

The Metaphysics of Constitutive Mechanistic Phenomena

Marie I. Kaiser

*Universität zu Köln, Philosophisches Seminar
Richard-Strauß-Str. 2, D-50937 Köln, kaiser.m@uni-koeln.de*

Beate Krickel

*Ruhr-University Bochum, Department of Philosophy II
Universitätsstraße 150, D-44780 Bochum, beate.krickel@rub.de*

Abstract

The central aim of this paper is to specify the ontological nature of constitutive mechanistic phenomena (i.e. of phenomena that are explained in constitutive mechanistic explanations). After identifying three criteria of adequacy that any plausible approach to constitutive mechanistic phenomena must satisfy, we present four different suggestions, found in the mechanistic literature, of what mechanistic phenomena might be. We argue that none of these suggestions meets the criteria of adequacy. According to our analysis, constitutive mechanistic phenomena are best understood as what we will call ‘object-involving occurrents’. Furthermore, on the basis of this notion, we will clarify what distinguishes constitutive mechanistic explanations from etiological ones.

- 1 *Introduction*
- 2 *Criteria of Adequacy*
 - 2.1 *Descriptive adequacy*
 - 2.2 *Constitutive-etiological distinction*
 - 2.3 *Constitution*
- 3 *The Ontological Nature of Constitutive Mechanistic Phenomena*
 - 3.1 *Phenomena as input-output relations*
 - 3.2 *Phenomena as end states*
 - 3.3 *Phenomena as dispositions*
 - 3.4 *Phenomena as behaviours*
- 4 *Phenomena as Object-Involving Occurrents*
 - 4.1 *What object-involving occurrents are and why we need them*
 - 4.2 *The object in the phenomenon*
 - 4.3 *The adequacy of option (5)*
- 5 *Conclusion*

1 Introduction

The notion of a phenomenon plays a crucial role in the debate about mechanisms and mechanistic explanation (hereafter ‘MEx’) that has become popular in the philosophy of the life sciences in the last two decades. A central claim of the so-called New Mechanists¹ is that scientific explanation consists in discovering and describing² mechanisms that are responsible for *phenomena*. There is an ongoing debate about what mechanisms are and what characterizes mechanistic explanation. Surprisingly, though, there is almost no discussion about the nature of phenomena in the context of the mechanistic approach (hereafter ‘mechanistic phenomena’). The goal of this paper is to fill this gap by providing a coherent metaphysical analysis of constitutive mechanistic phenomena.

Note that MExs (and their corresponding phenomena) are said to come in two varieties: etiological and constitutive MExs. The difference between these two types of MEx is that in etiological MExs mechanisms are said to *cause* phenomena, whereas constitutive MEx is grounded in a non-causal relation called (*mechanistic*) *constitution*³, which is supposed to hold between the mechanism and the phenomenon. Even though the New Mechanists also discuss etiological MExs,⁴ in this paper we will focus on *constitutive* MEx for the following two reasons: first, constitutive MExs are central to the New Mechanistic approach. There is a vast literature discussing various phenomena that are explained by constitutive MExs (i.e. by MExs that explicitly refer to relations of constitution) such as the human heart pumping blood (Bechtel and Abrahamsen [2005], pp. 425; Bechtel [2006], pp. 29–30; Glennan [2010], pp. 257; Craver and Darden [2013], 98–117), a cell synthesizing proteins (Machamer et al. [2000], pp. 18–21; Darden [2002], pp. 357; Craver and Darden [2013], pp. 31–4, 164–7), long-term potentiation at synapses of neurons (Machamer et al. [2000], pp. 8–11; Craver and

¹ Our paper focuses on Peter Machamer’s, Lindley Darden’s, and Carl F. Craver’s (hereinafter ‘MDC’) position. Stuart Glennan’s view about the metaphysics of mechanisms differs from MDC’s view in some important respects: at least in his earlier publications, Glennan criticizes MDC’s dualistic thesis that mechanisms consist of entities and activities and defends a monistic view about the ontological nature components of mechanisms ([2002]). Furthermore, Glennan seems to take bare objects like clocks or cars as mechanisms, even if they are not involved in a process (such as ticking or driving, [1996]).

² Defenders of the ontic view about scientific explanation (e.g. Craver [2014]) argue that MExs do not *refer to* mechanisms and are not *representations* of mechanisms, but that mechanisms themselves (which exist in the world) *do* the explaining and *are* the explanantia of MExs. Even though our account of constitutive mechanistic phenomena is compatible with both views, we stick to the received, more common view that explanations are representations, rather than things in the world itself.

³ The New Mechanists borrow the term ‘constitution’ from Wesley Salmon ([1984]). It must not be confused with the term as it is used in metaphysical debates (e.g. Baker [1997]). During the last years the notion of mechanistic constitution has gained increasing attention (e.g. Harbecke [2010]; Leuridan [2012]; Gillett [2013]; Baumgartner and Gebharder [2015]). But so far no approach has been developed that has found common acceptance.

⁴ Among the examples of etiological MExs discussed are explanations of adaptive evolutionary outcomes (Skipper and Milstein [2005]; Barros [2008]; Glennan [2009]), of the fall of the Roman Empire (Glennan [2010], p. 259), and of developmental results such as the formation of a gamete (Glennan [2002], p. 349).

Darden [2001], pp. 115–7; [2013], pp. 167–72; Craver [2007], pp. 65–72), spatial memory of humans (Craver [2007], pp. 165–70; Bechtel [2008], pp. 49–88; Bechtel and Richardson [2010], pp. 134–44), and cellular respiration (Bechtel [2006], pp. 36–7; Bechtel and Richardson [2010], pp. 51–9, 72–88).⁵ Constitutive MEx are at least as important to the New Mechanists as etiological MEx. Second, contrary to etiological mechanistic phenomena, the nature of constitutive mechanistic phenomena is far less understood. Etiological MExs are grounded in a causal relation between the mechanism and its phenomenon. Hence, etiological mechanistic phenomena are whatever the relata of causation are taken to be (e.g. events). Causation, events and related topics have long been the subjects of intensive discussions in metaphysics and in philosophy of science. In contrast, the notions of mechanistic constitution and of constitutive MEx have gained little philosophical attention to date.

So far, no explicit account of constitutive mechanistic phenomena has been provided. We think that such an account is essential to the mechanistic approach because the most central assumptions about constitutive MExs and constitutive mechanisms cannot be understood as long as one does not know what constitutive mechanistic phenomena are exactly. To see this, consider how three major claims of the New Mechanists hinge on the notion of a constitutive mechanistic phenomenon (note that the first claim applies also to etiological mechanistic phenomena):

1. Phenomena are the things that are *explained* by describing mechanisms.
2. Phenomena are the things that are *constituted* by mechanisms.
3. Phenomena are *individuating* for the mechanisms that constitute them.

The first claim states that phenomena are the things that are the objects of (constitutive) MExs; they are the things that are *explained* by describing the mechanisms that constitute them. Obviously, in order to understand what exactly MExs are, we also need to understand what the two parts of an explanation—the explanandum and the explanans—refer to. The explanans of a MEx (i.e. what does the explaining) is said to refer to a mechanism; the explanandum (i.e. what is to be explained) is supposed to refer to the phenomenon that is constituted (or caused) by the mechanism. Hence, we need to understand what mechanistic phenomena are in order to fully understand constitutive MExs. The second point has already

⁵ Other examples of constitutive MExs include the explanation of how cells convert light energy into chemical energy (i.e. photosynthesis; Tabery [2004]), of Mendel’s law of independent segregation (Glennan [2002], pp. 346–7; Craver and Darden [2013], pp. 149–51), of the action potential (Craver [2007], pp. 114–21; Craver and Darden [2013], pp. 43–50), and of HIV replication in host cells (Steel [2008], pp. 55–8).

been introduced: in the case of constitutive MExs, phenomena are supposed to be *constituted* by mechanisms. To understand this constitution claim we need to know *what it is* that is taken to be constituted by a mechanism. A third major claim of the New Mechanists is that mechanisms are *individuated* via the phenomena they explain (e.g. Glennan [2002], p. 344).⁶ Roughly, a mechanism is held to consist of only those entities and activities that are *constitutively relevant* to the phenomenon the mechanism is supposed to explain (Craver [2007], pp. 139–60). The way in which the phenomenon is characterized thus determines the individuation of the mechanism, that is, it determines which entities and activities belong to the mechanism, and which do not (Craver and Darden [2001]). This implies that if we do not know what phenomena are, we cannot identify the components of mechanisms.

