexamples, such as Socrates' dependence on his singleton. Fine then suggests that ontological dependence should be analyzed in more restrictive terms and that the notion should be tied to the essence of the dependent object. Then he proposes the following analysis:

$$D^{\text{ess}}x_1x_2 \equiv \Box_{x_1}\left(Ex_1 \rightarrow Ex_2\right) \tag{12}$$

In equation (12), unlike equation (11), the indexed modal operator $\left(\Box_{x_1}\right)$ has been introduced, which belongs to Fine's logic of essence (1995b), to indicate that necessity here is in virtue of the essence of x_1. Equation (12) represents Fine's essential-existential analysis of the notion of ontological dependence. Notice the resemblance between this analysis of dependence and the analysis of monadic essential property in equation (6). This formal similarity suggests that, under this analysis of dependence, the existence of the independent object (x_2) is part of the essence of the dependent object (x_1).

Finally, what may be called the "identity-based analysis", originally proposed by Lowe (1998) and further developed in Tahko and Lowe (2020), is mentioned. The idea behind this proposal is to ground the notion of ontological dependence not in the existence of the involved entities but in their respective identities. The identity involved here is not numerical but qualitative. Therefore, the qualitative profile of the dependent object would be essentially related to the qualitative profile of the independent object. Calosi (2020) suggests two ways to formalize this analysis.

$$D^{\text{id-1}}x_1x_2 \equiv \Box_{x_1}\left(Ex_1 \rightarrow Ex_2 \wedge \exists R\left(Rx_1x_2\right)\right) \tag{13}$$

$$D^{\text{id-2}}x_1x_2 \equiv \Box_{x_1}\left(Ex_1 \rightarrow \exists R\left(Rx_1x_2\right)\right) \tag{14}$$

In equation (13), x_1 depends on x_2 if, in virtue of the essence of x_1, the existence of x_1 implies the existence of x_2 and the existence of a relation between x_1 and x_2. In equation (14), in virtue of the essence of x_1, the existence of x_1 implies only the existence of the relation between x_1 and x_2 (no longer the existence of x_2). Notice the similarity between the analysis of dependence in equation (14) and the analysis of the dyadic essential predicate in equation (8). This formal similarity suggests that, under this analysis of dependence, an object is dependent because it is internally related to another. Hence, ontological dependence and asymmetric internal relation could be considered equivalent, at least according to the interpretation of internal relations made in this article. Interestingly, Calosi (2020) proposes (in a footnote) a simpler, third formulation of this analysis, in which the existential predicate is not directly involved. Namely:

$$D^{\text{id-3}}x_1x_2 \equiv \Box_{x_1} \exists R\left(Rx_1x_2\right) \tag{15}$$

Although equivalent to $D^{\text{id-2}}$ (see equation 8), $D^{\text{id-3}}$ makes the equivalence between ontological dependence and asymmetric internal relation even clearer.

Before proceeding, some partial conclusions derived from the work conducted in this section are highlighted:

(1) An understanding of internal relations as essential relations was achieved, and formal means were found to express them.

(2) It was shown that the fundamental or derivative nature of internal relations depends on the adopted metaphysical framework. If particularist metaphysics is rejected, internal relations can be considered fundamental.

(3) Various analyses of the notion of ontological dependence were made available. In particular, it was found that the analysis based on identity may have close connections to the notion of internality.

4. The Metaphysical Nature of Entanglement

Having examined the metaphysics of relations and ontological dependence, we are now in a position to address the central question of this paper: What is the metaphysical nature of quantum entanglement? It will be shown that this question does not have a unique or absolute answer, but rather one that is relative to the metaphysical framework one chooses to adopt. First, we discuss the inadequacy of treating entanglement as an external relation. Then, we defend an understanding of entanglement as an internal relation. Finally, we explore how this view aligns with structuralism, monism, and coherentism.

