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Reconciling Ontic Structural Realism and Ontological Emergence

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Abstract
While ontic structural realism (OSR) has been a central topic in contemporary philosophy of science, the relation between OSR and the concept of emergence has received little attention. We will argue that OSR is fully compatible with emergentism. The denial of ontological emergence requires additional assumptions that, strictly speaking, go beyond OSR. We call these *physicalist closure assumptions.* We will explain these assumptions and show that they are independent of the central commitments of OSR and inconsistent with its core goals. Recognizing the compatibility of OSR and ontological emergence may contribute to the solution of ontological puzzles in physics while offering new ways to achieve the goals that advocates of OSR set for their view.

Keywords Ontic structural realism · Ontological emergence · Physicalism

1 Introduction

Structural realism has played a central role in philosophy of physics in recent decades. At its heart, it is the view that physics should be concerned primarily with structural claims and that these claims should be interpreted realistically. The core idea is that physics tells

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us about structures and those structures are real. Furthermore, according to this view, physics does not shed light on non-structural aspects of reality. Philosophers are committed to structural realism either because they believe that no epistemic access to non-structural properties and entities is possible or because they contend that non-structural properties and entities do not exist.

This paper considers the question of ontological emergence from within the framework of structural realism. By ontological emergence we assume a relatively inclusive definition. We have in mind something along the lines of Paul Humphrey's characterization: "Emergence is, broadly speaking, the view that there are features of the world—objects, properties, laws, perhaps other things—that are manifested as a result of the existence of other, usually more basic, entities but that cannot be completely reduced to those other entities" (Humphreys, 2006: 90). In this sense, ontological emergence is a relation in which the *emergent* is partially dependent on and partially independent from its *emergence base*. In short, the emergence base provides the necessary but not sufficient conditions for the existence of the emergent. We recognize a variety of ways that the notion of emergence can be characterized. In broad terms, two defining characteristics; novelty and naturalness mark the concept of emergence. Symons writes, for instance: "When emergent properties are first instantiated, they are said to be novel in some difficult to specify, but presumably non-trivial, sense […] the kind of novelty that is associated with emergent properties is understood to constitute a metaphysically significant difference.[…] They are also thought to be part of the natural order in some intelligible sense […] emergent properties are not unnaturally or supernaturally new (their appearance is not miraculous) but instead can be understood scientifically insofar as they are intelligibly connected […] with other properties that are prior or more fundamental" (Symons, 2018b: 3). On this view, the fact that emergent properties are different in kind from what is prior or more fundamental does not preclude the possibility that we can understand them via scientific inquiry. Of course, there may be some aspects of this difference in kind that we cannot explain and we may treat them as brute facts. Symons and others have argued that admitting the possibility of brute facts about emergence is not in itself a threat to scientific rationality (Symons, 2018a). At this point, there is a lively and diverse literature in philosophy of science on emergent properties. Thus, it is striking that while ontic structural realism (OSR) has been a central topic in contemporary philosophy of science, very little attention has been given to the relation between OSR and ontological emergence. In part, this is likely due to anti-emergentist declarations by some prominent proponents of OSR. One widely shared assumption is that OSR's main versions block the possibility of ontological emergence.

We will argue that OSR does not entail anti-emergentism without additional and non-essential metaphysical assumptions. Given the significant philosophical costs of anti-emergentism, we show how OSR is independent of these anti-emergentist assumptions. We begin in Section Two by describing OSR and explaining some of the reasons it has emerged as a dominant framework for the philosophy of physics. We will also explain the kinds of problems that OSR is understood to solve and we will argue that it can more easily do so if it allows for some form of ontological emergentism.

Insofar as it is a form of realism, OSR ought to offer a plausible and realistic account of the ontology of successful physical theories. Ideally, a successful realist position in the philosophy of science should permit us to understand the relationship between the different entities, properties, and relations that constitute the domains of all successful sciences,

including the so-called special sciences. As we discuss in Section Three, even if capturing the ontology of the special sciences is beyond the resources of OSR, it should not preclude an account of the relationship between the different ontological kinds or levels within physics itself apriori.

In Section Four and Five we explore arguments connecting OSR and anti-emergentism. Central here is a principle known as the primacy of physics constraint (PPC). We will argue that there are conceptual and empirical problems with this principle that run counter to the naturalistic ambitions of proponents of OSR. Given the evidence of modern physics, PPC cannot be maintained consistently. In Section Six we will show that one can reject the premises that block emergentism while maintaining the central tenets of OSR. We will show that there are good reasons to adopt a version of OSR that is not constrained by assumptions derived from the kind of physicalism that was popular in 20th century analytic philosophy.

2 What is Ontic Structural Realism?

OSR is a philosophical position that emphasizes the role of structure in scientific inquiry. According to advocates of OSR, if we recognize that physics is concerned centrally with understanding structures, we almost immediately solve two broad sets of problems in philosophy of science (Ladyman, 1998; Cao, 1998). The first is the challenge to scientific realism posed by apparently radical ontological shifts in the history of science, the second is the disruption to traditional ontological assumptions that result from developments in fundamental physics. Steven French, for example, describes the principal motivations of OSR as being: "cases of ontological change in the history of science; and […] the implications of modern physics for the individuality and identity of putative objects" (French, 2010: 194) Rather than treating revolutionary theory change and the evidence of modern physics as challenges, OSR embraces both. OSR accepts arguments against traditional forms of scientific realism and accepts the unsettling implications of modern physics for the identity and individuality of objects.

Advocates of OSR contend that modern physics makes a certain kind of metaphysics of objects untenable (Chakravartty, 2003: 868). Specifically, in light of what we now know from physics it is not the case that the fundamental level of reality is composed of individual objects, that these individuals are ontologically independent, and that these objects are located within a spatiotemporal framework.

In addition to being informed by the history of physics, proponents of OSR also respond to a number of prominent anti-realistic arguments from the philosophy of science. These include the pessimistic meta-induction (Laudan, 1981) and the claim that theories will always be underdetermined by evidence (Papineau, 1996:7, da Costa & French, 2003: 189). These arguments are marshalled by proponents of OSR to make the case against both "object-oriented scientific realism" (French, 2006: 168, Psillos, 2001: S23) and epistemic structural realism (French, 2014: 22).

