# The Metaphysics of Mechanisms: An Ontic Structural Realist Perspective[1]

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## Abstract

Existing metaphysical accounts of mechanisms commit to the existence of objects or entities posited in scientific theories, and thus fall within the category of maximal metaphysics. In this paper, I demonstrate the incompatibility of object-based metaphysics of mechanisms with the prevailing trend in the philosophy of physics by discussing the so-called bottoming-out problem. In response, I propose and flesh out a structuralist metaphysics of mechanisms based on Ontic Structural Realism (OSR), which is a kind of minimal metaphysics. I argue that the metaphysical underpinnings of mechanisms are structures, whose metaphysical nature is elaborated through comparison with existing metaphysical theories of mechanisms. After that, I address the concern of whether objects in mechanisms can be accommodated in my account by invoking existing metaphysical theories of objects in special science by structuralists, such as Ladyman and Ross (2007)'s real pattern account and suggesting a potential alignment between OSR and processual ontology. Finally, I demonstrate how my view can naturally serve as the metaphysics for Mechanism 2.0 and be applied to systems biology.

Key Words: Minimal Metaphysics; Ontic Structural Realism; Mechanism; Philosophy of Biology

## Introduction

Over the past 20 years or so, the focus of discussions on explanation in the special sciences (as opposed to fundamental physics) has shifted from laws to mechanisms. The shift was the result of philosophers of science paying more attention to the actual practice of scientists, and much of the contemporary practices of sciences (especially the life sciences) are driven by the search for mechanisms, which can be broadly defined as the interaction of objects that are organized in a certain way. The group of philosophers that have been spurring this shift are commonly referred to as new mechanists. The success achieved by the new mechanists in scientific explanation has also led to a new trend in the metaphysics of science. Metaphysics-minded new mechanists have engaged in a series of discussions regarding the metaphysical

[1] This is the final draft of the paper forthcoming in *Synthese* topical collection on minimal (anti-) metaphysics.

commitments of mechanisms (e.g., MDC 2000; Glennan 1996, 2011, 2017; Illari and Williamson 2013; Kaiser and Krickel 2017, Krickel 2018).

It should be noted that all existing metaphysical accounts of mechanisms are based on an ontology of objects or entities, which can be traced back to an atomist tradition that holds that, "[t]he entities which we see in the world are typically composed of smaller entities, with these entities being composed in turn of smaller entities, and so on until one reaches some bottom level of entities – the atoms" (Glennan 2010, p.1). In other words, proponents of these accounts believe that there are (object-like) entities all the way down to some fundamental level. By committing to the existence of objects posited in scientific theories, existing metaphysical theories of mechanisms fall within the category of maximal metaphysics (Henschen and Hüttemann, 2022). I take this metaphysical commitment to be maximal because they typically invoke a 'thick' notion of objecthood just like standard scientific realism. According to this view, objects exist independently of the practice of sciences, possess intrinsic properties and identity, and often serve as the seat of causal dispositions.

In the debate on the metaphysics of science, the dominance of maximal metaphysics is gradually being replaced by minimal metaphysics, with its supporters exhibiting more restricted and minimal ontological commitments. In philosophy of physics, ontic structural realists argue that physical objects (with intrinsic identity and properties) are not part of our fundamental ontology, and all that exists at the fundamental level are structures (Ladyman 1998; Ladyman and Ross 2007; French and Ladyman 2003, 2006, 2011; French 2014) where the notion of 'structure' has been interpreted in different ways (see Ladyman 2007/2023) but can be broadly understood as a set of modal relations. Ontic Structural Realism (OSR) is a form of minimal metaphysics because its ontological commitments are confined to structures, with objects being reconceptualized as either ontologically 'thin' or merely conceptual. As ontic structural realists also aim to unify the metaphysics of different sciences and believe that the metaphysics of fundamental physics constrains that of special science (Ladyman and Ross 2007), it is well-motivated to consider the question of whether we can incorporate the metaphysics of mechanisms into the framework of OSR and have a structuralist account of mechanisms. [2]

[2] It is worth noting that that Glennan, the leading metaphysician of mechanisms, views it as an important task to reconcile the ontology of fundamental physics and that of special sciences. He says, "[w]e should not assume, just because it conforms with our intuitions, that nature is ultimately grounded by a fundamental level of 'little things and micro-bangings'". (2017, p.190).

In this paper, I offer a positive answer to this question by proposing and fleshing out a structuralist metaphysics of mechanism. The significance of this paper should be twofold: on the one hand, I fill a gap in existing metaphysical theories of mechanisms by providing a metaphysics that is compatible with the leading metaphysical account of fundamental physics. On the other hand, given the current relative lack of exploration into how OSR applies to the special sciences (for initial work in this direction, see French 2011; Ladyman and Ross 2007; Beni 2016), and the near absence of discussions on OSR and mechanisms, I demonstrate how to extend OSR to the special sciences within the framework of the new mechanical philosophy. This further rebuts objections asserting that OSR is only applicable to fundamental physics (see Ladyman 2007/2023). Moreover, successfully extending OSR to new mechanical philosophy can be more broadly viewed as promoting the success of minimal metaphysics. In this regard, this paper contributes to the ongoing transition towards minimal metaphysics in the metaphysics of science debate. [3]

The paper is structured as follows: after I briefly introduce two leading metaphysical accounts of mechanisms in the first section, I then discuss the so-called bottoming-out problem which poses a serious challenge to these two accounts and serves as a motivation for the structuralist metaphysics of mechanisms. I further strengthen this motivation in section 3. Afterwards, I briefly introduce Ontic Structural Realism in section 4 before I flesh out my structuralist metaphysics of mechanisms. After that, I address the concern of whether objects in mechanisms can be accommodated in my account by invoking existing metaphysical theories of objects in special science by structuralists, such as Ladyman and Ross (2007)'s real pattern account and suggesting a potential alignment between OSR and processual ontology. Finally, I demonstrate how my view can naturally serve as the metaphysics for Mechanism 2.0 and be applied to systems biology.