4.1. Entanglement as an External Relation

In this subsection, we examine the challenges of treating entanglement as an external relation within a particularist metaphysical framework. "Particularism" (a term likely coined by Teller, 1986), "particularist metaphysics", or "object-oriented metaphysics" (a term coined by structuralists) is a framework or family of frameworks that prioritize particulars over relations or structures. A prominent example is Lewis' Humean supervenience (1986). This view posits a plurality of basic particulars, with relations among them regarded as derivative, supervening on their intrinsic properties. This contrasts with structuralist or holistic frameworks, which treat relations or wholes as fundamental. In particularist metaphysics, fundamental essential features are regarded as exclusively monadic, while internal relations are considered merely derivative, as they are assumed to necessarily supervene on these features. Within this framework, only external relations are admitted in the basic ontology. Indeed, if internal relations were fundamental, modal facts would no longer be supervenient, and basic objects would become mutually dependent. Thus, positing fundamental internal relations would contradict Hume's dictum that basic objects are modally free. As a result, the metaphysical picture provided by particularism would ultimately collapse into holism.

Though dominant for most of the last century, the metaphysical nature of entanglement poses a serious challenge to particularist metaphysics. Due to its non-supervenience, entanglement in particularism cannot be accommodated but as an external relation incorporated into the basic ontology, alongside space-time relations. This move appears as a conservative way to deal with the metaphysical nature of entanglement without abandoning particularist assumptions. Some proponents of Humean supervenience, including Lewis himself, consider this solution (see, for example, Darby, 2012). Under this approach, entanglement could even take the place of the world-making relation (Jaksland, 2021). However, by treating entanglement as an external relation, particularist metaphysics faces significant difficulties, which we outline below.

First, external relations do not seem capable of imposing modal constraints on their relata, of the kind required by the entanglement relation. In fact, space-time relations typically admitted at the supervenience basis generally do not impose modal constraints on their relata. For example, it is accepted that the spatial position of one basic object is independent of the position of another basic object. If entanglement is accepted as an external relation that imposes modal constraints, then basic or primitive modality is being assumed, which contradicts Hume's dictum. Second, the proposed solution introduces a new element into the basic ontology, which may seem ad hoc and less parsimonious. Third, as shown in Section (2), the entanglement relation is not transitive and therefore cannot be decomposed into a series of dyadic relations. It must be conceived as a relation involving all its relata at once, in a global manner. In contrast, in particularist metaphysical frameworks such as Humean supervenience, everything basic is local and particular. For instance, space-time relations can be decomposed into multiple dyadic relations, ensuring locality. Thus, introducing a global item into the basic ontology could make the particularist metaphysical picture appear incoherent (see Darby, 2012). In summary, the attempt to accommodate entanglement as an external relation within a particularist or object-oriented metaphysics seems unpromising.

4.2. Entanglement as an Internal Relation

Having outlined several reasons that make it problematic to regard quantum entanglement as an external relation, we now present an argument in favor of understanding it as an internal relation. The fact that entanglement is a non-supervenient relation should not be taken as an indication that it is necessarily an external relation. Accepting entanglement, due to its non-supervenience, as an external relation is forced by the prior adoption of a reductionist view of internal relations within the framework of a particularist, object-oriented metaphysics. If we step out of that framework and distinguish between internal and external relations not based on their derivative or fundamental status but based on their essential or non-essential character (or by their modal strength, if the notion of essence seems too metaphysically loaded, see Section 3.1), then it becomes possible to conceive of entanglement as a non-supervenient internal relation. In contrast to external relations, internal relations, due to their essential character, can naturally give rise to the modal connections typical of entanglement. In fact, given that essential propositions are stronger than modal ones, the analysis of symmetric internal relations provided in equation (9) implies:

$$R^{\mathrm{int,sym}} x_1 x_2 \rightarrow \Box\left(Ex_1 \wedge Ex_2 \rightarrow \exists R^{\mathrm{sym}}\left(Rx_1x_2\right)\right) \tag{16}$$