The criticism of object-oriented scientific realism is thought to be strengthened by underdetermination arguments (French, 2011;2014). These arguments purport to show that there are different empirically equivalent theoretical formulations of the same set of evidence (Jones, 1991, Pooley, 2006). When applied to metaphysics, underdetermination arguments support the view that one can always find different metaphysical interpretations of the same

theory (see van Fraassen, 1991:491; French, 2011;2014). OSR offers a modified form of realism in combination with an ontology of structures. The metaphysical implications of modern physics can be addressed, according to proponents of OSR, if we replace the object-oriented ontology with an ontology built on relations, that is, a structure-oriented scientific realism and a metaphysics of structures.

Evidence from the history of physics encouraged philosophers to be concerned about the incommensurability of successive theories. Historians and philosophers of science observed that physical theories are abandoned and replaced by theories with apparently different ontological commitments.[1] Caloric, phlogiston, ether, and all the rest were parts of the ontological furniture of abandoned theories, replaced by new ways of carving up the world. As a result, realists were motivated to look more deeply at mathematical and other formal features of physical theory (Cao, 1998). During episodes in the history of science where ontological commitments appear to have changed dramatically, according to proponents of OSR there is continuity with respect to the commitments of pre- and post- revolutionary theories to structures. John Worrall showed that during these revolutionary periods at least some formal structural features of theories are preserved (Worrall, 1989). Those preserved structures can be shown to be crucial contributors to the successes of both the pre- and post-revolutionary theories. Thus, a realistic attitude to these preserved structures would be immune to worries about incommensurability, to the pessimistic meta-induction, and would partly explain the "no-miracles" intuition supporting realism. Underdetermination arguments also become less worrisome according to some proponents of OSR in roughly similar ways (See for example French, 2011). In summary, OSR offers good prospects for tackling apparent discontinuity in the history of science, the underdetermination of theories by evidence, the pessimistic meta-induction, as well as the ontological challenges posed by modern physics.

3 The Flat Ontology of Radical OSR

While there are very good reasons to adopt some version of structural realism, standard versions of OSR should not be expected to have the resources to answer all relevant metaphysical questions. Given that there is a large subset of metaphysical problems that are either orthogonal to OSR or that OSR cannot answer, proponents of OSR can either see their view as requiring supplementation or they can see that subset of unanswered questions as somehow illegitimate. For example, one could dismiss such questions in the following spirit: If scientific inquiry, on this view, is concerned solely with structural phenomena, then questions about non-structural matters are not properly scientific and can be ignored as idle flights of philosophical fancy. This is the general approach taken, most famously by Ladyman and Ross (2007).

However, within the structural realist camp there is a wide range of opinion on this point. Consider, for example, the dispute between Tian Yu Cao and his critics in a special issue on Cao's version of structural realism in *Synthese* in 2003. In his response to French and Ladyman, Cao argued that they "dissolv[ed] physical structure into mathematical structure"

[1] This is an observation that dates back at least to Poincaré (1905: 160) as John Worrall notes (1989: 109) but of course it came to prominence with the work of Thomas Kuhn (1962) and Norwood Russell Hanson (1958).

and noted that conflating mathematical and physical structure would generate an inadequate ontological theory. Mathematical structures, for example, have no causal powers whereas physical structures do (Cao, 2003: 57). Elsewhere in his earlier work Cao noted that the geometrical programme in the history of the development of field theories faced obstacles that undermine a purely mathematical conception of the physical world (Cao, 1998 esp Ch 5.). French and Ladyman, following (Worrall, 1989) denied that there is any principled distinction between mathematical and physical structure; structure is just structure. As noted above, both sides of this dispute will agree that OSR does not settle all metaphysical questions. As Cao pointed out, accounting, for example, for the difference between causal and non-causally relevant structures in purely structural terms is not possible.[2] The importance of such differences means that the distinction between physical and mathematical structure is forced upon us. Given that structural considerations alone do not answer all important questions, it is a mistake to dismiss all non-structural questions in philosophy of science.

Consider a related dispute among structuralist philosophers of mathematics. Structuralism in philosophy of mathematics is the view that the real content of mathematical theories is their descriptions of structures. For many structuralists the objects of mathematical inquiry are properly described solely in terms of their structural properties and according to some structuralists there is nothing more to being a mathematical object than the properties it instantiates in virtue of its place in that structure (Parsons, 2004: 57). The puzzle is how and perhaps whether these abstract structures are related to specific instances of mathematical knowledge. While this is a challenging problem for mathematical structuralists it has an even more pressing analog for those who hold a structuralist view of physics. Cao's challenge can be understood as equivalent to the puzzle of *ante rem* vs. *in re* structure in philosophy of mathematics. Structuralists *in re* are committed to the idea that structures exist only if they are instantiated by an instance of a mathematical system. Structuralists *ante rem* understand them as existing independently of their instances (Schiemer & Wigglesworth, 2019: 1201). If we take a structuralist perspective on physics, we must decide whether we regard its structures as existing independently of physics as we find it or as existing only in virtue of the existence of their instantiation in the physics of the actual world. Note first that there is no way internal to structuralist philosophy of physics to answer this question. Notice too that abstractionism—some version of which is a favored answer among philosophers of mathematics—must assume the existence of the concrete object of mathematical inquiry as a brute fact (Linnebo, 2018). For the abstractionist, we begin with the instances of mathematical knowledge as brute facts, then as metaphysicians we abstract away their non-structural features until we arrive at their structural essence. These considerations suffice to show that structuralism leaves many metaphysical and ontological questions unanswered. Arenhart and Bueno (2015) make a similar point in another way, noting that "ontic structural realists are unable to specify the nature of the structure they are supposed to be realist about" (Arenhart & Bueno, 2015: 137).