Given this importance of the notion of a phenomenon to the mechanistic approach, it is surprising that no account of mechanistic phenomena has been provided yet. Carl F. Craver refers to phenomena as ‘S’s ψ -ing’ ([2007], pp. 7, 121, 140), where ‘S’ is supposed to refer to a system, but it remains unclear what a system is and which system is meant. Many authors characterize the phenomenon to be explained in constitutive MExs as the ‘behaviour of the mechanism as a whole’ (Craver [2007], pp. 6, 161; Bechtel [2011], pp. 540; Leuridan [2012], pp. 401) but, as we will show in Section 3, this idea is inconsistent. In other passages Craver states that the phenomenon can be understood in terms of a ‘complex input-output relationship’ ([2007], p. 145) which seems to be incompatible with his idea that phenomena are ‘acting entities’ ([2007], p. 188). Besides these scattered claims no coherent account of constitutive mechanistic phenomena has been provided. The goal of this paper is to fill this gap. More specifically, our aim is to clarify what the phenomena of constitutive MExs are, how they are related to the mechanism and its components, and how they differ from phenomena that are explained by etiological MExs.

Our paper proceeds as follows: in Section 2, we introduce three criteria that any adequate approach to constitutive mechanistic phenomena must meet. In Section 3, we critically discuss four different suggestions of how the ontological nature of constitutive mechanistic phenomena could be spelled out that can be identified in the mechanistic literature. We reject the ideas that constitutive mechanistic phenomena are input-output relations (Section 3.1), end states (Section 3.2), dispositions (Section 3.3), or bare behaviours (Section 3.4). In Section 4, we develop an alternative account of constitutive mechanistic phenomena, according to which phenomena are concrete particulars that consist of a combination of an object (or system) and a behaviour, activity, process, event, or state (we will use the term

⁶ This claim has come to be known as ‘Glennan’s law’ (Illari and Williamson [2012], pp. 133).

‘occurrent’ to summarize these kinds of entities) in which the object is involved (Section 4.1). We elaborate on what the objects are that are involved in constitutive mechanistic phenomena (Section 4.2), and we conclude with confirming the adequacy of our account (Section 4.3).

2 Criteria of Adequacy

In this section we identify three criteria of adequacy that a plausible metaphysics of constitutive mechanistic phenomena must satisfy. Providing these criteria is necessary because a problem arises when trying to specify what constitutive mechanistic phenomena are. Recall the three claims of the New Mechanists that we introduced in the introduction: constitutive mechanistic phenomena are the objects of explanation, they are constituted by mechanisms, and they are individuated for mechanisms. The problem is that, so to speak, we have free variables at both sides of these equations: not only does the concept of a mechanistic phenomenon remain unclear, but many notions on the right hand side are also in need of specification. It is not clear what distinguishes etiological from constitutive MExs nor what mechanistic constitution is supposed to be. Moreover, the notion of constitutive relevance that is central to the individuation of mechanisms is afflicted with problems. This raises the worry that the development of a metaphysics of constitutive mechanistic phenomena is rather arbitrary: one could just postulate what constitutive mechanistic phenomena are and specify the remaining concepts (of constitution, of constitutive relevance, and of etiological vs. constitutive MEx) respectively. In order to avoid this objection, we will introduce three criteria that constrain the adequacy of a metaphysical account of constitutive mechanistic phenomena: (C1) *descriptive adequacy*, (C2) *constitutive-etiological difference*, and (C3) *constitution*.

2.1 Descriptive adequacy

The first criterion (C1) is inferred from a methodological (or *metametaphysical*) claim about the goals and criteria of adequacy that the New Mechanists accept. All proponents of the mechanistic approach agree that they seek to develop a philosophical account that provides an understanding of how science *actually* works, in particular of why it is successful (and why it sometimes fails). For instance, Craver’s theory of constitutive relevance is supposed to account for the different strategies (‘interlevel experiments’) that neuroscientists successfully use to identify components of mechanisms and to determine their boundaries ([2007], pp. 144–52). Likewise, the New Mechanists hold that a plausible philosophical analysis of the concept ‘mechanism’ must account for examples of mechanisms and MExs that are

considered paradigmatic and important to a certain scientific field, for example, because these mechanisms play a crucial role with regard to a specific scientific aim, such as the manipulation of the brain (Craver [2007]). This methodological stance might be characterized as being ‘naturalistic’ (Bechtel [2008]). Another way to put it is to say that the New Mechanists accept the criterion of ‘descriptive adequacy’ (Machamer et al. [2000], p. 8). This criterion states that a philosophical theory about science is adequate only if it correctly ‘describes’ actual scientific practice or the ontological commitments of for instance scientific explanations (see Kaiser [unpublished (b)]).

We think that this methodological stance also can be applied to metaphysical projects like ours. In other words, we associate our project of clarifying the metaphysics of constitutive mechanistic phenomena with the recent tradition of naturalized, scientific, or descriptive metaphysics (e.g. Ross et al. [2007]; Maudlin [2007], Callender [2011]).⁷ A naturalistic metaphysician states that scientific practice or scientific knowledge (e.g. our best scientific theories and explanations) is crucial to how we should think about the world.⁸ For our case, this implies that any plausible metaphysics of constitutive mechanistic phenomena must account for how phenomena are in fact characterized in constitutive mechanistic explanations, models, theories, and investigative practices of the life sciences. In other words, a metaphysical thesis about what constitutive mechanistic phenomena are is descriptively adequate only if it captures paradigmatic and important examples of phenomena that are successfully constitutively-mechanistically explained and investigated in scientific practice.⁹ The examples of constitutive mechanistic phenomena that we consider in this paper are those that we take to be paradigmatic and important to the life sciences (e.g. because they are instances of successful science).¹⁰ Among them are the contraction of a muscle fibre, the generation and transmission of an action potential, phototropism (i.e. plants growing in the direction of light), a rat showing spatial memory, the replication of DNA during cell division, and the coexistence of two species in an ecosystem. Since the New Mechanists also accept the methodological principle of descriptive adequacy and discuss primarily examples that *are*

⁷ Except for that we do not share the widespread reductionist view that only the physical sciences or only scientific theories are an adequate source of metaphysical claims.

⁸ For instance, Maudlin claims that ‘when choosing the fundamental posits of one’s ontology, one must look to scientific practice rather than to philosophical prejudice.’ ([2007], p. 1) and Callender argues that ‘[l]aying bare the metaphysical assumptions of our best [scientific] theories of the world is a crucial and important part of understanding the world.’ ([2011], p. 3).

⁹ Hence, we assume that, for instance, scientific explanations give rise to important metaphysical insights (e.g. into what constitutive mechanistic phenomena are). This, however, does not imply that epistemological relations (as explanatory relations) are confused with ontological ones (as relations of mechanistic constitution).

¹⁰ What it means to identify paradigmatic and important examples is specified in Kaiser ([unpublished (b)]).

paradigmatic and important to the life sciences we analyze several examples that are also covered by the mechanistic literature.

2.2 Constitutive-etiological distinction

The second criterion of adequacy (C2) relies on the claim that there exist two different kinds of MExs: constitutive and etiological ones (e.g. Craver [2007], p. 74).¹¹ In *constitutive* MExs a phenomenon is explained by a mechanism that *constitutes* the phenomenon. This is often expressed by the phrase that a phenomenon is explained by its ‘underlying mechanism’ (e.g. Machamer et al. [2000], p. 16; Bechtel [2005]; Craver [2007], p. 140) and the constitutive relations described in constitutive MExs are said to give rise to different levels of organization (Craver [2007], pp. 163–95). We will say more about what constitution in this context means in the next section. The explanation of spatial memory is a much discussed example of a constitutive MEx: the relation between the phenomenon and the underlying mechanism in this case is depicted for instance as the relation between a rat navigating through the Morris Water Maze and the rat’s hippocampus generating spatial maps (Craver [2007], pp. 165–70; see also Bechtel [2008], pp. 49–88; Bechtel and Richardson [2010], pp. 134–44).

In *etiological MExs*, in contrast, phenomena are explained by their preceding causes. A standard neuroscientific example of an etiological MEx is the explanation of neurotransmitter release (Craver [2007], pp. 22–8). Here, an event (the release of neurotransmitters into the synaptic cleft) is explained by its previous causes (Ca^{2+} -channels opening, influx of Ca^{2+} , the creation of a pore, and so on).

The crucial difference between constitutive and etiological MExs seems to be that in the former case the mechanism and the phenomenon are related by a *constitution relation*, which is supposed to be a non-causal relation, whereas in the case of etiological MExs the mechanism as a whole *causes* the phenomenon. An approach to mechanistic phenomena should not blur the distinction between these two types of MEx, but rather be compatible with it and provide the grounds for making sense of it.