## New Mechanism and Metaphysics

According to new mechanists, mechanisms can be defined as follows,

[3] According to Hüttemann (2021), we should establish a metaphysics for scientific practice in the sense of 'making explicit assumptions concerning the structure of reality that best explain the success of [that] practice' (p. 1). Furthermore, this metaphysics should be minimal in that 'it should contain no assumption that does not do any work in explaining scientific practice' (p. 11) (See French's book review, 2022) I am going to show that the mechanists' invocation of an object-based ontology does no work in explaining the scientific practice they appeal to and that as a result, a structuralist account offers a metaphysically more minimal explanation.

*The most fruitful way to define mechanisms is that a mechanism for a phenomenon consists of entities (or parts) whose activities and interactions are organized so as to be responsible for the phenomenon* (Glennan, Illari, and Weber, 2022, p. 145, italics original).

Within this definition, 'entities' refer to physical objects, which are the entities that engage in activities. Entities occupy spatio-temporal regions and serve as bearers of properties. Some examples include calcium ions, neurons, cells, DNA strands, ATP, chloroplasts, muscles, hearts, and organisms. On the other hand, 'activities' are the actions performed by these entities and are described by verbs. Activities are temporally extended and require the involvement of entities. Examples of activities encompass binding, opening, diffusion, phosphorylation, triggering, pumping, inhibition, reproduction, and stabilization (Glennan 2017; Kaiser 2018; Krickel 2018).

There are (at least) two different ontological views regarding mechanisms. I follow Kaiser (2018) and refer to them as dualism and monism. Monism only commits to the existence of entities, positing that all that exist are entities. According to monism, activities are reducible to entities and are the manifestation of the powers of the entities involved in the activity (Glennan, 2017, p. 32). Glennan, the leading monist, acknowledges that his view on (causal) powers is similar to that of Nancy Cartwright (1994; 1999), who supports a form of the dispositionalist account of causation (p. 188). Therefore, he believes that causal power is located in the powers or dispositions of entities[4].

In contrast to monists, dualists (MDC 2000; Krickel 2018; Illari and Williamson; 2013) commit to the existence of both entities and activities and they do not think that activities are reducible to the powers of entities. Instead, they argue that "the term 'activity' refers to a basic unit of the world that exists additionally to entities" (Krickel 2018, p.76), and they hold that activities and entities are ontologically on a par with each other.

Krickel (2018) provides a comprehensive metaphysical analysis of the dualist notion of activities. According to her, the features of activities include, but are not limited to, the following:

1. Activities are the causal components of mechanisms.
2. Activities involve activeness.

[4] Thanks to an anonymous reviewer for pointing out that the late Glennan (2017) has arguably converged to dualism and Kaiser's interpretation of him as a monist is potentially controversial. Nevertheless, we agree that monism, supported at least by early Glennan (1996), is something worth considering.

3. Activities are occurrents, whereas entities are continuants.
4. Activities are necessarily manifest or actualized.
5. Activities are irreducible (p. 90).

The first two features mean that activities are inherently active and causal, serving as the 'locus' of causal power. According to Krickel, "activities are supposed to be the causal components of mechanisms," and they (activities) 'produce change' (p. 74). Illari and Williamson (2013) explain this point well by stating: "[a]ctivities in a mechanism have modal force; they can ground counterfactuals about how the mechanisms would operate in other circumstances), and therefore, they can explain how the mechanism makes a difference to the phenomenon for which it is responsible" (p.75). [5]

Moving on to the third feature, Krickel defines occurrents as something that extend in time and have different temporal parts. For example, a football match consists of two temporal parts: the first half and the second half. Continuants, on the other hand, do not have temporal parts in this sense. An example would be a table, which remains the same over different time spans. Activities are occurrents that are temporally extended.

The fourth feature is entailed by the third one, suggesting that activities are necessarily manifest or actualized, rather than being merely dispositional. Krickel (2018) explains the difference between activities and entities' dispositions by stating, "[a]n entity might instantiate the capacity or disposition to φ even if it never φs. For activities it does not make sense to say that an entity engages in an activity without the activity actually occurring. If something is engaged in an activity φ, it is actually φ-ing" (p.76). Fifthly, activities are irreducible to entities but are ontologically on a par with entities.

The above is a brief introduction to New Mechanism and the two mainstream metaphysical theories of mechanisms. In the next section, I will discuss a significant challenge faced by these two theories, namely, the bottoming-out problem.

**Bottoming-out Problem**

New mechanists argue that there exists a hierarchy or hierarchical organization of mechanisms. That is, mechanisms at a particular level of hierarchy depend on several mechanisms at lower levels, and the causal power manifested at a certain level can be reduced to the causal power at lower levels. Glennan (2017), for example, holds that "the

[5] This feature is also picked up in Ontic Structural Realism, according to which, structures have modal force.

productive capacities of wholes derive from the productive capacities of parts," and "[t]he causal powers of systems arise from the organized causal powers of their components" (pp. 184). This concept can be illustrated through the following example provided by Glennan:

"When Franz speaks to Sisi, the utterance is composed of words, the words of phonemes, and so on down to the physical motions of the air produced by Franz's vocal tract, which, in turn, create vibrations within Sisi's ear. Franz's ability to communicate in this manner depends on various parts of his vocal system—his mouth, his teeth, his diaphragm, his vocal cords, etc." (Ibid, pp. 184-185).

In this example, the event of Franz speaking to Sisi, or Franz causing Sisi to hear him, relies on the mechanism where Franz's vocal system causes the surrounding air to move, subsequently leading to vibrations within Sisi's ear. Moreover, the causal power of Franz's vocal system further depends on the causal power of its components (e.g., mouth, teeth, diaphragm), and the causal powers of these components, in turn, depend on the causal power of their components at lower levels, and so on.