Now we are in a position to ask whether there is any reason internal to OSR proper that would block emergentist explanations. The first point we must tackle is which version of OSR is relevant here? As we shall see below, OSR proponents fall on a spectrum from radicals like Ladyman and Ross who advocate what we will describe as a *flat ontology* (since they reject composition) to more moderate figures who do not fully embrace full flatness.

[2] See Cao, 2010 pp. 223–225 for further discussion of the importance of causal and non-causally interpreted structures.

It is also worth noting at this point that none of the main versions of OSR incorporate the possibility of ontological emergence. We will sort the various proponents of OSR into Radical (R-OSR) and Moderate (M-OSR) depending on how flat they regard the world to be[3].

Put very simply, R-OSR asserts that there are no objects (or individuals), no intrinsic properties, and no causal powers. There are only relations and no *relata*. Eliminating objects, individuals, intrinsic properties, causality, and related concepts raises challenging metaphysical questions as we saw above in the case of the *in re* vs. *ante rem* problem. However, it raises more problems for OSR than it does for structuralists in philosophy of mathematics insofar as OSR is meant not only as a metaphysical theory but also as a way of saving realism in the philosophy of science. Prominent among the challenges faced by OSR as a philosophy of science is the problem of accounting for the relationship between the structure of physics and the ontology of the special sciences.

According to an extreme version of R-OSR, all that exists is the fundamental structure of the world and its features. This structure can be understood either in terms of the structure of current physical theories or as the ultimate structure of reality. These two meanings of the term "structure" are frequently conflated in the structural realist literature. Blending the two, this position is sometimes presented as holding that all there is in the world is its fundamental structure as presented to us by modern physics (French, 2018). Stated flatly, this claim involves an ontological commitment to the current state of physics that is difficult to defend given the reasonable expectation that current physics will be improved upon. "Structure", if taken to refer to the world-as-structure is not necessarily the same thing as the structure of physical theories but in both cases, for advocates of OSR the relevant properties of the structure are its laws and symmetries (French, 2014: 275).

Ladyman and Ross believe that they are being faithful to the kind of structure that contemporary physics provides. They present their project as genuine naturalized metaphysics in contrast with what they regard as the speculative flights of fancy that they associate with analytic metaphysics. Following Quine's example, the hard-nosed naturalist believes that ontological commitments should be read off our latest, best science rather than being rationally intuited. Setting aside the problem that a future, and presumably better, science will almost certainly arrive on the scene to complicate our commitments, let's consider what it would mean to read our ontological commitments off contemporary science as we find it. Our first challenge involves deciding which science to choose. Is it obvious which current science is best? Ladyman and Ross prefer physics of course, but even if we restrict our attention to physics we are faced with the question of which kind of physics is best. Advocates of OSR focus on fundamental physics: "[a] set of mathematical specified structures without self-individuating objects, where any measurement taken anywhere in the universe is in part measurement of these structures." (Ladyman & Ross, 2007: 44)—that is, traditional Quantum Mechanics (QM), General Relativity (GR), and, above all, Quantum Field Theory (QFT). According to Ladyman and Ross, QM and GR give us every reason "[T]o believe that the realists must interpret the theories as describing entities whose identity and individuality are secondary to relational structure in which they are embedded." (Ladyman & Ross, 2007:144). Why? Because, on the hand, in the context of GR if we accept that the structure of spacetime do not supervene on the reality of spacetime points (Ladyman & Ross, 2007: 143) then we can solve the longstanding dispute between relationism and sub-

[3] Frigg and Votsis (2011) provide a reliable taxonomy of kinds of OSR, classifying them according to different ways of conceiving the ontological relationship of relations and objects.

stantivalism (by rejecting both) concerning the nature of spacetime; and on the other hand, QM entails the apparent inapplicability of the Principle of Identity of the Indiscernibles (PII) to quantum particles[4].

However, there is the possibility of a weaker version of PII[5]—as acknowledged by Ladyman and Ross—and that the problem of identity and individuality might be solvable in the context of alternative quantum theories like Bohmian Mechanics.[6] Therefore, rather than simply reading ontological commitments straightforwardly from fundamental physics, Ladyman and Ross rely on a specific interpretation of QM and GR. From their perspective, "of course our best quantum theories are field theories" (Ladyman & Ross, 2007: 138). Therefore, both the problem of individuality and the existence of intrinsic properties should be placed in the context of QFT. Since in QFT it is also arguable that quantum entities do not have individuality, and it is arguable that in QFT laws and properties (like charge, mass, spin, etc.) are derivable from group symmetries, then on this view, individual objects (particles and fields) are ontologically otiose and can be eliminated; the world is nothing but structure and relations. Individual things are locally focused abstractions from modal structure (Ladyman & Ross, 2007: 153).

While there are reasons to favor their version of OSR, it comes with a cost. The most obvious of these is abandoning hope of a realistic treatment of the kind of ontological diversity that one might associate with the appearance of novel properties or entities over the course of natural history. For Ladyman and Ross, a flat-ontology (that is a no-levels of composition ontology) read off fundamental physics gives us reason to reject such emergent properties:

> [emergentism] warrants its name because it holds that "higher" levels of organization "emerge" indeterminably out "lower" levels one and then causally feed back "downward". Our position, denying that science suggests the world to be structured into levels at all, calls a pox on both houses in this dispute (Ladyman & Ross, 2007: 56–57).

According to Ladyman and Ross fundamental physics indicates that the world is not organized into levels (Ladyman & Ross, 2007: 55) and for that reason we can dismiss the possibility of Ontological Emergence. But it is important to recognize that this endorsement of flat ontology is not a consequence or requirement of OSR. Notice also that our best scientific theories do not preclude the possibility that the world is organised into levels.[7] In order to

[4] Quantum statistics or permutation symmetry raise the question of whether quantum objects are discernible and, therefore of whether they possess individuality–for the received view of quantum non-individuality (See e.g. French & Krause, 2006; French, 2014; Arenhart & Krause, 2014, Arenhart, 2015. See also Saunders, 2006 (weak discernibility), Dorato and Morganti, 2013 (identity taken as primitive) for criticism of the received view.