One might object that a MEx can be etiological as well as constitutive. There are three possible interpretations of this claim: First, one might hold that a MEx is strictly speaking both. This amounts to a logical contradiction. Causation requires cause and effect to occur at different times, whereas constitution requires the constituent and the constituted entity to

¹¹ The New Mechanists borrow the distinction between etiological and constitutive mechanisms from Wesley Salmon ([1984]). According to Salmon, constitutive mechanisms ‘account for a given phenomenon by providing a causal analysis of the phenomenon itself’, while an etiological explanation ‘tells the causal story leading up to its occurrence’ ([1984], p. 297).

occur at the same time. Second, one might hold that one and the same going-on in the world can be explained by providing an etiological MEx and by providing a constitutive MEx. For instance, one can etiologically explain protein synthesis by describing how a certain sequence of causes leads to the synthesis of a protein, or one can constitutively explain protein synthesis by referring to the components of a cell and describing how they act and interact such that the cell synthesizes proteins. On a closer inspection, however, it turns out that what we are explaining is not the same phenomenon, but two different phenomena: the etiological MEx explains the end-result (there being a protein) and the constitutive MEx explains the process of protein synthesis (we want to know what happens at every step of protein synthesis). Third, one might hold that some MExs have etiological as well as constitutive aspects. For example, mechanisms that constitute phenomena are usually triggered by some input that can be described as a cause of the mechanism. In some contexts, this input might be considered as a part of the explanation of the phenomenon (e.g. in the case of a neuronal signal triggering the mechanism of muscle contraction). One might hold that while the mechanism constitutes the phenomenon (and thus makes up the constitutive part of the explanation) the input causes the phenomenon (and thus makes up the etiological part of the explanation). We agree that this might be an accurate description of some MExs. Still, from a metaphysical point of view the two different aspects can be clearly distinguished.

2.3 Constitution

As we have pointed out, in constitutive MExs mechanisms are supposed to *constitute* phenomena. In a nutshell, our third criterion of adequacy (C3) states that constitutive mechanistic phenomena have to be such that they can plausibly be constituted by mechanisms. Since this criterion requires knowing what constitution is, we will begin with an explication of this notion.

The first thing to note is that the term ‘constitution’ (or ‘constitutive’, as in ‘constitutive MExs’) is a technical term invented by the New Mechanists that is not necessarily connected to the term ‘constitution’ as it is used in metaphysics (Craver [2007], pp. 108, fn. 1). Second, it is not entirely clear what the New Mechanists take constitution to be. Here, we will assume a rather weak and, as we think, uncontroversial notion of constitution that is based on (but not identical to) Craver’s notion of *constitutive relevance* (Craver [2007], pp. 139–60):¹²

¹² Other, more substantial accounts of mechanistic constitution are Harbecke ([2010]) and Gillett ([2013]).

(*Constitution*) The collection of those entities and activities that are constitutively relevant to a phenomenon P make up the constitutive mechanism M for P . In this case, the M is said to *constitute* P .¹³

According to Craver, constitutive relevance is a binary relation between a mechanism's component, which is characterized as an 'acting entity', that is, as ' X 's ϕ -ing' ([2007], p. 145; more on this claim below), and a certain phenomenon, which is referred to as ' S 's ψ -ing'.¹⁴ Craver identifies two conditions that must be satisfied for an acting entity (X 's ϕ -ing) to be constitutively relevant to a certain phenomenon (S 's ψ -ing):

- (1) *Parthood condition*: X must be a *part of* S , and
- (2) *Mutual manipulability condition*: X 's ϕ -ing and S 's ψ -ing must be *mutually manipulable*.

Craver's characterization of constitutive relevance has recently been subject to criticism (see Leuridan [2012], Baumgartner and Gebharder [2015]). These criticisms mainly focus on the *mutual manipulability condition*. Since this condition is not central for our line of reasoning, we will not discuss these objections here. A further problem of Craver's account is that it is not clear what exactly ' S ' refers to (we will elaborate on this problem in Sections 3.5 and 4.2). A third problem is that Craver leaves open how the parthood relation should be spelled out in this context (see Leuridan [2012]). It is not clear whether the *parthood condition* requires only spatial parthood (between entities, i.e. objects) or temporal parthood as well (between activities, i.e. occurrences). Craver seems to have both in mind (at one point he adds in brackets that temporal inclusion is also required; [2007], p. 153) but he never explicitly states that. We will argue that *spatial* parthood is not always required for something to be a component in a constitutive mechanism (see Sections 4.2 and 4.3). Furthermore, there are good reasons to assume that the parthood condition also has to require temporal parthood between the ϕ -ings and the ψ -ing. To see this, we need to have a closer look at what mechanisms are.

¹³ Note that constitutive relevance is only a *necessary* condition for constitution. Plausibly, the notion of constitution also implies that the mechanism (given a certain context) is *sufficient* for the phenomenon. Furthermore, we agree that constitution understood in this way is as problematic as Craver's approach to constitutive relevance. But we show that these problems either can be solved or do not influence the validity of our line of argument.

¹⁴ In contrast, constitution is a binary relation between the mechanism as a whole M (not one singular component) and the phenomenon P (i.e. S 's ψ -ing).

There are various characterizations of mechanisms on the market. The following characterization summarizes the central ideas that are important for our purposes: ‘a mechanism for a phenomenon consists of entities and activities organized in such a way that they are responsible¹⁵ for the phenomenon’ (Illari and Williamson [2012], p. 120). This characterization highlights one important feature of mechanisms: they are said to be composed of *entities* and *activities*.¹⁶ This claim is often called ‘entity-activity dualism’ (see Machamer et al. [2000]; Machamer [2004]; Bogen [2008]; Illari and Williamson [2013]; for a different view see Glennan [1996], [2002]; for critical views see Tabery [2004]; Psillos [2004]; Campaner [2006]; Torres [2008]). The basic idea of this dualistic thesis is that mechanisms consist of components that belong to two distinct ontological categories: entities (which are conceived as material objects that have certain, relatively stable properties) and activities (which are the things that objects do or are engaged in).

We think that there are good reasons to characterize the components of mechanisms not in terms of entities and activities, but in terms of *objects* and *occurrents*. First, in metaphysical debates the term ‘entity’ is used as an umbrella term for everything that exists (according to a certain ontology). Hence, ‘entity’ might refer to properties, processes, relations, events, and so on, not only to material objects, as the New Mechanists understand this term. Instead of ‘entity’ we will thus use the term ‘object’ (or sometimes ‘component object’) to avoid misunderstandings.

Second, we see two major problems for the notion of an activity: on the one hand, activities are conceived of as irreducible and fundamental things that involve an unanalyzable kind of ‘activeness’ and ‘productiveness’ (see Machamer [2004]; Bogen [2008]; for a critic see Psillos [2004]; Krickel [unpublished]). We want our approach to be neutral with regard to the question of whether there exist irreducible activities in this problematic sense. On the other hand, the category of activities is unnecessarily narrow. It excludes, for example, states of objects such as the voltage-gated sodium channel being open. Furthermore, it excludes passive behaviours such as the release of calcium ions from the endoplasmic reticulum into the cytosol from being components of mechanisms. All we need for the purpose of the present paper is the claim that mechanisms are composed of objects and of the states, events, or

¹⁵ We think that the term ‘is responsible for’ is too vague and metaphorical. It should be replaced by the more precise terms ‘constitutes’ (for constitutive mechanisms) and ‘causes’ (for etiological mechanisms).

¹⁶ We are aware of the fact that other possible features of mechanisms, such as their start- and end-conditions and their regularity (for objections see Illari and Williamson [2012]; Bogen [2005]; Andersen [2012]; Craver and Kaiser [2013]; Krickel [unpublished]), may also be relevant in this context. For example, if it turns out that mechanisms are necessarily regular, then mechanistic phenomena are also necessarily regular. And if mechanisms have start and end conditions phenomena also have start and end conditions. The approach we will develop in Section 4 can easily be extended such that it captures these further features.

processes in which these objects are (engaged). Activities are plausibly characterized as special kinds of processes (e.g. as causal processes that involve changes and an object that is ‘active’—whatever that exactly means). We will thus speak of mechanisms as constituted by *occurents*, rather than by *activities* (or ‘operations’, Bechtel [2006], [2008]) because we do not want our account of mechanistic phenomena to be committed to the problematic notion of an activity. We chose the term ‘occurents’ because in metaphysics states, events, and processes are generally subsumed under this label. Examples of occurents are football matches, muscle contraction, diffusion, and the like. We have to make one restriction with regard to the claim that mechanisms consist of objects and *occurents*: Machamer et al. introduced the notion of an activity primarily to account for the fact that ‘mechanisms do things’, that ‘[t]hey are active’ ([2000], p. 5). Whatever is meant by these quotes, the idea that ‘mechanisms do things’ seems to exclude that mechanisms are composed of states that merely consist in the *instantiations of dispositions* (rather than in their manifestations). Hence, our claim that mechanisms consist of occurents is restricted to events, processes and states that do not merely consist in the having or instantiation of dispositions (we will call them *non-dispositional occurents*). Occurents are usually contrasted with the category of *continuants*. Continuants are objects like tables, stones, cells, muscle fibres, and the like. It is not easy to specify the difference between occurents and continuants. Intuitively, they differ in how they are spread out in time (see Simons [1991]): while continuants *exist* in time, that is, for a certain duration, occurents *occur* during a certain time interval. Occurents are *temporally extended* and have *temporal parts* in a way that continuants do not.¹⁷ To sum up, we will assume that the ‘entity-activity dualism’ defended by the New Mechanists is better expressed in terms of objects (i.e. continuants) and occurents (see Krickel [unpublished] for more detailed arguments).