From the equivalence proposed in equation (3), Rx_1x_2 can be replaced in the consequent of equation (16) by $(Ux_1 \leftrightarrow Dx_2) \wedge (Dx_1 \leftrightarrow Ux_2)$. Thus, for the case of entanglement resulting from the singlet state, we obtain:

$$R^{\text{int,sym}}x_1x_2 \rightarrow \Box\left(Ex_1 \wedge Ex_2 \rightarrow \exists R^{\text{sym}}\left((Ux_1 \leftrightarrow Dx_2) \wedge (Dx_1 \leftrightarrow Ux_2)\right)\right) \quad (17)$$

Note that, according to equation (17), if entanglement resulting from a singlet state is considered an internal relation $R^{\text{int,sym}}x_1x_2$, then it follows that, necessarily, the existence of systems x_1 and x_2 entails the existence of a relation R^{sym} such that the correlations $(Ux_1 \leftrightarrow Dx_2)$ and $(Dx_1 \leftrightarrow Ux_2)$ associated with the singlet state obtain. The required modal strength is captured by the necessity operator applied to the consequent. This scheme could be generalized to entanglement relations other than the one resulting from the singlet state. This suggests that entanglement is best conceived as a type of internal relation, as this naturally supports the modal connections associated with it. While entanglement remains non-supervenient in this approach, its essential nature as an internal relation ensures that the correlations associated with it possess sufficient modal strength. This avoids the issues that arise when entanglement is treated as an external relation.

Before moving on, a remark is in order. The proposed analysis of the entanglement relation, which involves modal operators and Fine's logic of essence, relies on classical predicate logic. While this approach provides a useful framework for exploring the metaphysical nature of entanglement, it is important to note that classical logic may not fully capture the non-classical features of quantum systems, such as contextuality. Future work could explore the use of quantum logic or other formal frameworks better suited to quantum phenomena. However, for the purposes of this paper, classical logic serves as a useful simplifying assumption that allows us to focus on some salient aspects of the metaphysics of entanglement. We now proceed to explore how entanglement, understood as an internal relation, aligns with structuralism, monism, and coherentism.

4.2.1. Physical and Mereological Assumptions

Before advancing with the detailed explanation of how entanglement as an internal relation fits within structuralism, monism, and coherentism, it is necessary to briefly discuss certain assumptions required by some of these metaphysical frameworks. As made explicit in equation (16), one necessary condition for entanglement to be considered an internal relation is that it occurs necessarily among quantum systems. Consequently, it must be assumed that entanglement is a widespread phenomenon affecting all quantum systems in the universe. This relates to the physical hypothesis of an "entangled universe" (EU). Calosi (2014) states this thesis as follows:

(EU) There is a quantum state of the universe and it is an entangled state.

Although plausible, this assumption is controversial. In its favor, there is the fact that the dynamics of quantum mechanics (the Schrödinger equation) preserves entanglement. That is, an entangled quantum state cannot spontaneously evolve into a separable state. Moreover, in general, interactions result in entangled states. This allows for the assumption that the state of the universe is entangled or will eventually reach that condition. However, some very influential interpretations (including the so-called orthodox interpretation) postulate the occurrence of "collapses" under certain circumstances, meaning non-unitary jumps from superpositions to eigenstates, causing quantum systems to disentangle. Thus, (EU) is sensitive to the interpretation of quantum mechanics one chooses to adopt.

Strictly speaking, for entanglement to be considered an internal relation, not only is (EU) necessary but also a stronger form of that assumption. In fact, entangled states like the one proposed by Bigaj (2012) (see Section 2) must be excluded. Recall that it is possible for a multipartite system to have an entangled state in which, however, two subsystems are not entangled (see the example in equation 4). If that is the case, for these particular subsystems, entanglement could not be an internal relation. Therefore, a stronger version of (EU) is required. In terms of Calosi (2014):

(EU*) There is a quantum state of the universe, and it is a true n-multipartite entangled state.