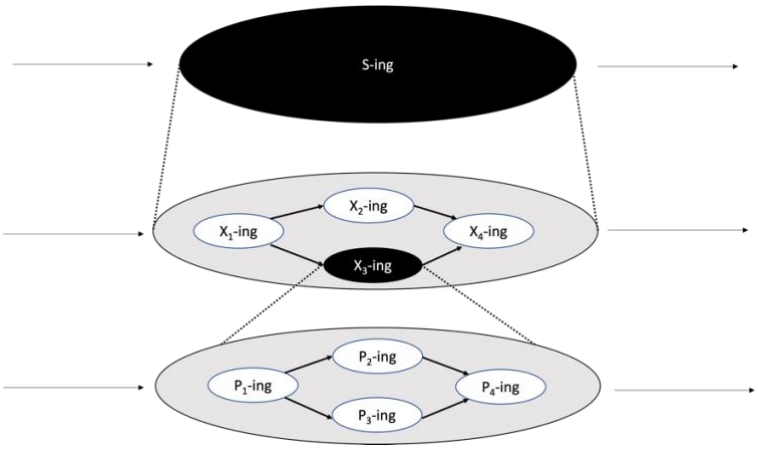


Figure 1: A schematic of mechanistic levels (adapted from Povich and Craver 2017, p. 187)

The question then arises: when and how does this reduction process reach its endpoint, or when and how does the hierarchy bottom out? The engagement between the metaphysics of mechanisms and philosophy of physics becomes inevitable at this point when addressing the bottoming-out problem, because both monism and dualism need to explicate the ontology for fundamental reality to tackle this issue. In response, Glennan (2017) proposes the concept of "fundamental mechanism." He says, "[l]et us call a mechanism (that

is, a set of entities engaging in activities and interactions) that does not depend upon other mechanisms, a *fundamental* (or basic) mechanism" (p.185, italics original). Furthermore, he thinks what constitute fundamental mechanisms are going to be decided by physics. He writes, "[…] physical theory will, at any given time, have identified some set of entities and activities as the most fundamental known, and that such a set of entities and activities might turn out to constitute a genuine ontologically fundamental level" (p.187). According to him, entities within the fundamental mechanisms are going to possess the fundamental causal properties, and fundamental mechanisms will be the places where higher-level mechanisms bottom out.

Dualists offer a similar response. When addressing the question of where the causal power bottoms out, Krickel (2018) inclines to believe that "there is activity causation at the fundamental level but that we have to accept this as a brute fact about nature that is not grounded in anything more fundamental" (p.87). This leads her to hold a position similar to Glennan's and to accept the existence of fundamental mechanisms. However, the fundamental mechanism here is understood within a dualist framework, which means it consists of fundamental entities and activities.

The problem with Glennan and Krickel lies in their consideration of entities with intrinsic identity and properties as parts of their fundamental ontology. Several prominent philosophers of physics have argued against the existence of such entities or objects at the fundamental level. In other words, they find an object-based ontology of fundamental physics problematic, and this position is supported by metaphysical implications found in major theories of modern physics, including quantum mechanics (QM), quantum field theory (QFT), and the general theory of relativity (GTR) (see Esfeld and Lam, 2011). One major criticism of the existence of fundamental physical objects is pointed out by French and Redhead (1988), who argue that an object-based ontology of quantum mechanics would lead to underdetermination regarding the individuality of quantum particles. The argument is later discussed in a series of works by French and Ladyman (e.g., Ladyman 1998, French and Ladyman 2003, and French and Ladyman 2011), which motivated them to develop Ontic Structural Realism (see more below).

Given that prominent metaphysical accounts of physics believe that no objects or entities exist at the fundamental level, object-based metaphysics of mechanism faces a

serious challenge in explaining where higher-level mechanisms bottom out[6]. This problem significantly undermines the object-based metaphysics of mechanism and motivates us to develop a metaphysical theory of mechanisms from the bottom up, which must be informed by the metaphysics of physics. As indicated at the beginning of the paper, Ontic Structural Realism (OSR) is a metaphysical theory of physics that has received much sympathy from many philosophers of physics, with its advocate arguing that it offers an ontology "best befitting of modern physics" (McKenzie, 2017, p.1). In this paper, I will propose and flesh out a structural metaphysics of mechanisms based on OSR. However, before doing that, I would like to further strengthen the motivation for my account, firstly by responding to a push-back from Glennan in his co-authored paper (2014), and then by demonstrating that the bottoming-out problem is not just a matter of philosophical concerns, but it also relates to scientific practices.

**Strengthening the Motivation**

I shall strengthen the motivation for a structuralist account of mechanisms by considering how to respond to two questions.

1. *Is there a 'fundamental classical level' where higher-level mechanisms bottom out?*

Kuhlmann and Glennan (2014) defend mechanical explanation in light of the apparent incompatibility between QM and the new mechanical philosophy by appealing to the phenomenon of decoherence. Specifically, a quantum system's wave function is typically expressed as a linear combination of wave functions representing different states, implying that the system is often in a superposition state, where it exists as a linear combination of different possible states. Interactions between different quantum systems can result in interference effects. The phenomenon of decoherence refers to the interaction of a quantum system with its macroscopic environment, leading to entanglement with the environment and causing the superposition and interference to disappear locally. In other words, decoherence results in the quantum system losing some of its 'quantumness', exhibiting behaviors that is approximately classical and deterministic. Kuhlmann and Glennan argue that decoherence leads to the emergence of a so-called "fundamental classical level", which consists of entities

[6] See Kuhlman & Glennan (2014) for a presentation of the incompatibility between QM and mechanist ontology, and also Kuhlman (2018) for a discussion on physics and mechanism.

or objects behaving classically, that can be used to ground the mechanistic explanation of higher-level phenomena.

Some might interpret their claim metaphysically and think that classical objects really exist, which undermines the motivation for the structuralist account of the mechanism that I am going to develop. However, it is important to note that the 'quantumness' is not eliminated entirely in decoherence, and the resulting behavior can be described as classical only for practical purposes. Hence, it is worth emphasizing that decoherence says nothing about metaphysics; that is, it says nothing about what QM tells us exists in the world, and it is compatible with multiple interpretations of QM that give rise to different ontologies (See e.g., Maudlin 2019).