Now, let us come back to Craver’s characterization of constitutive relevance and his parthood condition. Since constitutive mechanisms are composed of objects that are engaged in occurents and are thus not only extended in space but also in time, it is plausible to assume that constitutive relevance requires not only spatial parthood¹⁸ (between the component objects, the *Xs*, and the *S* in the phenomenon) but also *temporal parthood*: an occurent (ϕ -ing) is a component of the mechanism for a certain phenomenon (*S*’s ψ -ing) only if it *occurs*

¹⁷ In some sense continuants are also temporally extended: since continuants necessarily exist in time and space, they have to exist for a certain time interval (it makes no sense to hold that they exist only at time points). Another attempt to characterize the difference between continuants and occurents is to claim that the former are wholly present at each moment they exist, whereas the latter are spread out in time and thus are wholly present only given a certain time span (see Lewis [1986]; Simons [1991]; Smith [2012]).

¹⁸ Note that in Sections 4.2 and 4.3 we criticize the spatial parthood condition and argue that it should not be interpreted as a necessary condition.

during the phenomenon's occurrence (the ψ -ing), that is, only if the ϕ -ings are temporal parts of the ψ -ing. If we took the parthood condition to involve only spatial parthood between mechanistic component objects and phenomena objects this would have odd consequences given that mechanisms are also composed of occurrents. For example, a particular occurrence of an ion-channel opening at t_i can only be a component of the mechanism for a particular occurrence of the action potential that occurs during a time interval including t_i . It cannot be constitutively relevant for an action potential that occurs, for instance, two days later than t_i . Hence, Craver's parthood condition should be modified:

(1*) *Parthood condition*: X must be a spatial part of S , and ϕ -ing must occur during ψ -ing.

One consequence of this modified notion of constitutive relevance that is particularly relevant to our analysis is the following. Because constitutive relevance plausibly requires mechanistic components to occur *at the same place and time as the phenomenon*, phenomena must be entities that have spatial *and* temporal parts and that are spatially *and* temporally extended.

In sum, we take three criteria of adequacy to be crucial for any plausible metaphysical approach to constitutive mechanistic phenomena:

- (C1) *Descriptive adequacy*: An approach to constitutive mechanistic phenomena must account for how they are characterized in the explanatory and investigative practices of the life sciences.
- (C2) *Constitutive-etiological difference*: An approach to constitutive mechanistic phenomena must be consistent with and make sense of the difference between etiological and constitutive MEx.
- (C3) *Constitution*: Constitutive mechanistic phenomena must be such that they can plausibly be constituted by mechanisms. This requires that phenomena must have spatial and temporal parts, that is, that they must be spatially and temporally extended.

In the next two sections we will put these three criteria to work. Our analysis will show that each of them provides important constraints on what is a plausible metaphysics of constitutive mechanistic phenomena.

3 The Ontological Nature of Constitutive Mechanistic Phenomena

In this section we identify and discuss four different ways of spelling out the ontological nature of constitutive mechanistic phenomena. Each of these four options is implicitly or explicitly suggested by different authors working on mechanisms and MExs. We will argue that none of these suggestions meet all criteria of adequacy developed in the previous section.

Here is an overview of the four possible interpretations of the ontological nature of phenomena we are going to reject, plus our own suggestion (option 5):

- | | |
|--|---|
| 1. <i>Input-output</i> | The phenomenon is a complex input-output relationship.
(Cummins [1983]; Craver [2007]) |
| 2. <i>End state</i> | The phenomenon is the end state of a mechanism.
(Craver and Bechtel [2007]) |
| 3. <i>Disposition</i> | The phenomenon is a dispositional property/capacity.
(Cummins [1983]; Ylikoski [2013]) |
| 4. <i>Behaviour</i> | The phenomenon is a behaviour. (Glennan [2002];
Craver [2007]) |
| 5. <i>Object-involving
occurrent (OIO)</i> | The phenomenon is an object (<i>S</i>) engaged in an
occurrent (ψ -ing). |

3.1 Phenomena as input-output relations

The first option is that phenomena explained by constitutive MExs are input-output relations. Following Robert Cummins ([1983]), Craver often characterizes constitutive mechanistic phenomena in this way (e.g. [2007], pp. 145, 214; see also Glennan [2002], p. 347, [2005], p. 445). That they refer to *constitutive* mechanistic phenomena (and not to etiological ones or to both) is indicated, for example, by the fact that when Craver talks about interlevel-experiments (which are methods for intervening into constitutive mechanisms) he assumes that ‘*S*’s ψ -ing can be understood as a complex input–output relationship’ (Craver [2007], p. 145).

The suggestion that constitutive mechanistic phenomena are input-output relations can be interpreted in at least two ways: first, a phenomenon might be the input-event plus the output-

event. According to this interpretation, the process between the input and the output does not belong to the phenomenon. Rather, this process is the mechanism itself (or the mechanism's working, referred to as '*S*'s ψ -ing'). Figure 1 illustrates this suggestion (in this and in the following figures the grey areas symbolize the phenomenon, the dashed line the mechanism):

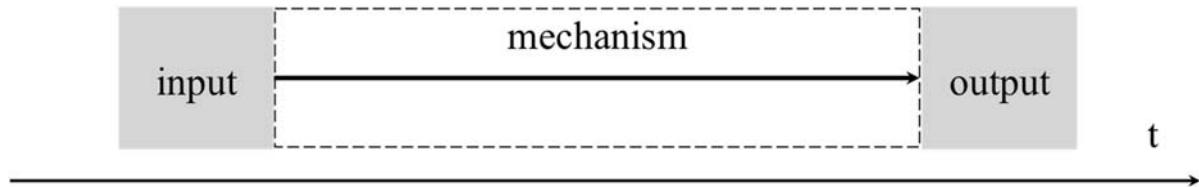


Fig. 1: Option (1a) Phenomena as inputs plus outputs of mechanisms.

This interpretation is suggested by claims such as '[b]etween these inputs and outputs is a mechanism' (Craver [2007], p. 146).¹⁹ According to this option, explaining a mechanistic phenomenon amounts to giving a description of the causal steps that lead from the input to the output (i.e. that connect the first, earlier part of the phenomenon with the second, later part). Some examples of the explananda of constitutive MEXs might be characterized in that way. For instance, one might say that MEXs explain the fact that a muscle fibre is not contracted at t_1 , but contracted at a later time t_5 , or the fact that there exists one DNA double strand at t_1 , but two of them at a later time t_5 .

One problem with this suggestion is that if phenomena were just input-events or input-processes plus output-events or output-processes, the difference between etiological and constitutive mechanisms and MEXs would vanish. Recall that etiological mechanisms are the causes of their phenomena which take place earlier than the phenomena they produce. According to the first reading of option (1), constitutive mechanisms are also just causes of (the latter part) of a phenomenon. In other words, this interpretation blurs the difference between etiological and constitutive MEXs since it implies that both etiological *and* constitutive mechanisms occur at different times than the phenomena, and that in both cases the grounding relation would be causation. Hence, the first reading of option (1) violates (C2).

A second objection is that constitutive MEXs understood in this way do not represent a constitution relation at all. Because the constitutive mechanism takes place temporally between the two parts of the phenomenon (i.e. the input-event and the output-event) the mechanism and its components cannot be said to be temporally included in the phenomenon. However, as we have argued in the previous section, temporal parthood seems to be a

¹⁹ It should be emphasized that only few passages in Craver ([2007]) support this reading and that claims can also be found that explicitly suggest the opposite.

requirement for constitution (in addition to spatial parthood). This suggestion thus violates (C3): if phenomena are the inputs plus the outputs of mechanisms, they are *not* such that they can plausibly be constituted by mechanisms.

A final problem is that the first reading of option (1) does not satisfy (C1). That is, it does not correspond to how scientists in fact characterize the phenomena for which they provide constitutive MExs. According to this reading, phenomena consist of two events or processes, where one is a cause of a mechanism and the latter is an effect of that mechanism. But the action potential, for example, is not modelled as the process that leads to the opening of the ion-channels near the axon hillock *plus* the process that is caused by the release of neurotransmitter into the synaptic cleft. Rather, neuroscientists characterize the action potential as what happens *between* these two processes, for example as a certain voltage pattern along a neuron’s axon.