This principle postulates not only that the state of the universe is entangled but also that each concrete object is entangled with all other concrete objects. The thesis is stronger and, therefore, more controversial than (EU). However, entanglement is known for being preserved between very distant objects. This, along with certain commonly accepted cosmological scenarios where the universe begins in a singularity, makes this assumption still plausible.

Monism requires two additional mereological principles. The first is the principle of unrestricted composition:

(UC) For every non-empty set of objects, there exists an object that is the mereological sum of those objects.

In a monistic metaphysical framework, (UC) ensures that there exists an object that is the mereological sum of all concrete particulars, which we call the universe. The second principle required by monism is the tiling constraint (TC) (Calosi, 2014):

(TC) The universe is a mereological sum of mereologically disjoint basic entities.

The adoption of (TC) is necessary for the option between monism and particularism to be decidable. In fact, from (TC), it follows that if the universe is basic, then nothing else can be. There is no need to go further into the meaning of these principles here. Interested readers may delve deeper into the literature on monism (Schaffer, 2010a, 2010b; Calosi, 2014).

4.2.2. Entanglement in Structuralism

With these physical and mereological assumptions in place, we can now explore how entanglement, understood as an internal relation, fits within structuralism. This metaphysical framework has been gaining recognition in the area of the metaphysics of science for several years, becoming an important rival to particularist, object-oriented, metaphysics. Structuralism holds that concrete particular objects asymmetrically depend on a structure considered fundamental. This structure is precisely composed of a set of relations that mediate between those objects. In this metaphysical framework, relations are conceived as more fundamental than their relata, making the objects mere nodes or points of intersection within the structure. Entanglement, as a non-supervenient relation, can naturally occupy the role of the fundamental structure within this metaphysical framework. Calosi and Morganti (2021) propose a formalization of structuralism in which they employ the essential-existential analysis of the notion of ontological dependence (D^{ess} , see equation 12). For simplicity, suppose the universe is bipartite, containing only two objects, x_1 and x_2. Structuralism then proposes that

$$\Box_{x_1x_2}\left(Ex_1 \wedge Ex_2 \rightarrow \exists R^{\text{irr, sym}}\left(Rx_1x_2\right)\right) \tag{18}$$

where R takes the place of the fundamental structure. In this formulation, D^{ess} is a relation where the dependent terms are the objects x_1 and x_2, and the structure R is the independent term.

With a formulation of structuralism at our disposal, it becomes clear that entanglement is advantageously understood as an internal relation within this framework. This is because the internality of the structure allows us to infer an asymmetric dependence relation between the objects and the structure, as required by this form of structuralism. Consider that, from our analysis of the symmetric internal relation (equation 9), it follows

$$R^{\text{int,sym}}x_1x_2 \rightarrow \Box_{x_1x_2}\left(Ex_1 \wedge Ex_2 \rightarrow \exists R^{\text{sym}}\left(Rx_1x_2\right)\right) \tag{19}$$

Note that the consequent in equation (19) approaches the formal expression of structuralism proposed in equation (18). In equation (18) it is only added that the structure is an irreflexive relation, a condition that is satisfied if we accept that the structure is identified with the entanglement relation, which is considered irreflexive (see Section 2). This indicates that, starting from entanglement as an internal relation, an argument in favor of this form of structuralism can be constructed. McKenzie (2014) arrives at the same conclusion, presenting a similar argument, in which the starting point is the existence of relations that weakly discern indistinguishable fermions and result from the application of the symmetrization postulate. Nonetheless, if one intends to provide a complete defense of this form of structuralism, it would be necessary to discuss the ontological status that should be assigned to the properties of quantum systems that do not depend on the state and thus could not be entangled, such as mass, charge, etc. It is unlikely, at least in non-relativistic quantum mechanics, that such magnitudes can be reduced in terms of relations. Additionally, an argument should be introduced to establish that the dependence between objects and structure is not reciprocal. In other words, it would be necessary to exclude the moderate variant of structuralism. This is not the appropriate place to delve further into these points.