Kuhlmann and Glennan explicitly admit this point in their paper (p.352) and emphasize that they are defending an epistemic claim about why we might legitimately use mechanical explanations in the macroscopic world. While we might agree with their defense here, the metaphysical issues about mechanisms in the light of fundamental physics are still unsolved. As Cordovil (2024) nicely puts it, "even though decoherence can give an approximate explanation of why the 'classic level' seems to be different from the 'quantum level,' it does not solve the problem of how to bridge the two realms since, in the end, everything is part of QM's domain" (p.186)[7]. Therefore, developing a metaphysical theory of mechanisms that is compatible with fundamental physics remains a pressing task.

*2. Is the bottoming-out problem purely philosophical (instead of practical)?*

A structuralist metaphysics of mechanism can be further motivated by considering scientific practice. Doing so can also address the worries that potentially come from new mechanists who focus on practical issues regarding scientific explanation. In fact, a considerable number of new mechanists, unlike Glennan and Krickel, do not aim to defend a 'global' metaphysics of mechanisms applicable to all levels including the fundamental level of physics. Instead, they are only concerned with the local reduction of mechanisms in certain domains. For them, mechanisms bottom out at the levels that "are accepted as relatively fundamental or taken to be unproblematic for the purposes of a given scientist, research group, or field," and "the description of lower-level mechanisms would be irrelevant to their interest" (MDC 2000,

[7] Cordovil (2024) proposes a solution to this problem by treating classical objects as ontologically emergent. He makes sense of the emergence by appealing to Santos (2015)'s relational ontology. I don't have space here to evaluate his proposal, but just to note that Santos's relational ontology, as I will discuss more below, is friendly to structuralism. Cordovil's writing seems to also indicate this point.

p.13). Since fundamental physics is rarely involved in the discussions of mechanisms in sciences concerned with macroscopic phenomena, they would consider the incompatibility between the metaphysics of mechanisms and the metaphysics of physics to be an inadequately motivated problem.

However, it turns out that at least in certain research domains of special sciences, fundamental physics is indispensable for the explanation of phenomena. Hence, in these fields it is necessary for the metaphysics of mechanisms to be compatible with that of fundamental physics[8]. Quantum biology is such an example, which utilizes quantum theory to explain biological phenomena beyond the reach of classical physics. Quantum properties like superposition, coherence, and entanglement are increasingly recognized as vital in understanding diverse biological processes, including photosynthesis, magnetoreception, olfaction, enzyme catalysis, respiration, and neurotransmission (Marais et al., 2018).

Consider the case of light-harvesting in photosynthesis. Photosynthetic organisms convert sunlight into energy via antenna systems, absorbing photon energy as electronic excitation. This excitation energy travels to the reaction center, where it is converted to chemical energy through charge separation (Lambert et al, 2012; Lloyd, 2011; Engel 2011). The energy transport mechanism used to be thought as a classical 'hopping' mechanisms through which the excitation energy randomly moved from one chlorophyll to the next neighboring chlorophyll step by step. However, as early as the 1930s, Franck and Teller (1938) proposed a quantum-coherent mechanism for the transmission of the excitation energy, characterized by wave-like properties that enable simultaneous propagation through multiple pathways (see also Lloyd, 2011; Engel 2011; Marais et, al, 2018). Initially met with skepticism, the quantum-coherent model gained credibility when quantum 'beats' were observed in 2007 during photosynthetic processes in distinct bacterial species (Engel et al., 2007; Lee, Cheng, and Fleming, 2007). Subsequent studies by the Engel and Scholes groups confirmed significant quantum-coherent energy transfer at physiological temperatures in bacteria and marine algae (Engel et al., 2010; Scholes et al., 2010).

[8] Thanks to an anonymous reviewer for pointing out that Kuhlman and Glennan do not maintain that decoherence provides a single fundamental classical level and think that classicality (and with it the possibility of classical mechanisms) emerges as a local/piecemeal matter. In this sense, Kuhlman and Glennan are on board with the idea that certain kinds of biological phenomena may be explicable by appealing to quantum mechanical effects. I believe that this strengthens the motivation to the introduction into the philosophy of biology arena of a philosophical stance adopted with respect to QM, namely, OSR.

According to new mechanists, explaining photosynthesis requires us to break it down into several mechanisms at a lower level. One of these lower-level mechanisms is going to involve the movement of the excited electron from its original location to the reaction center. Since the travel of the exciton is a quantum phenomenon, the metaphysical picture behind it must be in alignment with the metaphysics of quantum mechanics. As noted above, structuralist accounts of quantum mechanics posit that there is no fundamental object possessing intrinsic properties and identity, which is in contradiction with object-based metaphysical theories. The failure of object-based metaphysics at this lower level would further impact its legitimacy in the upper level. New mechanists argue that higher-level mechanisms are reducible to lower-level mechanisms. However, if we consider that higher-level mechanisms are composed of entities understood by monists and dualists, then these higher-level mechanisms cannot be reduced to lower-level mechanisms that involve no such entities.

The above discussion about quantum biology shows that the bottoming-out problem is not merely a philosophical issue but is closely related to scientific practices, further challenging the object-based metaphysics of mechanisms. I argue that the best solution to the problem here is to develop a metaphysics of mechanisms that is physics-informed and applicable to the special sciences. In the following, I flesh out such an account based on OSR, starting with an introduction to OSR.

**Ontic Structural Realism**

One of the motivations behind OSR is to address the metaphysical implications of modern physics (especially quantum physics). As briefly mentioned earlier, an object-based metaphysics faces fundamental underdetermination regarding the individuality of physical objects in quantum mechanics. [9] OSR overcomes this underdetermination by advocating an ontological shift from objects to structures, arguing that all that exist in the fundamental level are structures that are represented by mathematical equations of fundamental theories of physics (see Ladyman 1998; French and Ladyman 2003, 2011; French 2006, 2014, 2019;

[9] Simply put, there are two perspectives regarding the nature of these objects. One perspective considers them as individuals, each with well-defined identity conditions. The other perspective views them as non-individuals (see more on French and Krause, 2006). For the anti-realist, this poses a challenge to the realist because the realist cannot clarify the metaphysical status of the objects central to their ontology, given that both perspectives are equally valid.