There is a second interpretation of option (1). On this second reading, depicted in Figure 2, the claim that phenomena are input-output relations is supposed to be a claim about how phenomena are *individuated*: a phenomenon P is whatever satisfies a particular causal profile described by a certain input-output relation.

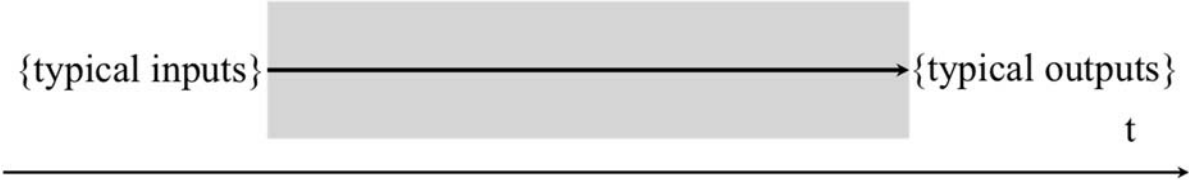


Fig. 2: Option (1b) Phenomena as things individuated by causal roles.

This interpretation is compatible with many different assumptions about what kinds of things constitutive mechanistic phenomena are, whether they are material objects, categorical properties, dispositions or capacities, manifestations of dispositions or capacities, processes, events, and so on. Everything in our metaphysical repertoire that can be individuated by a causal profile is a possible candidate for being a phenomenon. Consider for instance the mechanism of muscle contraction. According to the second reading of option (1), the phenomenon-to-be-explained in this case might, for example, be the capacity of a muscle fibre to contract if a neuronal signal arrives. The phenomenon in question, the capacity, is individuated by the stimulus conditions—the incoming neuronal signal (the input)—and the manifestation result—the contracted muscle fibre (the output). Alternatively, the explanandum phenomenon in this case might be characterized as the process of contraction, which is individuated by its causal profile, for example by the causes that lead to the process

of contraction (i.e. an incoming neuronal signal) and by the effects of the contraction process. Due to the fact that the second reading of option (1) does not specify whether phenomena are capacities, objects, processes, and so on it provides no basis for evaluating criteria (C2) and (C3). It thus fails to provide a complete account of constitutive mechanistic phenomena.

With regard to criterion (C1) the second reading of option (1) is also problematic. The reason is that this way of individuating constitutive mechanistic phenomena is too simplified and neglects the fact that many phenomena that are studied in the life sciences are what Craver calls ‘multifaceted’ ([2007], p. 125; see also Craver and Darden [2013], pp. 56-60). Craver argues that in order to fully characterize a phenomenon one must also know its precipitating and inhibiting conditions (i.e. the conditions under which the phenomenon occurs and fails to occur), its different manifestations (i.e. different instances of the same phenomenon), and its modulation conditions (i.e. the conditions that change certain features of the phenomenon). In order to individuate a phenomenon it is thus not sufficient to merely state its typical causes and effects. Rather, one also has to state in which way the instances of a phenomenon differ under different circumstances and different sets of inputs and outputs. Take for example the action potential. This phenomenon is only partially characterized by mentioning its inputs (e.g. stimulating the neuron) and outputs (e.g. activating neighbouring cells). Instead, the action potential essentially consists in a certain pattern of electrical current along the axon that can be divided into different phases and that can peak at different values. But these features of the action potential cannot be accounted for by just mentioning the typical inputs and outputs. An input-output description is underdetermined with regard to what happens between the occurrence of the input and the output. For example, it is at least possible that there is a typical action potential input followed by a typical action potential output without the typical pattern of electrical current occurring. Furthermore, especially when it comes to explanation, the input-output characterization of phenomena is insufficient: scientists do not merely want to know how stimulating a neuron activates its neighbouring neuron. They also want to explain the pattern of electrical current along the neuron’s axon that occurs when the neuron gets stimulated. An explanation of the action potential is complete only if it explains how this pattern is produced. Hence, the second reading of option (1) also violates criterion (C1).

3.2 Phenomena as end states

Option (2) states that constitutive mechanistic phenomena are end states of mechanisms. The claim is, for example, that the mechanism for cell division explains how the state of there

being two cells is brought about; that the mechanism for muscle contraction explains how a the state of the muscle fibre being contracted is reached; or that the mechanism for species coexistence explains how the state of two species coexisting in a certain geographic area came to happen. Another example, taken from the mechanistic literature, is the constitutive MEx of how a heart attack causes the death of a general (Craver and Bechtel [2007]). Craver's and Bechtel's idea seems to be that 'the state of death' ([2007], p. 557) of the general is explained by how a variety of physiological mechanisms cease to function. Their discussion reveals that this is a clear case of a *constitutive* MEx: they speak about parts and wholes (namely about the heart muscle being a part of the general) and argue that the 'non-functioning [of certain physiological mechanisms] *constitutes* the general's death' (Craver and Bechtel [2007], p. 557, our emphasis).

The idea that constitutive mechanistic phenomena are end states of mechanisms can be interpreted in two ways: first, one might think that the end state of a mechanism is itself a component of the mechanism. Second, end states of mechanisms might be the results of mechanisms that obtain after the mechanism has occurred. In what follows we argue that both suggestions are inconsistent.

Let us begin with the first interpretation of option (2). Consider the mechanism for cell division. The end state of this mechanism is the state of there being two cells. According to the first interpretation of option (2), this end state of there being two cells is a component of the mechanism. Now, does it make sense to say that the state of there being two cells is a constitutive mechanistic phenomenon given that it is a component of the mechanism? There are at least two reasons to reject this idea: first, what characterizes a state from a metaphysical point of view is that it involves no changes. Furthermore, states have no definitive ending (i.e. states do not end unless an intervening event occurs). For example, the state of there being two cells, the state of the muscle fibre being contracted, the state of two species coexisting, and the state of the general being dead exist principally infinitely (unless something happens that causes their ending).²⁰ As a consequence, if one takes phenomena to be end states of mechanisms which are themselves parts of the mechanism, one is committed to the claims that the mechanism for cell division lasts as long as the there are two cells, that the mechanism that leads to the death of the general lasts as long as the death of the general, and

²⁰ Of course, as a matter of fact, most states have a start and an end. However, these start and end points are irrelevant to the identity of a state. Events differ from states in this respect. The event of the general's dying occurs at a definitive time and has a clear ending—it ends when the general is dead. The event of the muscle fiber's contracting ends when the muscle fiber is contracted.

that the mechanisms for muscle contraction lasts as long as the muscle is contracted. This is an odd consequence.

A further problem of this first interpretation of option (2) is that it is not descriptively adequate (and thus violates (C1)). Granted that the phenomenon to be explained is a certain state (e.g. there being two cells, the muscle being contracted, the general being dead), the objects involved in these states are not components of the mechanisms that explain these states. Rather, they are higher-level objects or wholes. What is to be explained is, for instance, the being contracted of the muscle fibre, not the states certain components of the mechanism for muscle fibre contraction are in (such as the overlapping of the actin and myosin filaments). It is thus odd to speak about the phenomenon as the end state *of the mechanism* (which is a collection of component objects and occurrents; recall Section 2.3). Rather, if at all, constitutive mechanistic phenomena are states of certain higher-level objects that are brought about by the mechanism in some way (it remains to be clarified how these objects might be related to the mechanisms, see Section 4.2).

In contrast to this first interpretation, the second interpretation of option (2) seems to be a more plausible description of constitutive mechanistic phenomena. According to this reading, end states of mechanisms are *results* of mechanisms that occur *after* the mechanism's occurrence. The mechanism for cell division, for instance, explains the state of there being two daughter cells, which is the result of the cell-division mechanism. Figure 3 illustrates this interpretation of option (2):

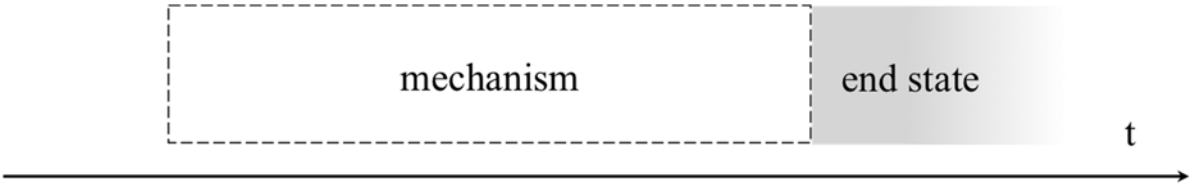


Fig. 3: Option (2) Phenomena as end states.