Now, an objection raised by Calosi and Morganti (2021) is briefly addressed. They argue that taking entanglement as the fundamental structure is not enough to account for a rigid dependence between the objects and the structure, but only for a generic collective dependence. The authors argue that it is not possible to precisely select which of the many entanglement relations that can occur between a number of quantum systems supports the rigid dependence of the objects on the structure. The authors assume that entanglement can be properly expressed in terms of a plurality of entanglement relations, each relative to a particular observable. However, as discussed in Section (2), Cinti et al. (2022) demonstrated that entanglement is a single relation that cannot be relativized to observables. This allows for the establishment of rigid dependence of objects on the structure, thus dispelling the skeptical doubt raised by the aforementioned authors.

4.2.3. Entanglement in Monism

This subsection explores how entanglement, as an internal relation, can be accommodated within a monistic framework, particularly in priority monism. While structuralism prioritizes relations, monism emphasizes the primacy of the whole over its parts. We first mention a weaker thesis, metaphysical holism (see Calosi, 2014). This doctrine holds that if two (or more) objects exhibit modal connections, they cannot be basic but must be dependent parts of a common whole. According to Calosi and Morganti (2021), holism can be formalized as follows:

$$\Box_{x_1 x_2}\left(Ex_1 \wedge Ex_2 \rightarrow \exists u\left(x_1 << u \wedge x_2 << u\right)\right) \tag{20}$$

Here, $<<$ represents the mereological relation of proper parthood (i.e., if $x << u$, then x is a proper part of u). In this formulation, the notion of ontological dependence analyzed in essential-existential terms (D^{ess}) is again employed, so that x_1 and x_2 depend on u. Note that the fundamental whole to which a number of concrete particulars depend can be their mereological sum or a larger whole of which the particulars at issue are proper parts. It should be emphasized that the argument in favor of holism crucially depends on Hume's dictum regarding the independence of basic objects, a principle shared by proponents of particularist metaphysical frameworks. Recall that, according to this principle, basic objects must be independent, meaning there cannot be modal connections between them. Therefore, if modal connections are found between objects, they cannot be basic but must be parts of a fundamental common whole. In terms of Ismael and Schaffer (2020), modally connected objects have a common ground. Actually, the argument of these authors is somewhat subtler: where there are modal connections, while it is not possible to establish a common cause, there is a common ground.

If those modal connections are only local, then we remain in a form of relatively innocuous holism. However, there is currently a stronger form of holism in the metaphysics of science that is gaining some recognition in recent years. This is priority monism, defended by Schaffer (2010a, 2010b). According to priority monism, ontological chains of dependence are well-founded and culminate in the universe, the only basic entity. In contrast to radical monistic theses that deny the existence of a plurality of concrete particulars, priority monism represents a moderate form of monism that accepts the existence of a plurality of concrete particulars, though it denies their basic status. Priority monism, as a strong form of holism, requires that all objects in the universe be modally connected. At this point, one could appeal to entanglement or some other type of physical relation to ensure the required modal connections. In one of Schaffer's works, a basic universe, integrated as a whole, is obtained from the idea that "all things are internally related" (2010b). Of course, if entanglement takes the place of the internal relation that modally connects all things, then commitment to (EU*) is required. Additionally, by its very nature, priority monism requires that there be a mereological sum of all objects in the universe, i.e., (UC) is required. Furthermore, to ensure that the universe is the only basic object, (TC) is required.