[5] See Saunders, S. (2006), "Are quantum particles objects?", *Analysis*, 66: 52–63;

[6] Ladyman and Ross dismiss this last possibility since—according to them—Bohmian Mechanics is often rejected by Physicists and Philosophers (Ladyman and Ross: 181) because of its alleged ad hocness, lack of simplicity and incompatibility with relativity theory.

[7] Focus on levels can distract from the radical nature of flat ontology. Arguments against levels-talk in philosophy of science are rarely intended to entail that there are no metaphysically relevant differences of kind in nature. Notice that the emergentist is committed to the idea that over the course of natural history, novel differences in kind can appear. Notice, for example, that one could imagine an emergentist who questioned the standard hierarchical organization of the sciences into levels. It is important to recognize that full-blown anti-emergentism is not simply a criticism of levels-talk. Rather it is a denial that metaphysically relevant differences in kind ever emerge. This is a much more radical claim than the anti-levels talk argument which

make their case, Ladyman and Ross must be correct in claiming that levels-talk is vindicated neither by QFT, nor by GR and that all relevant scientific facts are induced on QFT and GR. This is an unreasonably strong conclusion from the fact that charge, mass, spin, etc. are derivable from group symmetries in QFT.

The anti-emergentist step in their reasoning depends on assuming a version of physicalism similar to the kinds of physicalism that figured prominently in philosophy of mind in the late 20th century. Their version of physicalism is embodied in a principle known as *the primacy of physics constraint* (PPC):

> Special science hypotheses that conflict with fundamental physics or such consensus as there is in fundamental physics, should be rejected for that reason alone. Fundamental physical hypotheses are not symmetrically hostage to the conclusions of the special sciences (Ladyman & Ross, 2007: 44).

The intended meaning of "conflict" here is presumably something like the following: The only acceptable hypotheses of the special sciences are those that are not equivalent to denials of established doctrine in fundamental physics. However, one could accept the broadly physicalist intention behind PPC without settling the question of how the principle should be applied. For example, a physicalist who accepts PPC is still left with the intramural dispute between quantum physics and general relativity (GR). Given the fact that there are disputes internal to physics, PPC requires additional qualification. After all, PPC does not tell us how to proceed in cases where a hypothesis from some special science conflicts with quantum theory but not general relativity, or vice versa.

Consider features of the ontology of sciences other than physics that do not fit well with microphysicalist fundamentalism which do not seem to be excluded by OSR. For example, why must part-whole relations, such as one might find in the biological domain (e.g., the relation between the structure of a particular molecule within the cell, such as DNA, and the structure of the cell taken as a whole) be dismissed solely because at the level of fundamental physics composition relations of this kind can (arguably) be ruled out. Such relations could be emergent as brute facts for example.[8] Furthermore, there is nothing in fundamental physics that rules out levels of composition in domains other than fundamental physics. Even if it were somehow the case that fundamental physics is ontologically flat, we could not thereby dismiss emergentism. This is simply because non-flatness itself could emerge from fundamental physics. Strikingly, Ladyman considers an analogous possibility with respect to the metaphysics of causality[9]. In his view, fundamental physics rejects causality. But he acknowledges the existence of causality in special sciences. Therefore, he concludes: "since there is (probably) no causation in fundamental physics and there is causation in the special sciences then all causal powers are likely to be emergent" (Ladyman, 2009: 124). While it would be a mistake to make too much of Ladyman's comment, it is quite striking that emergentism is taken as being an option for a metaphysical concept that does not fall within the purview of QFT, in this case the concept of causal powers. We would argue that

is usually restricted to a criticism of the hierarchical structure of nature rather than the idea that there are no emergent differences of kind.

[8] For a discussion of the relationship between brute facts and emergence see Symons, 2018a.

[9] Ladyman and Ross seem also to admit that matter (in the classical sense of the term) is ontologically emergent: "matter in the sense of extended stuff is an emergent phenomenon that has no counterpart in fundamental ontology" (Ladyman & Ross, 2007: 20).

causal powers are a much thicker metaphysical notion than the kind of distinctively biological part-whole relations mentioned above. After all, the latter can be regarded in purely structural terms, which is certainly not the case for causal powers.[10]

Ladyman and Ross recognize that their ontology is not consonant with the apparent ontological diversity that we encounter in ordinary experience and in the special sciences. In response to this concern, they urge an account of apparent ontological levels that reinterprets them in terms of considerations of scale. By recognizing that science operates on distinct scales, they endorse what they call rainforest realism (RR). According to RR the world is not composed by levels of composition or complexity, but by scales: 'the scale relativity of ontology', namely the thesis that the existence of objects is relative to particular temporal and spatial scales (and relatedly to energy scales in particle physics) (see Ladyman, 2009: 121). For Ladyman, neither cats, nor physical atoms exist in any ordinary sense that we would recognize, instead, they exist as patterns. For RR all that genuinely exists are what Ladyman calls, following Daniel Dennett (1991), *real patterns*: "to be is to be a real pattern" (Ladyman, 2009: 123). These real patterns are scale-dependent since they can only be identified at their own spatio-temporal scale.

According to Ladyman and Ross, each ontology (apart from fundamental physics) is relative to a spatio-temporal scale. This leaves unanswered the question of the relationship between each ontology and how ontologies at different scales can be characterized in a non-arbitrary manner. Ladyman's way of addressing these questions runs as follows "[…] coarse-graining and approximation are necessary for all or almost all special science ontologies to emerge from fundamental physics. This explains why even token identities do not obtain between say a cat and its constituent atoms. A cat is coarse-grained with respect to atomic theory" (Ladyman, 2009: 121). On this view, cats, molecules, and galaxies, only exist on the appropriate scale; cats do not figure in ontological judgments at the galactic scale, nor at the atomic scale; galaxies do not exist at the cat-scale nor at the atomic scale; atoms do not exist nor at cat-scale nor at the galactic scale. However, the ontological commitments of distinct scientific enterprises cannot be treated as strictly scale-relative. As is well-known, organizing them according to a set of hierarchical levels in the spirit of Putnam and Oppenheim fails to capture the ontological commitments of successful theories in the way that a realist theory should hope for. To take just one example, black holes are relevant to theories of galactic-scale events in ways that might require us to include them in the ontology of any good theory governing galaxies. The complex spatio-temporal structure of black holes makes application of solely geometrical concepts very challenging.[11] Similarly, and more prosaically, if an engineer is miniaturizing electronic devices, at a certain point in the development of circuits they will need to consider phenomena such as quantum tunnel-