Ladyman and Ross 2007). [10] It has also been argued that OSR is supported by various features of quantum mechanics, quantum field theory, and the general theory of relativity (Esfeld 2004; Esfeld and Lam 2008, 2012).

Ontic structural realists clarify the stance of OSR by comparing it to dispositionalism. According to the 'standard' form of dispositionalism (Vetter 2014), what exist at the fundamental level of physics are physical objects with dispositions. Dispositions are intrinsically possessed by objects and are understood as properties that are associated with causal powers, e.g., the negative charge of an electron. Dispositions necessarily manifest themselves when the corresponding stimuli are present. Dispositionalists hold that the causal or modal force 'sit' in dispositional properties possessed by objects, which ground the truth of counterfactual statements regarding causation (Mumford 1998; Hüttemann and Kaiser 2013, 2018).[11] Consider a scenario in which an electron is under the influence of an electromagnetic field. Dispositionalists would argue that there exists an electron as a physical object and it intrinsically possesses dispositional properties, e.g., its negative charge, and the acceleration of the electron is the manifestation state of the disposition when it is subjected to an electromagnetic field (the stimulus condition). The modality is rooted in the disposition. Maxwell's laws, which describe how electrons move in this scenario, arise from or depend in some way on this disposition. And it is the disposition that renders the following counterfactual statement true: if an electron were to fall under the influence of an electromagnetic field, it would experience an appropriate force and associated acceleration.

French (2014) argues that OSR can be derived by 'reverse-engineering dispositionalism' (p.264). While dispositionalists argue that objects are ontologically primitive, and laws depend on the dispositions of these objects, structuralists propose that laws themselves, which should be understood as features of structures, are ontologically primitive. In this view, objects asymmetrically depend on these structures. Structuralists shift the bearer of modal power from objects to structures by considering the laws themselves to be inherently modal. In the above example, what exist primitively are Maxwell's law or the structure(s) captured by Maxwell's law that possess modal power, and the electron

[10]According to French (2014), structures are what, in particular, are embodied in the relevant laws and symmetries, together with the concrete representations of the latter, in fundamental physics.

[11] I am aware that there are many new developments in dispostionalism (e.g., Synthese topical collection on New Foundations of Dispositionalism, Mumford 2009, Austin 2017, Anjum and Mumford 2018). I am referring to this form of dispositionalism here for the sake of illustrating OSR, following French (2014, p.239).

asymmetrically depends on the structure. And it is the structures themselves that ground the truth of the corresponding counterfactual (French 2014, chapter 10).

In sum, there are two major differences between dispositionalism and OSR. Whereas the former takes physical objects to exist primitively, the latter believes structures are ontologically fundamental. Second, dispositionalists hold that modality resides in the dispositions of objects, but structuralists believe that the modal force is possessed by structures themselves.

Furthermore, objects in OSR are 'reconceptualized'. A frequently discussed challenge to OSR is to say that it is inconceivable that there are relations but no relata (Ladyman 2007/2023; Ladyman and Ross 2007). However, this objection has no force against OSR because there are still relata according to OSR. What structuralists insist is that relata here should not be interpreted in an ontologically robust way. Instead, relata (objects) asymmetrically depend on relations (structures).

French (2010; 2014) distinguishes two forms of asymmetrical dependency: the first one states that the identity of objects depends on the relations of the structure, which then yields a form of contextual (as opposed to intrinsic) identity of entities. This supports a 'thin' notion of entities that can be understood to exist derivatively and depend on structures, holding that objects have identities that are given contextually by structures (Ladyman 2007; Saunders 2003). Another option is to say that 'the very constitution (or essence)' of objects is dependent on the relations of the structure. In this case, objects have no metaphysical status at all but only serve as merely 'heuristic devices' that allow us to "construct, articulate, or appropriately represent the relevant structure" (French 2019, p.26). [12]I will not take sides between these two views because each of them has its own strengths and weaknesses, and ultimately, whichever stance is more correct will not affect my argument in this paper. The minimal stance I adopt in this paper is to reject the 'thick' notion of objects, and I remain agnostic about how we 'reconceptualize' objects.

To recap, OSR argues that at the fundamental level of reality, what exists are inherently modal structures, and there are no objects that possess intrinsic identity and properties. In the next section, I propose a structuralist metaphysics of mechanisms based on OSR.

[12] It should be noted that eliminativist OSR still allows the usage of the concept of objects for pragmatic purposes, as French (2014) points out, "the elimination is with respect to our fundamental ontology—to suggest that tables, chairs, people, particles, whatever should be eliminated from that ontology is not to suggest that we may not speak of such things, or pragmatically negotiate our way around them, or whatever." (p.166, note2)

**Structuralist Metaphysics of Mechanisms**

My structuralist metaphysics of mechanisms claims that the metaphysical underpinnings of mechanisms are structures. I argue that only structures exist primitively, and entities should be reconceptualized along the lines indicated above, that is, as either 'thin' objects whose identities are contextually given by the relevant mechanisms or simply as heuristic devices that enable us to construct, articulate, or represent the relevant mechanisms.

Structuralists have clarified their position through a comparison with dispositionalism, and a similar strategy can also be applied to clarify the stance of my structural metaphysics of mechanisms. Glennan argues that mechanisms describe the causal framework of the world. He (2017) states, "[a] statement of the form 'Event c causes event' will be true just in case there exists a mechanism by which c contributes to the production of e" (p. 156). Glennan's monism adopts a theory of causation that is essentially a form of dispositionalism[13]. He argues that the causal production in mechanisms should be best understood as "[i]nteractions occur *in virtue of the causal powers of individual entities* involved in the interactions" (p.188, my italics). When referring to causal power, he means 'capacities or dispositions not yet manifested' (p. 32). This entails that he commits to a metaphysical picture in which what exists fundamentally are entities with intrinsic dispositions, and causation is the manifestation of these entities' dispositions.