Suppose once again, for simplicity, that the universe has only two parts, x_1 and x_2. In continuity with equation (20), the inference of priority monism from the internal relation that modally connects all objects could be formalized as follows:

$$R^{\text{int,sym}} x_1 x_2 \to \Box_{x_1 x_2} \left(Ex_1 \wedge Ex_2 \to \exists u \left(u = x_1 + x_2 \right) \right) \tag{21}$$

Here, + represents the mereological sum, and u refers to the universe as a whole. $R^{\text{int,sym}}$ is the internal relation from which Schaffer infers priority monism, a role that can be fulfilled by entanglement. Schaffer himself does not provide an analysis of this kind, as he treats the notion of ontological dependence as a primitive, unanalyzable notion (Schaffer, 2009). There are no available attempts in the literature to analyze priority monism in terms of an analysis of ontological dependence. Therefore, establishing the validity of equation (21) is a pending task.

Before concluding this subsection, two clarifications are made. First, for Schaffer's argument to work, the internal relation in question does not need to be considered internal in the strongest sense being adopted here, i.e., as an essential polyadic feature. It only needs to be the case that the internal relation in question imposes modal constraints on its relata. Of course, the argument proceeds smoothly if internal relations are understood in terms of essence, as modal claims follow from essential ones (see Section 3.1). Second, monistic entanglement can be somehow considered a derivative relation, in contrast to structuralist entanglement. This is because the entanglement relation between parts can be considered necessitated by a certain monadic property of the whole. In the example of the two entangled fermions provided in Section (2), it was mentioned that a property associated with a certain value (0) of total spin is assigned to the composite system. In monism, it can be considered that the entanglement relation resulting from the singlet state depends on (0) total spin.

4.2.4. Entanglement in Coherentism

Calosi and Morganti (2021) are recent proponents of coherentism. They reject hierarchical metaphysical frameworks in which chains of ontological dependence run in a one-way direction from objects to the fundamental whole or from them to a fundamental structure. Their main reason for this rejection is that both structuralism and monism involve a series of controversial assumptions, such as (EU*) and (WF). Monism, moreover, requires the mereological principles (UC) and (TC) (see Section 4.2.1). The authors only accept reciprocal or symmetric relations of ontological dependence, resulting in a non-hierarchical metaphysical framework, known as coherentism.

This subsection examines how entanglement, as an internal relation, supports coherentism by establishing symmetric dependence relations between objects. Unlike structuralism and monism, which posit hierarchical dependence distinct from entanglement, coherentism can directly accept entanglement as the symmetric dependence relation assumed in this framework. This non-hierarchical approach aligns naturally with entanglement's symmetric and non-transitive character. This may make the integration of entanglement and coherentism appear more parsimonious than in structuralism and monism.

Let us spell this out. In structuralism and monism, entanglement is not itself considered an ontological dependence relation, but rather a relation from which asymmetric dependence relations follow. These asymmetric dependence relations take the set of the relata of the entanglement relation as one of their terms. The other term may be the whole (in monism) or the entanglement relation itself (in structuralism). Coherentism is simpler in that it avoids this complexity and can consider entanglement as a relation that is equivalent to reciprocal dependence, or at least one from which reciprocal dependence follows for the same relata. The formalization of coherentism that Calosi and Morganti (2021) propose is:

$$\Box_{x_1}\left(Ex_1 \to Ex_2\right) \wedge \Box_{x_2}\left(Ex_2 \to Ex_1\right) \tag{22}$$

The equation (22) means that for x_1 it is essential that x_2 exists and vice versa. Again, the notion of dependence being used here is the essential-existential (D^{ess}). In equation (22), two asymmetric reciprocal relations are present, whose conjunction amounts to a symmetric dependence relation.