[10] It is notable that once the possibility of causation enters the picture above the purely physical level, there is room for accounts of strong emergence of the kind offered for example in Jessica Wilson's recent book *Metaphysical Emergence* (2021). Her discussion of the role of causal powers in the characterization of emergence emphasizes the non-physical aspects of the causal powers of emergent causal powers. For another perspective on the relationship between causation and emergence see Symons (2002).

[11] Cao (1998, Part 1) has an extensive discussion of the limitations of the strong geometrical program in the context of the general theory of relativity. For example, black holes pose a special challenge to the success of a strong geometrical program for reasons Cao explains.

ing. Again, in this case, the notion of spatial scale does not behave in the ways that Ladyman and Ross describe.[12].

Consider a non-relativistic and non-quantum level phenomenon: From a top-down perspective, we might wish to understand the epigenetic effects of someone's personal history on their genetics. How do we consider, for example, the ontological status of traumatic events in the context of our reflection on epigenetic changes that affect heredity in an organism? Epigenetic theories that take account of personal histories figure in the study of the biology of inheritance. While we may ultimately decide that epigenetic theories are false, we should not reject them because of our prior ontological commitments. A philosopher who holds a genuinely naturalist perspective should be willing to revise their ontology given the development of science.

One can cite many counterexamples to strictly scale-relative ontologies. Many of the scientific advances that we find most valuable in medical science, engineering, and other domains involve theories that cross-cut spatial and temporal scales in ways that do not lend themselves to an easy classification in terms of spatio-temporal scaling. Note also that if considerations of spatio-temporal scale are not applicable to fundamental physics, it is unclear how a physics fundamentalist can account for the manner in which different scales relate to each other. Nor is there any explanation for why the spatio-temporal scale would not be applicable to fundamental physics. Does spatio-temporal scale emerge from the energy scale? What would it mean for a scale to emerge?

RR recasts ontological diversity in terms of a non-fundamentalist commitment to patterns at specific scales. In other words, one could read this as saying that the ontologies of all sciences have the same dignity. However, the commitment to PPC, prohibits ascribing properties to "higher-level" entities that conflict with fundamental physics. No cats move at superluminal speeds or break CPT symmetry. PPC is equivalent to the fundamentality of physics and it entails that other ontological scales are emergent relative to physics. Thus, given PPC and RR we can begin to see how there is plenty of room for an account of ontological emergence within the OSR framework.

At this point we are faced with several puzzles: How do scale-dependent objects or properties emerge? What are the dependence relationships between entities from special-temporal scales? If reality is stratified according to spatio-temporal scales, how can the higher-level scale fail to be composed of the entities in the lower-level scale? Ladyman and Ross acknowledge the existence of different ontological "strata", but they are silent with respect to how these objects and properties come into existence, relate, or are organized. RR sees the ontological commitments of the special sciences as a purely pragmatic matter. Standford writes, for example, that "[w]e ''track'' or ''locate'' these patterns by agent-relative, merely pragmatic division of the world into individuals, causes, events, and processes which do not indeed exist" (Standford et al., 2010: 165). By contrast, PPC is not a merely pragmatic principle. Nevertheless, one cannot begin to answer questions concerning the ontological status of patterns in the special sciences using PPC. The emergence of novel properties from within the unsupplemented OSR framework is left unexplained.

How then can the structuralists introduce new metaphysical principles to answer otherwise unanswerable questions? One possible candidate for a principle that addresses emer-

[12] For a discussion of the philosophical implications of quantum tunneling in computer engineering see Symons, 2019: 19.

gentism is the 'Principle of Naturalistic Closure' (PNC) defended by Ladyman and Ross in their metametaphysics:

> Any new metaphysical claim that is to be taken seriously at time *t* should be motivated by, and only by, the service it would perform, if true, in showing how two or more specific scientific hypotheses, at least one of which is drawn from fundamental physics, jointly explain more than the sum of what is explained by the two hypotheses taken separately. (2007, 30)[13].

The criterion that PNC offers for evaluating metaphysical claims could be satisfied by an emergentist account of the relationship between the ontologies of different areas of scientific practice. An explanation of the emergence of the ontology of some special science would certainly perform a *service* (to use their terms) insofar as the unsupplemented resources of *fundamental physics* by stipulation do not cover what falls beyond the confines of that domain. Given the standards of PNC, such an emergentism would compare very favorably with an unsupplemented scale-dependent RR.

Notice also that assuming an agent-relative conception of real patterns dramatically reduces the interest of scale-dependent RR and basically returns us to R-OSR's problem of relations without *relata*, now reformulated in terms of real patterns. At this point, questions proliferate: from the perspective of practicing physicists, if real patterns are all that exist and they are scale dependent, what is the ontological status of Space-Time? Could it make sense to say that space-time is itself a real pattern? Finally, as we have seen, scale-dependent RR simply fails to explain the relationship between different real patterns existing at different scales, what, for example is the relationship between the real patterns of fundamental physics, the real patterns of non-fundamental physics, and the real patterns of chemistry or biology. Moreover, what is the status of the agents or minds whose pragmatic interests are said to carve the world into scale-dependent beings? Are these agents also objects? If so, what is their relationship to fundamental physics? Again, it seems that advocates of RR acknowledge the existence of different "strata" but are unable to explain their existence or the relations between them.