A structuralist metaphysics of mechanisms can be derived by inverting the ontological order in Glennan's view. Within a structuralist metaphysics of mechanisms, *mechanistic statements pick up structures that are ontologically primitive.* Causal power should be shifted from objects to structures, which means that structures are inherently causal. Entities here are not ontologically primitive but secondary to structures.

An important question that needs to be addressed is how to understand the metaphysical nature of the mechanistic structures. I believe that a good way to answer this question is to compare mechanistic structures with the notion of 'activity' proposed by dualism. Recall that dualism posits that activities are one of the basic units of the world in addition to entities. According to dualists, activities are, from a metaphysical point of view, inherently causal occurrents. Occurrents, as an ontological category in contrast to constituents, extend in time and have different temporal parts. We can find many similarities

[13] Thanks to an anonymous reviewer for pointing out that it is debatable whether Glennan adopts dispositionalism, but this account is worth exploring here for the sake of illustrating my view.

between the notions of activity and structure; in particular, both are active and dynamic relations (cf. Glennan 2017, p. 51), which are inherently causal and act as the 'seat' of causal power. Thus, I argue that we can give activities a structuralist reading to accommodate mechanisms within structuralism by viewing activities as structures that are ontologically primary. In other words, I contend that mechanistic structures are activities understood in structuralist terms, which means that *mechanistic structures are also inherently causal occurrents.*

A further comparison with dualism will help clarify my position. In fact, a structuralist metaphysics can be derived from the dualist account by simply reinterpreting the ontological status of entities. Dualists support an ontologically thick notion of entities, considering them to possess intrinsic identity and properties and to exist primitively. However, structuralists reject this thick notion of entities and views entities as merely 'nodes' of structures. As mentioned earlier, there are two different approaches to this re-conceptualization within OSR, in which entities are reinterpreted as either 'thin' objects, whose identities are contextually determined by the relevant mechanisms, or as 'heuristic devices' that enable us to construct, articulate, or represent the relevant mechanisms. As alluded above, I commit to the rejection of an ontologically thick notion of entities but do not hold a specific stance on how to reconceptualize entities, and my account is compatible with both approaches to reconceptualization. Accordingly, while dualists believe that entities and activities symmetrically depend on each other, structures are considered to be more fundamental within the structuralist metaphysics of mechanisms, and entities asymmetrically depend on structures.

Krickel (2018) characterizes mechanisms as Entity-involving Occurrents (EIOs). As a dualist, she argues that mechanisms are metaphysically composed of entities and activities, which should be understood as actualized occurrents. Importantly, she emphasizes that entities and activities (occurrents) have a strong relationship of interdependence in the sense that "there are no entities that [...] are not engaged in at least one occurrent [...] Similarly, occurrents do not exist free-floating without any entity that engages in them." Put differently, she holds that "an entity necessarily participates in an occurrent, and occurrents necessarily involve at least one entity" (p. 79). EIOs are therefore spatiotemporally extended. Consider a moving car. An EIO can be the car moving from $t_1$ to $t_2$. For Krickel, a car that does not engage in any activities cannot exist, which implies that we must always understand the existence of the car in temporal terms. Similarly, she thinks that no activities can occur

without being dependent on entities, meaning that we must always understand activities in spatial terms.

Structuralists can accept this metaphysical picture with some adjustments, that is, by deflating the metaphysical status of entities and inflating the metaphysical status of activities. In a structuralist metaphysics, entities need to be understood as being asymmetrically dependent on the activities. In my view, Dualists have been mistaken in assuming that there are two kinds of existences, one as entities, and the other as activities – they want the ontological category of entities to account for the fact that activities are not free-floating and spatially extended, and the ontological category of activities to accounts for the fact that mechanisms are dynamic and "do things", and are thus temporally extended (MDC, 2000; see also Kaiser 2018, p.123). However, a structuralist metaphysics can capture the spatiotemporal features of mechanisms by only committing to *the existence of activities understood in structuralist terms*, which are spatiotemporally extended[14]. Structuralists can accept that the activities (occurrents) always involve entities (thus are not free-floating), but only in the sense that entities are reconceptualized as merely conceptual or ontologically 'thin'. Hence, I believe the phrase "entity-involving Occurrents (eIO)", where the lowercase 'e' highlights the rejection of the 'thick' notion of entities, best summarizes the metaphysical nature of mechanisms in my account.

However, since objects play foundational roles in the actual practices of biology and other special sciences, one might worry whether objects can be appropriately accommodated in my structuralist account. In response, I shall first emphasize that the main aim of this paper is to show that the recent 'mechanism turn' in the philosophy of science discussion is compatible with OSR, and I take it to be a further task to provide a fully-fledged metaphysics of objects in the special sciences within the framework of OSR, which will have to be addressed in future work[15]. Nevertheless, I shall elaborate further in the following section on why the indispensability of objects in the special sciences does not constitute a *reductio ad absurdum* to OSR's advocacy of the ontological shift away from objects. My discussion will consider the existing attempts by structuralists to accommodate objects in special sciences and suggest potential routes for further development.

[14] I have been using different labels here, including 'mechanistic structures,' 'causal occurrents,' and 'activities understood in structuralist terms.' For me, they all refer to the same 'thing,' which might also be expressed as inherently causal/modal dynamical structures. Thanks to an anonymous reviewer for pushing me to clarify this.
[15] Thanks to an anonymous reviewer for highlighting this point and suggesting potential ways to respond to the aforementioned worry.

**Object in Special Sciences**

Structuralists have already done a lot of work on how objects in the special sciences should be metaphysically reinterpreted along the lines of OSR. Perhaps the most discussed approach is the one presented in the seminal book by Ladyman and Ross (2007, Chapter 4), where L&R make sense of the existence of such objects as viruses in terms of the account of real patterns inspired by Dennett's work (1991) (See also Ladyman and Lorenzetti forthcoming; See Ladyman 2017, 2023 for summary). They argue that existence should be explicated in terms of real patterns or 'to be is to be a real pattern'. According to them, real patterns are 'those that indispensably figure in projectable generalizations that allow us to predict and explain the behavior of the world' (Ladyman, 2017, p.157). For example, they suggest that 'a wave on the beach is a real pattern to a surfer, or a lifeguard, because it is taken as the basis for prediction and explanation' (Ladyman, 2023, p.49). Waves are ephemeral and fuzzy real patterns, and in general, real patterns are more or less definite and durable, such as viruses and similar putative objects in biology. L&R's account can thus provide a metaphysic for objects described in mechanisms – they exist as localized real patterns.