Still, taken as a suggestion for an analysis of constitutive mechanistic phenomena, the second interpretation of option (2) is also problematic. The reason is that it violates (C2) in that it blurs the distinction between etiological and constitutive MExs. If constitutive mechanistic phenomena are taken to be states that are the results of mechanisms, constitutive MExs just turn out to be etiological MExs. Remember that in etiological MExs phenomena are taken to be effects of mechanisms. In both types of MExs, then, the phenomenon would occur after the mechanism and their relation is a causal one.

3.3 Phenomena as dispositions

A third option is to claim that constitutive MExs explain capacities or dispositions²¹ (Ylikoski [2013]). Figure 4 illustrates this idea. Note that there are different ways to interpret option (3). First, there are different views of the metaphysics of dispositions, which might require different analyses in the context of constitutive mechanisms. Here, we will assume that dispositions are properties that are not necessarily manifest but merely potential. In this sense, an object can have a disposition without ever manifesting it. We thus take option (3) to be different from the idea that constitutive mechanistic phenomena are *manifestations* of dispositions. Second, option (3) can be read as stating that constitutive MExs explain an object's *having* a disposition or its *losing* or *acquiring* a disposition. We will assume that the having of the disposition is what is to be explained (otherwise the grey box in Fig. 4 would have a definite ending or beginning). Third, authors who claim that constitutive MExs explain dispositions are not explicit in what they take the spatial and temporal relations between the (instantiation of the) disposition and the mechanism to be. Here we will make the assumption that the mechanism occurs during a time span when the object instantiates the disposition (without manifesting it).

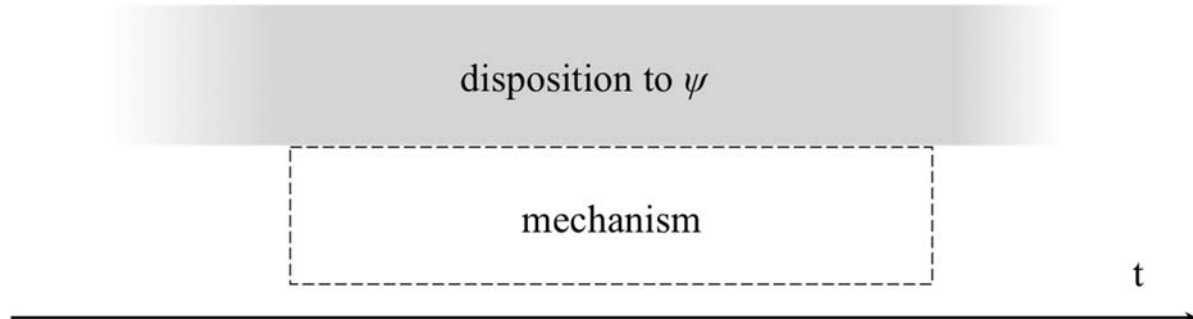


Fig. 4: Option (3) Phenomena as dispositions.

The general idea that constitutive mechanistic phenomena are dispositions/capacities is *prima facie* plausible since it seems to correspond to the explanatory practice in the life sciences. When cognitive scientists want to explain spatial memory, they are interested in a certain capacity of, for example, humans (namely, the capacity of humans to navigate through familiar environments). Likewise, a phenomenon that botanists seek to explain is the disposition of plants to grow in the direction of light when exposed to it. This phenomenon is called ‘phototropism’ and it is typically explained by describing the constitutive mechanism of how the light source is detected, how this affects the polar transport of auxin (a plant

²¹ We use these two terms interchangeably.

hormone), which in turn causes differential growth in the shaded side and in the light-facing side of a stem.

Despite its initial plausibility option (3) faces several problems. We will focus on two objections. The first problem is that explanations of dispositions do not refer to mechanisms as they are understood by the New Mechanists. The reason is the following: explanations of dispositions refer again to dispositions (not to their manifestations). To see this consider the following question that demands an explanation of a disposition: ‘What makes the glass fragile?’ (Ylikoski [2013]). The answer to this question might be something like ‘the bonds between the molecules the glass is made of are such that they are easily breakable by external impact.’ This answer refers to the parts of the glass and their dispositions (i.e. the chemical bonds being breakable).²² But given the framework of the New Mechanists this answer does not describe a mechanism since mechanisms consist of objects and *non-dispositional occurrents* (recall Section 2.3).²³ Hence, explanations of dispositions, in contrast to explanations of manifestations of dispositions (see below) do not refer to mechanisms, and are thus not constitutive MExs.

One might object that explanations of dispositions do not necessarily refer to dispositions. Rather, the explanation of, for example, the fragility of glass in fact mentions only non-dispositional occurrents: ‘The glass is fragile because when a sufficiently large force is executed on it the bonds between the molecules break’. The breaking of the bonds is plausibly a non-dispositional occurrent. But the problem is that as soon as we introduce non-dispositional occurrents into the explanation, the explanandum phenomenon changes. We no longer explain why the glass is *disposed to break*, but what happens when the glass *is breaking*. That is, we explain the *manifestation* of the disposition, not the having of the disposition itself.

We thus conclude that option (3) violates criterion (C3): if constitutive mechanistic phenomena were (non-manifested) dispositions they could not plausibly be constituted, and thus constitutively explained, by mechanisms. Object-occurrent dualism (Section 2.3) implies that mechanisms are *actually occurring*. They are necessarily *manifested* and not merely potentially occurring. But dispositions are merely potential. Hence, mechanisms can only

²² Likewise, the contractability of a muscle fiber is explained by the dispositions of the muscle fiber’s parts such as the disposition of the endoplasmic reticulum to release calcium ions if an action potential arrives.

²³ A dispositionalist will probably challenge this claim and argue that mechanisms in fact are composed of objects having certain dispositional properties. We agree that mechanisms conceived in this way clearly could explain dispositions. But this is not the view the New Mechanists have and the argumentative strategy of this paper is to accept their view and to analyze what, given this framework, constitutive mechanistic phenomena are.

constitute and constitutively explain the manifestations of an object’s dispositions, not the object’s dispositions as such.

Second, if one takes a closer look at the explanatory practice of the life sciences the initial plausibility of option (3) vanishes: paradigmatic examples of constitutive MExs do not explain dispositions, but rather the processual manifestations of dispositions. Consider the mechanism of muscle contraction. The phenomenon that biologists want to explain by citing this mechanism is not the disposition of a muscle fibre to contract when a neuronal stimulus occurs. Rather, they want to explain the *entire process* of how a muscle fibre contracts. Similarly, the regulation mechanism of blood flow control does not explain the organism’s disposition to regulate its blood flow. Rather, the explanatory target of the MExs is the complex process of regulation—for instance, how the decrease of blood pressure caused by a sudden rise out of a warm bath is normalized again. To avoid misunderstandings: our claim is not that biologists *never* aim at explaining how certain objects have certain dispositions. We argue that these are not the phenomena that biologists explain when they offer *constitutive mechanistic* explanations. The metaphysical view that mechanistic phenomena are dispositions thus fails to satisfy (CI).

3.4 Phenomena as behaviours

Another possible interpretation of the ontological nature of phenomena of MExs is that they are behaviours. This option is suggested by Craver’s prevalent claim that constitutive MExs explain the *behaviour* of the mechanism as a whole, which he also refers to as the ψ -ing of S (e.g. [2007], pp. 139, 214). This characterization has been taken over by several other authors (e.g. Bechtel [2011], p. 540; Leuridan [2012], p. 401). Figure 5 illustrates option (4).

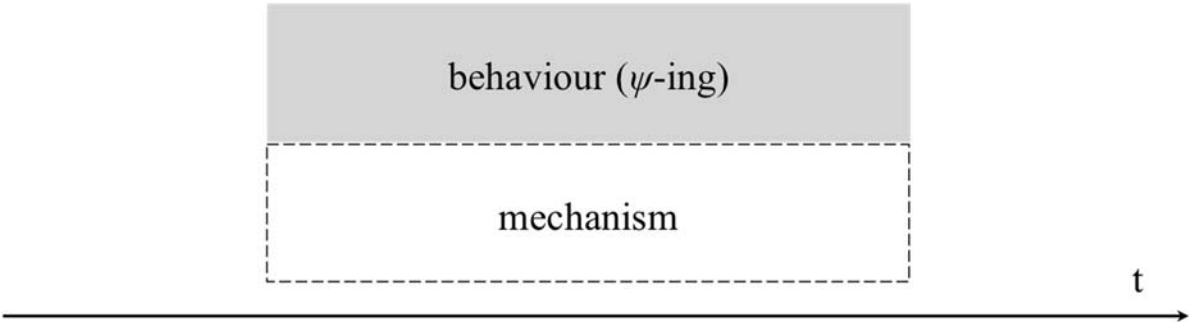


Fig. 5: Option (4) Phenomena as behaviours.