4 Physicalism and Radical Ontic Structural Realism

Proponents of R-OSR regard themselves as doing philosophy in a way that is informed by what we know from our latest and best science. They are generally critical of what they see as the rationalist excesses of analytic metaphysics and they call on principles like PPC and PNC to regulate metaphysical research (Ladyman & Ross, 2007). While they think of themselves as naturalists, proponents of OSR have assumed that naturalized metaphysics is equivalent to physicalism. This is a defect of R-OSR for reasons we will explain below.

Physicalism is a view that was a dominant current in analytic philosophy from at least the mid-1950 s to the mid-1990 s. On this view, mental and other kinds of properties are either identical to or are determined in some way by physical properties. In this spirit, Ladyman asserts that physics is the science which must be able to account for all natural phenomena (Brown & Ladyman, 2009: 34).

[13] Cited by Cian Dorr (2010).

Physicalism has never been a very satisfying ontological position. If we believe that all there really is is the physical (whatever *the physical* turns out to be) then what are we to make of numbers, propositions, conscious states, possibilities, moral or aesthetic value, linguistic meaning? As Daniel Stoljar recounts, much of the task of analytic philosophy in the late Twentieth Century involved reconciling such prominent features of common sense judgment with the ontology that philosophers mistakenly thought they had gleaned from physics (Stoljar, 2010). In retrospect, it certainly appears that reconciling our common sense judgments with the austere ontology of physicalism was a task that shaped much of philosophy in the decades from the 1950 s to the 1990 s. As Stoljar and others have discussed in detail, this task of reconciliation assumed that the ontological questions were, or were soon to be, settled by physics. Physicalism was a philosophical stance that outsources responsibility for answering ontological questions to physics. One point should be clear from the foregoing discussion: if one is tackling ontological problems within physics, then a doctrine that assumes that these problems are settled by physics is simply a non-starter.

From the 1960 s to the 1990 s physicalism served as a kind of background common sense default position for most analytic philosophers. In sub-disciplines like philosophy of mind, moral philosophy, or philosophy of biology, scant attention was paid to what physics really teaches about the basic constituents of reality. This inattention combined with the assumption that a scientifically respectable philosophical position is required to commit to something like the truth of physicalism along with the vaguely articulated assumption that physicalism is somehow equivalent to naturalism. Proponents of OSR line up with this basic set of physicalist assumptions when it comes to the ontologically or metaphysically basic features of reality. Emergentism was seen as scandalous insofar as it rejects some of the assumptions that undergird the core physicalist consensus.

Physicalists and emergentists differ in their understanding of what counts as metaphysically basic and prominent advocates of OSR side with the physicalists. Terence Horgan puts the difference as follows: "A physicalist position should surely assert, contrary to emergentism … that any metaphysically basic facts or laws -- any unexplained explainers, so to speak—are facts or laws within physics itself." (Horgan, 1993, p. 560 (quoted in Crane, 2010)). While many advocates of OSR also assume that the only satisfactory approach to ontological questions is in terms of microphysicalist fundamental ontology, this position is not necessarily entailed by OSR as we will explain below (See also Symons, 2015; 2018b).

Consider the challenge of holding both scale relative ontologies for the special sciences and a commitment to PPC and PNC. In order for a hypothesis in the special sciences to conflict with fundamental physics in a way that PPC says is objectionable, the referent must have characteristics that make it comparable to those entities or phenomena that are subject to the laws of physics. That is: elephants do not move at superluminal speeds or break CPT symmetry, insofar as they are physical objects, not insofar as they are approximated-scale dependent biological entities. Let's consider how PPC can have more content than the claim that entities do not behave in ways that conflict with microphysics. For Ladyman, physics is the fundamental science such that measurements at all scales and at all locations in spacetime are potential falsifications or confirmations of it (Ladyman, 2009: 116). However, the only way we could say that a measurement in economics, for instance, falsifies or confirms fundamental physics, would be if we could somehow reduce economic interactions to physical ones. Notice that this strongly reductionist claim is not essential to OSR. Without an implausibly strong form of reductionism PPC is largely irrelevant to the ontology of the

special sciences. Thus, given the framework of RR, it cannot be used to disqualify emergent entities from consideration. Obviously, if strong reductionism were true, emergentism would be false. But PPC, RR, and OSR are not committed to the kind of implausibly strong reductionism that would exclude emergent features of the special sciences.

By PNC any metaphysical claim that provides the basis for either rejecting or accepting distinctive ontological commitments of some special science should be "taken seriously" since it would thereby provide the kind of explanatory resources that unsupplemented OSR lacks. Notice that this is true for both emergentism and strong reductionism. Given the limitations of PPC and the meta-metaphysical principle of PNC there is a question here that goes beyond OSR and requires a defense of either reductionism or emergentism.

Recall that PPC is generally understood by proponents of OSR to serve as a reductionist strategy for blocking emergence within R-OSR. Take, for example, their criticism of modal reasoning in analytic metaphysics where they argue that, from the perspective " […] *of those engaged in special science activity, fundamental physics gives the modal structure of the world*" (Ladyman & Ross (2007): 288, emphasis in the original). In the same way that the modal structure of the world is determined by fundamental physics (a metaphysically extravagant claim by the way) any other structures that might be identified by the special sciences have whatever reality they have in virtue of their relationship to the structure of fundamental physics. This kind of reductionism is, of course, directly contrary to emergentism. For Ladyman and Ross "[…] if there is emergence, this means that there are real patterns that do not reduce to physical patterns" (2007: 264). While RR seems to acknowledge the existence of different (emergent) ontologies, the proponents of RR generally insist that they are reducible to the structure given by fundamental physics. Again, notice that this rejection of emergent ontologies is not the result of any explicit commitments drawn from OSR *per se*[14].

One way to respond to some of these concerns is to reformulate R-OSR in an asymmetrical fashion. This means that the existence of both relations and *relata* (objects) is acknowledged, but ontological priority is given to relations since objects are ontologically dependent (or somehow derived) from the relational structure. Objects are constituted by the relations in which they stand as mere nodes of relations within the structure (see, e.g. Ladyman & Ross, 2007, French & Ladyman, 2011, Ladyman, 2016). In this view, objects are nothing over and above the fundamental structure and its features. Moreover, asymmetrical R-OSR is not eliminativist with respect to objects (belonging to the everyday world, the special sciences, or even to fundamental physics), but is eliminativist with respect to levels of composition (and of any other kind). There is only one fundamental level—and according to R-OSR this level is given by modern physics (properly understood).