However, it should also be noted that L&R's account of objects in special sciences is not the only option on the table. David Wallace (2012; 2022; 2024) defends a different account of real patterns, interpreting them in a pragmatist way[16]. In addition, Steven French (2011; 2013; 2014, Chapter 12) has also attempted to extend OSR to biology, where he (2016) argues for an eliminativism of biological objects. However, French (2014) does not deny the usefulness of the concept of objects and, therefore, does not object to their use in scientific practice and everyday life. For him, objects exist conceptually as heuristic devices.

Moreover, I argue that OSR can benefit from aligning more closely with the so-called processual ontology, which has recently come to the fore through the discussion of Dupré and others (e.g., Dupré & Nicholson 2018; Dupré 2021). This account also argues against object ontology and advocates for a processual ontology according to which all that exists are processes. Dupré & Nicholson (2018) defend their account by invoking several empirical motivations in biology, including ecological interdependence. They argue that the fact that biological entities, ranging from molecules to cells, organisms, and ecosystems, exist interdependently and interconnectedly motivates an ontological shift from discrete objects to

[16] Wallace's discussion primarily focuses on physics. He argues that mathematized physical theories successfully represent the reality of the objective world (thus, he supports a kind of structural realism). However, mathematized theories can be redescribed in terms of objects. Such redescriptions, or, in his own term, 'predicate precification' of a theory, are useful for our thinking and understanding. For him, objects do not correspond to anything in the underlying reality of the world.

dynamic processes in biology. Furthermore, they hold that 'objects' in general should be more appropriately understood as 'temporarily stable nexuses' that can be abstracted from 'the flux of dynamic biological processes' (Dupré and O'Malley, 2007, p. 842). Reconciling OSR and processual ontology is a complex task that deserves more thorough treatment, which will be deferred to future work. But the preliminary remark I can at least make is that these empirical motivations for the ontological shift away from objects, as listed in processual ontology, should certainly open up more room for a biology-based OSR, with objects retained, at least heuristically, as the afore-mentioned stable nexuses. In any case, I hope what I have presented so far has indicated serval potential ways for accommodating objects in OSR.

**Systems Biology and Mechanism 2.0**

This section presents an additional benefit of the structuralist metaphysics of mechanisms, namely, that structuralism can be very naturally applied to some fields of biology, serving as the relevant metaphysical framework. The fields I am referring to are those discussed in the literature of the so-called mechanism 2.0, which calls for expanding the mechanistic explanation framework and extending the concept of mechanisms. Mechanism 2.0 mostly focuses on systems biology, where the mechanisms involved are nonlinear, dynamic, and described quantitatively, with mathematical models playing indispensable roles in explanation (Brigandt 2013; Levy and Bechtel 2013; Levy and Bechtel 2016; Fang 2021). This is in contrast to mechanism 1.0, which mostly concerns fields such as cell biology and molecular biology, where mechanisms are linear and non-dynamic. I will show in the following how structuralism is a perfect fit for the metaphysics of mechanism 2.0 in systems biology and deserves serious attention from philosophers interested in this topic[17].

Levy and Bechtel (2016), in their seminal paper advancing mechanism 2.0, point out that there are many examples of mechanisms, especially from systems biology, where the components involved are not discrete entities but change continuously and have no clear boundaries. They also comment on the dualist position developed in Kaiser and Krickel, stating that they find it unclear whether the notion of biological objects can be retained in the examples they have looked at. They have also suggested 'to view Mechanism 2.0 in the context of process ontology' (p.14), though do not further elaborated on this point.

[17] Outside of mechanical explanation, I also think structuralism is a suitable ontology for dynamical explanation (e.g., Meyer 2020). Thanks to an anonymous reviewer for drawing my attention to the close link between structuralism and dynamical systems.

In light of this, Fang (2021) proposes a new concept of mechanism, arguing that mechanisms should be defined as "dynamic causal systems that involve various components interacting, typically nonlinearly, with one another to produce a phenomenon of interest" (p.796). Fang raises serval examples of mechanisms describing causal structures with no clearly identified entities, which create a very sympathetic context for structuralism. One of such examples comes from neuroscience where scientists have identified a mechanism whose dynamic character are best captured with certain quantitative tools. Moreover, the relevant mechanisms can be decomposed into several sub-mechanisms where the components are not clearly identifiable entities but rather quantities representing things like 'changes in blood flow' and 'changes in blood volume'. These are obviously not entities understood in the object-based metaphysics of mechanisms and may be more appropriately characterized as activities. Whereas an object-oriented metaphysics of mechanisms is inapplicable in this case, I argue that the metaphysics here can be well articulated through a structuralist account. Structuralism allows us to read ontology directly off the mathematical models, and hence according to which dynamic causal processes are metaphysically underpinned by structures, with entities being reconceptualized accordingly.

Let us look at another example in systems biology in more detail, which concerns active matter composed of cytoskeletal components, such as filaments and molecular motors. Active matter refers to a category of materials or systems made up of individual constituents capable of converting energy into directed motion or mechanical work, resulting in emergent properties and dynamic behaviors at larger scales (Das et al., 2020). Filaments are thread-like structures made of proteins, serving as the primary building blocks of the cytoskeleton, a dynamic and adaptable cellular structure (Fletcher and Mullins, 2010). The molecular motor refers to a specialized protein molecule that moves along filaments (Schliwa and Woehlke, 2003). The interaction of a large number of molecular motors and filaments at high density leads to the self-assembly of complex and intricate configurations, giving rise to the emergence of new properties and collective behaviors at larger time and length scales[18]. These configurations play essential roles in mechanisms related to cell motility, muscle

[18] 'Emergence' is a complex notion in philosophy. There are different understandings of emergence, such as strong emergence, weak emergence, epistemic emergence, ontic emergence, etc. My discussion here leaves these possibilities open. What matters is that on all these accounts 'emergent' properties can only be ascribed to the whole system, not its constitunts.

contraction, and cell division, among others (Needleman and Dogic, 2017; Popkin, 2016; Das et al., 2020)[19] .