We now show how reciprocal dependence follows from entanglement when considered an internal relation, thus favoring coherentism. Calosi and Morganti (2021) themselves propose that entanglement can be accepted as an essential relation (for us, internal) that endorses coherentism. In their equation (25), the authors formalize the relation between two entangled objects as follows:

$$\Box_{x_1 x_2} Rx_1 x_2 \tag{23}$$

Note that it is precisely the intended meaning of the symmetric internal relation $R^{\text{int,sym}}x_1x_2$ according to the perspective assumed in this article, that is, a relation that holds necessarily in virtue of both relata's essences (see equation 9). The fact that reciprocal dependence follows from the internal relation between two objects can be expressed in the following terms:

$$R^{\text{int,sym}}x_1x_2 \rightarrow Dx_1x_2 \wedge Dx_2x_1 \tag{24}$$

Equation (24) means that if x_1 and x_2 are symmetrically and internally related, then reciprocal dependence relations exist between them. If we accept that entanglement is an internal relation and if equation (24) is valid, then entanglement can be considered as supporting coherentism. Next, we evaluate under what conditions the validity of equation (24) can be established. Recall that in Section (3.2), a close similarity was found between the notion of internality and ontological dependence analyzed in terms of identity (D^{id}). In particular, the second and third formulations of that analysis ($D^{\text{id-2}}$ and $D^{\text{id-3}}$) seem to be equivalent to an asymmetric internal relation (see equations 14 and 15). Based on equation (15) and from

$$R^{\text{int,sym}}x_1x_2 \equiv \Box_{x_1x_2} Rx_1x_2 \equiv \Box_{x_1} Rx_1x_2 \wedge \Box_{x_2} Rx_2x_1 \tag{25}$$

it is possible to establish that a symmetric internal relation (such as the one instantiated by the relation of entanglement) is equivalent to two reciprocal asymmetric ontological dependence relations. Namely:

$$R^{\text{int,sym}}x_1x_2 \equiv D^{\text{id-3}}x_1x_2 \wedge D^{\text{id-3}}x_2x_1 \tag{26}$$

This simply means that if x_1 and x_2 are internally and symmetrically related, then their identities are reciprocally dependent. This suggests that this third formulation of the identity-based dependence analysis is preferable for use within coherentism. It is clear that equation (26) implies equation (24), which was the expression intended to be proven valid. Therefore, it can be concluded that the internality of entanglement also allows for the construction of an argument in favor of coherentism. Moreover, coherentism appears to be the metaphysical framework that benefits most from considering entanglement as an internal relation, as it provides the most parsimonious fit.

Final Remarks

In this paper, we have argued that quantum entanglement should be understood as a non-supervenient internal relation. We have considered that internal relations are essential polyadic features that are allowed to be fundamental, resolving the tension between the non-supervenience of entanglement and its typical modal strength. This perspective offers several advantages over the external relation view of entanglement within particularist metaphysical frameworks. In particular, it naturally sustains the modal constraints associated with entanglement—something that particularism cannot achieve without introducing several issues, as discussed in Section (4.1). Additionally, it provides a more flexible integration of entanglement within a variety of metaphysical frameworks. Adapting to these frameworks, entanglement can be considered fundamental, derivative, or even a relation of symmetric dependence. Furthermore, treating entanglement as an internal relation, as defended in this article, allows for the formulation of arguments in support of structuralism, monism, or coherentism

These contributions advance the existing literature by offering a novel perspective on internal relations and the metaphysics of entanglement. While previous work has treated entanglement as an external relation or focused on its non-supervenience, our approach reinterprets it in terms of essence, providing strong motivations for integrating entanglement into various metaphysical frameworks beyond particularism.

A final remark is in order. As discussed in Section (4.2.4), coherentism appears to be the metaphysical framework that accommodates entanglement in the most parsimonious way. However, coherentism can also be made compatible with holism or even priority monism, provided one accepts the additional assumptions required by this framework. It may even be worth exploring the possibility of treating coherentism as a form of moderate structuralism, where structure and related objects hold ontological parity. As Calosi and Morganti (2021) suggest, such an approach could allow coherentism to reconcile key insights from both structuralism and monism, bringing together the best of both worlds.

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