However, the assumption that structure-objects relationship is asymmetrical is not obviously correct. Kerry Mckenzie notes, for example, that "[…] the extreme version of (OSR) as developed by Ladyman and French turns out to be in trouble because although

[14] Ladyman and Ross are critical of the idea that patterns at different scales could be regarded as emergent. For instance, they say: "Thus, Batterman's 'emergentism'—which we endorse while considering its label semantically unwise—is a special case of scale relativity of ontology" (Ladyman & Ross, 2007: 24). Note that Batterman's (2001) account of asymptotic emergence focuses on the kinds of singularities that mark the limits of models in one level of theoretical representation and mark the need for another kind of representation, for example in the case of phase transitions. It is striking that, as with the failure of the strong geometrical program in GTR (described by Cao in his 1998) the structural realist must take account of singularities in their geometrical representations in ways that force them beyond merely structural questions.

the dependence of objects on the structure can be derived, so can the dependence of structure on objects". Thus R-OSR fundamentalism is challenged, since "one cannot eliminate the objects without thereby eliminating the structures" (McKenzie, 2014: 23). The same response holds if one articulates fundamentalism in terms of symmetry or laws. Notably, one central claim of R-OSR is that contemporary fundamental physical theories characterize particles in terms of symmetry, making symmetry more fundamental than particles. But once again, McKenzie argues convincingly that "physical symmetries cannot exist independently of physical objects—any more than there can be laws of nature without anything to behave in accordance with them" (McKenzie, 2015: 10).

In sum, according to R-OSR, there is a fundamental relational structure where objects are, at best, determined by pre-given relations. In R-OSR all non-fundamental ontological content is either derivable from fundamental structural properties or is simply eliminable.

5 Moderate OSR

Moderate OSR (M-OSR) marks a set of positions that are intended to avoid some of the pitfalls of R-OSR while still emphasizing the centrality of relations. Thin-Objects or Thin-Atomism M-OSR involves the merging of Symmetric M-OSR and a "primitive ontology" approach (see especially, for instance, Allori, 2013;2015). According to Thin-Objects M-OSR: "there are fundamental physical objects, namely, matter points, but all there is to these objects are the spatial relations among them. Thus, they do not have an intrinsic nature, but a relational one" (Esfeld et al., 2015). Thus, there is a fundamental level to physical reality composed of individual objects—atoms of matter. But in opposition to traditional atomism these points do not have intrinsic properties, they are fully characterized by being entities-in-distance-relations. These so-called distance relations are the only mode of existence for these objects. So, *relata* (matter points) and relations (distance) are interdependent but distinct entities that share the same ontological weight. Thus, as in R-OSR ontology is fundamentally structural, but this structure is not only composed by relations (laws or symmetries) but also by individual objects. Thus, M-OSR does not ask us to accept a relational structure without relata as fundamental to our ontology. Despite their differences, both versions of OSR agree on one point, namely that we should be ontologically committed primarily to relations—even if we admit objects, we should dismiss intrinsic properties (McKenzie, 2016).

Does the preceding characterization of OSR entail the rejection of ontological emergence? In our view, current leading forms of OSR should be agnostic about this issue. To say that one is ontologically committed to the relational structures of our best scientific theories, does not need to lead us to any particular thesis regarding the question of whether emergence is true or not. Similarly, rejecting intrinsic properties, neither supports nor dismisses ontological emergence for reasons we will explain here.

According to Esfeld's metametaphysical perspective, ontology should be developed in conjunction with science, as a kind of "philosophy of nature". On this view, metaphysics should drive and ground science, or as Esfeld and Deckert (2018: 12) put it: "[…] metaphysics becoming physics, or physics being done on the basis of first ontological principles". For Esfeld, M-OSR is combined with Primitive Ontology (PO) in a way that he regards as

promoting Bohmian Mechanics (Dürr et al., 2012)[15]. According to his account of Bohmian Mechanics, the primitive ontology of this physical theory consists in one actual distribution of matter in space at any time (no superpositions), and the elements of the primitive ontology are localized in space-time, being "local beables" in the sense of Bell (2004, chap. 7). This means that something has a precise localization in space at a given time (Esfeld, 2014).

The elements of primitive ontology (or primitive stuff) are point particles (or matter points). The conjunction of M-OSR and PO amounts to Esfeld and Deckert (2017) regarding matter points as primitives meaning that they are not composed of anything and they do not have intrinsic properties and their existence is asserted as a brute fact at the fundamental physical level.

Unlike R-OSR, M-OSR endorses a 'levels-ontology' in terms of organizational complexity and compositional relations. Nevertheless, according to Esfeld, everything is reducible to the fundamental structure of the world. Now, this is not a consequence of M-OSR, nor PO, but it is instead the result of the type of ontological assumptions endorsed by Esfeld—that is, a network of ultimate matter-points and just one type of relation—namely, a spatial relation of distance. Thus all other properties—even properties belonging to current fundamental physics—are simply eliminated a priori.

The particular primitive ontology endorsed by Esfeld postulates only spatial properties. In this two-categorial ontology (there exist particles (objects) as well as distance relations (relations)), no entity can undergo a qualitative kind of change, by acquiring or losing some properties, because there is only one fundamental type of property (distance relation) which is always instantiated. Therefore, entities can only change quantitatively in terms of their fundamental spatial relations and properties. All other types of properties and relations are merely supervenient on the spatial ones, thus being micro-reducible to them. In this sense, any higher-level property or relation instantiated by some mereological complex must be seen as the mere epiphenomenal result of some composition between the fundamental spatial relations and properties of its parts. However, exactly how from composition between the fundamental spatial relations, all other properties can be entirely derived is not explained. Moreover, we are not provided with reason to believe that all other scientific theories can be derived from Bohmian Mechanics (Cordovil, 2018). Finally, for such a view to be plausible it must provide some reason to believe that some future physics—for example some theory of quantum gravity—will always regard spatial relations as fundamental. No such arguments are provided.