In order to evaluate option (4), we have to distinguish two claims: first, we have to discuss the claim that a constitutive mechanistic phenomenon is the behaviour of *the mechanism*.

Second, the idea might be that the phenomenon just is a behaviour (without specifying the object that is engaged in the behaviour). Let us start with the first claim. We will show that, from an ontological point of view, the phrase ‘behaviour of a mechanism’ is deeply flawed. First of all, it is not entirely clear what Craver and others have in mind when they talk about the behaviour of a mechanism. There are two possible interpretations, which arise from a distinction that has been introduced by Stuart Glennan. On the one hand, the behaviour of the mechanism might be understood as the ‘*external behaviour* of the mechanism’ ([2005], p. 447; our emphasis). For example, the external behaviour of a muscle fibre is contracting and external behaviours of an organism may include reproducing or hunting. On the other hand, the behaviour of the mechanism might be understood as the ‘*internal working* [or internal behaviour] of the mechanism’ (Glennan [2005], p. 447). For example, the internal behaviours of the muscle fibre when it contracts consist in various molecules moving and binding to each other and so on; the internal behaviours of an organism extend from the circulation of blood to the production of germ cells to the digestion of food.

The problem is that in the context of the mechanistic approach no interpretation successfully states what constitutive mechanistic phenomena are. Constitutive mechanisms cannot explain the external behaviour of a mechanism as a whole. The reason is that behaviours in this external sense can only be ascribed to *objects* (this is a conceptual truth). But according to the mechanistic approach, mechanisms are no objects. The reason is that, as we have shown in Section 2.3, the New Mechanists assume that mechanisms consist of component objects *and* component *occurrences*. As a consequence, mechanisms themselves not only have locations, more or less clear spatial boundaries, and spatial parts, but they also have durations, involve changes, and also have temporal parts. Hence, also mechanisms are things that *occur*. There is something *going on* when a mechanism occurs. Mechanisms do not merely consist of spatially extended component-objects that are only disposed to act but do not actually perform any action (as, e.g. Glennan [1996], [2002] thinks)²⁴. Without the wheels in the clock moving and interlocking, there is no mechanism that is responsible for keeping the time; without the heart pumping blood through the organism there is no mechanism for oxygen transport; and without the actin and myosin filaments sliding past each other there is no mechanism for muscle contraction. A mechanism exists only if its component objects are

²⁴ Glennan is the only mechanist who holds the view that mechanisms are objects like machines (e.g. [1996], p. 51). Glennan does not defend entity-activity dualism. Instead, he argues that mechanisms are complex systems, such as hearts ([2002], p. 344), watches, cells, organisms, or social groups ([2002], p. 345) that have parts with certain dispositional properties. If the dispositions become manifest, the parts interact with each other such that they produce a particular phenomenon. The interactions are characterized by certain kinds of generalizations (see [1996], [2002], [2005]). In recent years, however, Glennan’s position seems to have become more similar to MDC’s dualism (he speaks about mechanisms as being constituted by entities, interactions, and activities).

involved in certain occurrents and a certain phenomenon in fact occurs.²⁵ This implies that mechanisms are *occurrents* rather than continuants (i.e. objects).

In a nutshell: external behaviours in the sense characterized above can only be ascribed to objects. Mechanisms are no objects since they are composed of component objects *and* occurrents. Hence, mechanisms cannot be engaged in external behaviours. An example can help to further clarify our argument: if a certain volume of gas cools down, this can be explained by the mechanism of molecules decreasing in speed. In this case, the phenomenon to be explained by the constitutive MExs is the behaviour (the cooling down) of a certain object (the volume of gas). It would not make sense to ascribe the behaviour (the cooling down) to the mechanism, that is, the collection of the moving and interacting gas molecules. It is the gas that cools down, and not the collection of the moving and interacting molecules that cools down. It would be a category mistake to ascribe behaviours such as cooling down to processes such as the molecules decreasing their speed. The latter might be the cause or constituent of the behaviour, but it is not the agent in it. Besides this, ascribing external behaviours that are to be explained (such as navigating the Morris Water Maze, or keeping the time, or the like) to mechanisms amounts to committing the *mereological fallacy* (see Bennett and Hacker [2003]). It is not the brain that is thinking—only persons, of which brains are parts, can think. In the same sense, it is not the spatial memory mechanism that navigates the Morris Water Maze, nor is it the clock-mechanism that keeps the time. Rats navigate the Morris Water Maze, and clocks keep the time.

Nor can constitutive mechanistic phenomena be the internal behaviours of mechanisms. Rather, the internal behaviours of mechanisms are the occurrences/activities of the objects that are the *components* of the mechanisms. But these occurrences/activities are supposed to be what *explains* the phenomenon that is brought about by the mechanism. Hence, they cannot be the phenomenon-to-be-explained. If one takes the phrase ‘behaviour of the mechanism as a whole’ to refer to internal behaviours of mechanisms, one confuses the explanandum phenomenon with what the explanans refers to.

Hence, the first interpretation of option (4), according to which constitutive mechanistic phenomena are behaviours of mechanisms, is inconsistent. What about the second interpretation? According to this interpretation, constitutive mechanistic phenomena are not behaviours of mechanisms, but *just behaviours* (i.e. *bare* behaviours that exclude the object

²⁵ This implies that, strictly speaking, there exist no such things as ‘inactive mechanisms’ that exist but do not work or proceed. One might commonsensically accept that objects like clocks and hearts are mechanisms. But this can only be loose talk since, in the mechanistic framework, entity-activity dualism implies that mechanisms are things that *occur* and that are thus not only spatially, but also temporally extended.

that is engaged in the behaviour; see Illari and Williamson [2012]). This idea might be plausible at least at the type-level: scientists are often interested in, for example, photosynthesis, osmosis, spatial memory, and so on, without being interested in the particular objects that are engaged in these processes. Still, constitutive mechanistic phenomena cannot be bare behaviours in this sense—at least not primarily. Here is why: first, the New Mechanists assume entity-activity dualism (or rather ‘object-occurrent dualism’; recall Section 2.3). One of their main reasons to accept this dualism is that they reject the idea that there can exist activities/occurrents *without* there being an entity/object that is engaged in it. Hence, they should also reject the claim that phenomena are bare behaviours. Second, (C3) requires constitutive mechanistic phenomena to be such that they can be constituted by mechanisms. We have argued that this implies that phenomena must be such that they can have spatial parts. But behaviours as such cannot have spatial parts. Only the objects that exhibit behaviours can have spatial parts (this is why behaviours might be said to indirectly have spatial parts). Constitutive mechanistic phenomena can thus not be *bare* behaviours.

To conclude, it is plausible to assume that constitutive mechanistic phenomena are objects that are engaged in behaviours. But these objects cannot be mechanisms. But, then, what are the objects and how are they related to the mechanism? These questions (and others) will be addressed in the next section, in which we present our own suggestion for how to understand the ontological nature of constitutive mechanistic phenomena.

4 Phenomena as Object Involving Occurrents

Figure 6 provides an overview of the four suggestions discussed in the previous section that turned out to be inadequate characterizations of constitutive mechanistic phenomena:

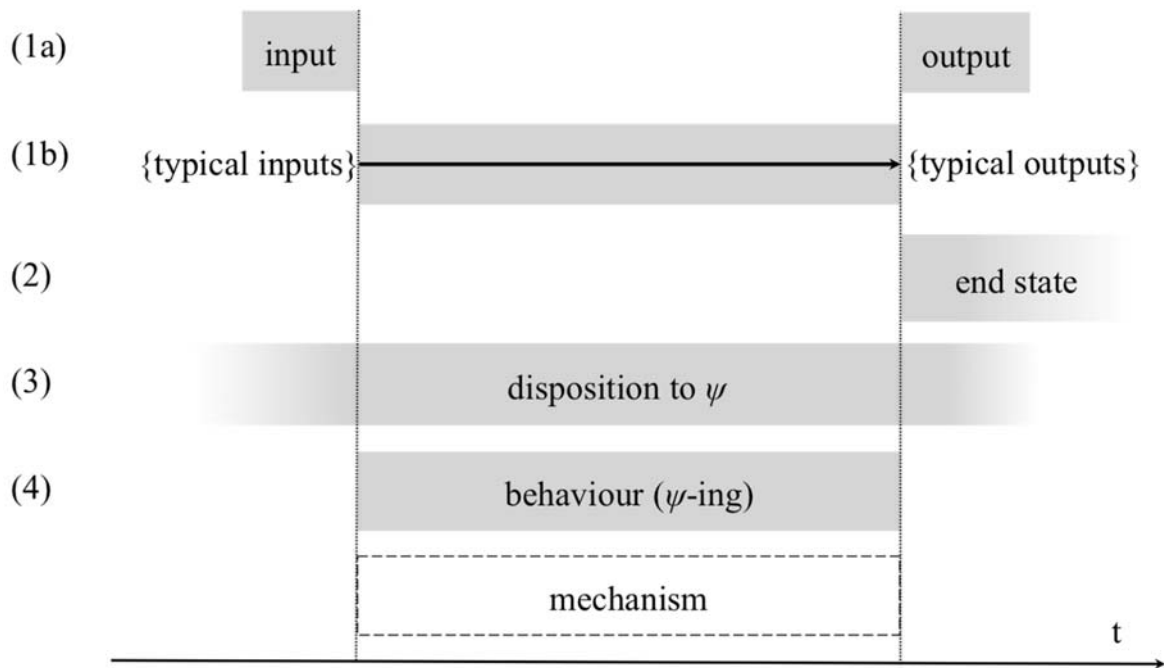


Fig. 6: Overview of the four options discussed in Section 3.