Biophysicists have developed quantitative theories aiming at modeling filament-motor mixtures. One prominent theory is the active gel theory (Joanny et al., 2007; Jülicher et al., 2007; Joanny and Prost, 2009), where scientists employ a coarse-grained continuum model and treat the filament-motor mixture as a viscoelastic gel (Menon, 2010). It should be emphasized that the model does not focus on the microscopic molecular level, describing the dynamics of individual motors and filaments. Instead, it operates on larger time and length scales, modelling the emerging system as a whole and describing the system's properties using macroscopic variables.

It is important to note that the subject of the model constructed by biophysicists does not conform to the traditional notions of entities as understood by monists and dualists. Consider any mechanism that involves the filament-motor mixture, for instance, in cell crawling. (Ananthakrishnan and Ehrlicher, 2007). An object-oriented metaphysics of mechanisms is going to face difficulties in elucidating the metaphysics here. A mechanist can say there are activities going on here, but they would struggle to identify a stable object with clear boundaries. However, structuralism can accommodate this case by saying all that exists here is an active and temporally extended occurrent that is inherently causal, whose causal features are captured by the corresponding equations.

Some might still want to defend an object-oriented metaphysics here by arguing that we can find a way to decompose the system into discrete objects, namely, filaments and motors, so what is really going on here metaphysically is a story of objects and their activities[20]. Burnston (2021) has recently argued that we can decompose dynamic, complex systems with emergent behaviors and properties into discrete parts. But the price of doing so is that we must abandon an atomistic reading of parts that possess intrinsic properties, but instead, think that the properties of parts depend on the context in which they are embodied, and they acquire properties through interaction with other parts. In a similar vein, Santos (2015; 2020; 2024) has developed the so-called Dynamic Relational Ontology, according to which the identity and properties of an object in an integrated system depend on the relations it is involved in, and he also shows how his account is compatible with mechanistic explanation.

[19] See Sanchez et al (2012) for a picture of an active filament-molecular motor network viewed on a large scale (p.431).
[20] Thanks to an anonymous reviewer for pressing me to consider this objection.

My responses to this objection are twofold. Firstly, we should note that the parts of a system and the dynamic system per se are on different levels. If ontic emergence happens in this case, then the dynamic system is something that is over and above the individual parts. In that case, the metaphysical underpinning of the system is best understood as causal occurrents. Mathematical equations, instead of the language of objects, are the means we use to describe them.

Nevertheless, since I am open about whether there exists ontic emergence in this paper, we should also consider the possibility that the thesis of ontic reductionism is true, in which case the higher-level system is metaphysically reducible and identical with its lower-level parts. I argue that even in that case, Santos's ontology is more of a friend to structuralism than to object-oriented metaphysics. According to Santos's ontology, objects do not possess intrinsic properties and identity; instead, he believes that objects' properties and identity are contextually determined by relations. This is directly contradictory to what object-oriented metaphysics says. Although dualists think objects symmetrically depend on activities, they still believe that objects possess intrinsic properties and identity! Santos' understanding of objects is therefore closer to how structuralists understand objects. Though Santos (2015) explicitly claims that he does not 'subscribe to ontological structural realism in either its eliminative or moderate versions' (p.440, note 17), I think that this may be due to a misreading of OSR, as the reasons he rejects OSR are that he thinks 'no relatum exists without being related to something else, and no relation instantiates without relating some relata' (Ibid). However, as alluded above, structuralists can well agree on this point in the sense that they are not denying there are relata, but just claiming that such relate are not constituted by ontologically thick objects. In any case, if Santos and his supporters are dissatisfied with the radicalness of eliminative versions of structuralism, the moderate structuralism (Esfeld and Lam, 2011), which argues that relata and relation symmetrically depend on each other, is something for them. But I think their notion of an object is also very close to the 'thin' notion of an object that is defended by Ladyman and others, which says there are still objects but whose properties and identity are given contextually by structural relations. Thus, I think that Santos's position can potentially be accommodated within structuralism.

**Conclusion**

Due to the dominance of new mechanical philosophy within the discussions of special sciences (especially life sciences), a successful defense of minimal metaphysics of

mechanisms should significantly contribute to the shift towards minimal metaphysics in the metaphysics of science debate. I provide such a defense in this paper by reconciling the metaphysics of mechanisms with OSR and proposing a structuralist account of mechanisms. In my account, the ontological commitments for mechanisms are only confined to structures. It 'contains no assumption that does not do any work in explaining scientific practice' (Hüttemann, 2021, p.11), and should therefore be embraced by minimal metaphysicians.

In this paper, I highlight the tension between existing metaphysical accounts of mechanisms and leading metaphysical theories of physics by presenting the bottoming-out problem. This problem motivates the development of a physics-informed metaphysics of mechanisms. I further strengthen the motivation by contesting claims regarding the existence of a fundamental classical level and showing that fundamental physics is indispensable in some fields of special sciences, such as quantum biology.

In light of this, I elaborate on a structuralist account of mechanisms by arguing that the metaphysical underpinnings of mechanism are structures that should be understood as inherently causal occurrents. Entities asymmetrically depend on structures and should be reconceptualized accordingly. Additionally, I discuss the potential ways for my account to offer a metaphysics of entities or objects in mechanisms by referring to existing attempts of structuralists and suggesting a potential alignment between OSR and processual ontology. Finally, I demonstrate how my view can naturally serve as the metaphysics for Mechanism 2.0 and be applied to systems biology.

However, the questions regarding which metaphysical view of objects structuralists should adopt and how OSR and processual philosophy can be reconciled in biology still deserve further exploration. I hope this paper can serve as a starting point that paves the way for further research, ultimately leading to the development of a fully-fledged structuralist reading of biology.

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