6 Structural Realists and Ontological Emergence

As we have seen, proponents of both R-OSR and M-OSR wish to exclude the possibility of ontological emergence. However, in both cases the possibility of ontological emergence is blocked by commitments that go well beyond what OSR directly entails. In the case of R-OSR this additional assumption is that ontology must take the form of physicalism.

[15] The long-standing issue with Bohmian Mechanics is the problem of what is the role of the wave-function within the configuration space. At this point, the PO approach is decisive. It detaches the theory's Ontology from its formalism and therefore allows that the wave-function may be considered as a non-primitive element.

For M-OSR ontological emergence is denied because of its commitment to an ontology of primitives and thus to a version of classic micro-reductionism.

Neither physicalism nor micro-reductionism are entailed by OSR whose central commitment is simply that we should be ontologically committed primarily to relations, and insofar as we invoke objects, we should not characterize those objects in terms of intrinsic properties. Again, to say that one is ontologically committed to the relational structures of our best scientific theories, does not lead to any particular thesis regarding the question of whether emergence is true or not. Likewise, the view that we should not individuate objects by reference to their intrinsic properties is orthogonal to our evaluation of ontological emergence. Ultimately, OSR is agnostic about emergence and as we have shown, only the introduction of additional theses unables emergence on the OSR's framework.

Despite using the expression "our best scientific theories," Ladyman and Ross let one branch of science; physics, drive our metaphysics. And even within Physics, they contemplate only a subset of candidate fundamental theories. As we have argued here there are no *naturalistic* or *scientific* arguments that justify this kind of commitment to physicalism.

Esfeld's assertion that there are no intrinsic properties and that everything is ultimately reducible to atomic relational compositions is not a consequence of OSR's core view, but rather a result of the conjunction of M-OSR and PO (Allori, 2015:107). Both Allori's PO and Esfeld's thin-atomist M-OSR assume micro-physicalism *a priori*. Again, there is no justification of that assumption from within OSR. Instead, PO is defended in terms of its apparent parsimony and explanatory power with respect to the relationship between the quantum and classical domains. If we understand PO—as Esfeld also seems to do—as the call for an ontology that is not simply derived nor inferred from a formalism, but that our ontology should instead be postulated as the *referent* of that formalism (Esfeld, 2014: 99; Egg and Esfeld, 2015: 3230), i.e. an ontology *behind* the formalism of our theories, which makes the formalism compatible with the manifest image, then, such micro-physicalism is clearly a step beyond the requirements of OSR.

Given the considerations presented so far, one can envisage a variety of ways in which ontological emergence can be reconciled with OSR. If we distinguish OSR from physicalist and micro-physicalist commitments, we could admit the existence of different levels of composition and organization of reality (following, in this respect, M-OSR), articulating it, for example, via a *relational-transformative* account of interlevel emergence (Santos, 2015; 2021). In this view, OSR could be made compatible with the idea that new emergent higher-level structural properties and laws may be generated from the transformative relations between lower-level sub-structures. Relations and structures could still then be the real star-performers of science and reality but having a structuralist view of the world would not then be equal to an essentially flat or static view of it. In particular, this view could be made possible if structures were seen as primarily 'concrete structures', taken as relations between first-order properties, in contrast to mere 'abstract structures', taken as higher-order, formal (logical or mathematical) properties of relations (Chakravartty, 2007: 37, 40).

An alternative transformational view on emergence, specifically applied to fundamental physics, was defended by Humphreys (2016), Guay and Sartenaer (2016) and Sartenaer (2018). According to Humphreys, emergence occurs when an individual that is considered to be a fundamental element of a particular nomological domain transforms itself, by a change in at least one of its essential properties, into a different kind of individual, thereby becoming a member of a different nomological domain (Humphreys 2016: 60). Although

this alternative view seems to fit well with R-OSR given its 'flat' or 'no-levels' account of emergence, it is difficult to see how it can be made compatible with OSR, given that relations are not taken to be necessary for the production or explanation of the transformation processes leading to emergence (Sartenaer, 2018: 9).

Finally, Silberstein (2017), and Silberstein et al. (2018), also proposed a way to make OSR and emergence compatible, thereby refusing OSR's 'physics-centric fundamentalism' (2018: 184–186). According to their notion of 'contextual emergence', "new properties, entities, laws, etc., emerge out of multiscale contexts of various sorts", and it is "the contextual nature of reality" and, moreover, "the interdependence and interpenetration of scales that makes contextual emergence possible" (2018: 172–173 and 184). Therefore, "the arrow of determination and explanation in contextual emergence (…) is not exclusively bottom-up but multi-directional" (2018: 176). One distinctive feature of this view is that emergence is conceived within the framework of an adynamical, 'Relational Blockworld' view of reality.

7 Conclusions

In order for OSR to serve as a form of scientific realism rather than playing proxy for physicalism, it should have the resources to address the ontology of the special sciences and to show how they relate with each other and with physics. Philosophers who advocate ontological emergence hope to account for the existence of causal properties, laws and even structures, that manifest some degree of autonomy in different domains of scientific inquiry. A version of OSR that does not preclude ontological emergence would be a richer metaphysics that eventually can allow OSR to achieve some of its central aims. If we want to endorse scientific realism we ought to be able to defend it without restricting ourselves to a single science. And if we want to be naturalists we should not let our metaphysical prejudices guide our understanding of the sciences.

What blocks ontological emergence in the case of R-OSR is the view that fundamental physics is the source of ontological commitment; the thesis that fundamental physics vindicates flat ontology; and the view that flat ontology is incompatible with ontological emergence. What blocks ontological emergence in the case of M-OSR is the *a priori* microphysicalist assumption that is understood to result from PO. We have argued that these additional anti-emergentist commitments are independent of OSR. If we are correct, the possibility of developing a version of OSR that incorporates ontological emergence is thus open and should be explored.

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