In this section we introduce our own proposal for spelling out the metaphysics of constitutive mechanistic phenomena.

4.1 What object-involving occurrents are and why we need them

Option (5), our own approach, states that the phenomena explained by constitutive MEs are *object-involving occurrents* (OIOs)²⁶. We take OIOs to consist of an *object* (or system) that is engaged in a certain *occurrent*. As already mentioned in Section 2.3, occurrents are process, event, and states (where activities, behaviours, and the like are plausibly special kinds of processes, events, or states). Some of these occurrents involve changes (such as events or processes), others do not (such as states), some might exist only at particular points in time (as some authors claim is true of events), some imply definite endings (as is the case with many processes), and so on. Recall that the only constraint is that the occurrents that make up OIOs must be non-dispositional, that is, they cannot be states which consist in the having of a disposition (instead of being manifestations of dispositions). Objects are, for example, organisms, brains, cells, or ion-channels. The objects engaged in constitutive mechanistic phenomena typically have relatively clear spatial boundaries (such as membranes), which surround objects and allow a distinction between inside and outside (see Kaiser [2015], [unpublished (a)]). Our notion of an object is also supposed to refer to systems. Systems are

²⁶ We thank Geert Keil for suggesting this label.

typically composed of more than one object and most biological systems, such as gene regulatory networks, the immune system, populations, or ecosystems, have less clear spatial boundaries than objects. OIOs have spatial as well as temporal parts. They occur at the locations of the objects and they have durations. The view that constitutive mechanistic phenomena are OIOs is depicted in Figure 7. Note that the figure leaves open the exact spatial relations between the phenomenon and the mechanism (we will specify them in Sections 4.2 and 4.3).

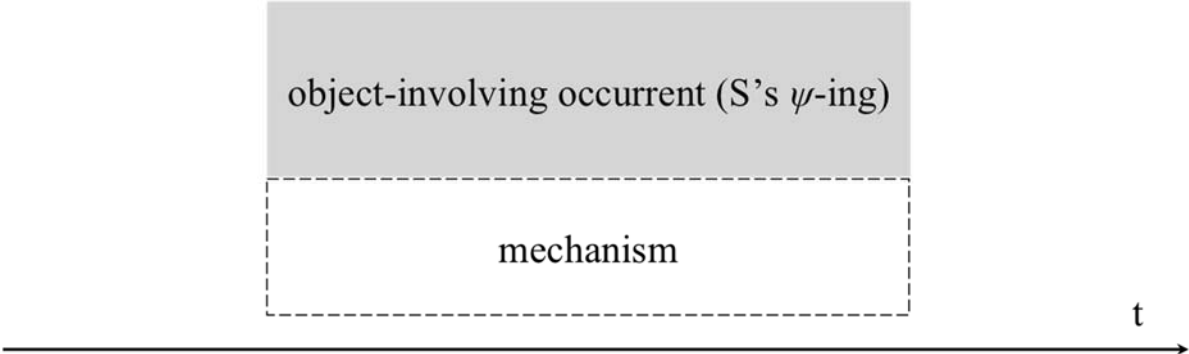


Fig. 7: Option (5) Phenomena as object-involving occurrents (OIOs).

We take typical examples of OIOs to be a muscle fibre contracting (an object showing an activity/behaviour), an ion channel's being open (a state of an object), the neurotransmitter's being released (an object engaged in, what we will call, a passive behaviour), and an organism's reproduction (an object that is involved in a complex process). All of these examples are phenomena that life scientists study, manipulate, and seek to explain by developing constitutive MExs.

From a metaphysical point of view, phenomena are primarily *tokens* such as a particular muscle fibre contracting, a particular neuron in Peter's brain firing, a particular rat navigating the Morris Water Maze, and the like. Corresponding phenomena types are described by *generic generalizations*, like 'muscles contract when a certain stimulus is present', 'neurons fire when a certain stimulus is present', and 'rats find the platform when put into a Morris Water Maze'. The validity of these generalizations depends on the existence of the corresponding phenomena tokens.²⁷

²⁷ Note that this view is compatible with the fact that scientific research often begins with phenomenon types. One interesting question that might be discussed in this context is the question of how idealized phenomena types can have concrete instances. We do not want to address this question here because it needs more careful analysis that cannot be provided in this paper.

Note that the introduction of the term ‘object-involving occurrents’ is not meant to introduce some new ontological category. At least according to one reading of events, OIOs are simply events (if events are taken to necessarily involve events). We use the term ‘object-involving occurrent’ rather than ‘event’ since the notion of an event is highly ambiguous (some hold that events are property instantiations in objects, others hold that they involve property instantiations in space-time regions; some hold that events necessarily involve change, others deny that, and so on). By using the term ‘object-involving occurrent’ we emphasize that constitutive mechanistic phenomena consist of both objects *and* the occurrents in which the objects are engaged. Constitutive mechanistic phenomena always involve objects because the kind of object involved in a phenomenon is crucial for identifying the mechanism that produces and explains the phenomenon (more on this in the next section). Furthermore, constitutive mechanistic phenomena must involve occurrents because what needs an explanation is not an object as such, but only what the object is doing or how it is behaving.²⁸

It is worth emphasizing that the view we present in this paper is monistic and pluralistic at the same time. We argue that constitutive mechanistic phenomena cannot be conceived of as input-output relations, as end states, as instantiations of dispositions (rather than their manifestations), as bare behaviours (without involved objects), or as external behaviours of mechanisms. Instead, we claim that they are object-involving occurrents (OIOs). This is a *monistic* view because we argue that all constitutive mechanistic phenomena are of the same ontological kind (i.e. it gives one answer to the question ‘What are constitutive mechanistic phenomena?’). However, in another respect our account is also *pluralistic* as the occurrents in which objects can be involved are of different kinds: they are, for instance, behaviours, events, processes, activities, or states that are manifestations of dispositions.

4.2 The object in the phenomenon

As we have argued in Section 3.4, the object that is engaged in the behaviour to be explained by a constitutive MEx cannot be the mechanism. Mechanisms are not the kind of things we can ascribe behaviours to (since mechanisms already consist of internal behaviours, that is, of component occurrents) and a mechanism cannot be what does the explaining and be part of what is explained at the same time. It is not the mechanism of muscle contraction that is contracting. Nor is it the action potential mechanism that fires, or the spatial memory mechanism that navigates through the Morris Water Maze. Rather, the relevant objects are

²⁸ The concept of an ‘acting entity’ (Craver [2007], p. 189) that Craver introduces shares some similarities with our concept of an object-involving occurrent. Both involve objects that ‘do something’, that engage in occurrents.

individuals that in most cases are larger objects or systems that *contain* one or often more mechanisms (or at least a great deal of the objects that constitute the mechanisms). It is the muscle fibre (not the mechanism of muscle contraction) that contracts; it is the neuron (not the action potential mechanism) that fires; it is the cell that divides (not the cell division mechanism); and it is the mouse (not the spatial memory mechanism) that navigates through the Morris Water Maze. These objects (i.e. the muscle fibre, the neuron, the cell, and the mouse), to which we ascribe the behaviours or occurrents to be explained (i.e. contraction, firing, division, and navigating), cannot be mechanisms for two reasons. First, as we have already shown, mechanisms consist of component objects *and* occurrents and are thus not the kind of thing to which we can attribute behaviours. Second, even if we leave the component occurrents/activities aside and consider only component objects/entities, in most cases the objects or systems that show the behaviours to be explained will be *different from* the collection of all the component objects that constitute the mechanism for that behaviour.

Let us dwell on this last point. We see at least two major respects in which the object or system that is involved in the mechanistic phenomenon differs from the collection of all component objects/entities that constitute the mechanism: first, biological objects like muscle fibres, neurons, cells, or mice often exhibit *more than one characteristic behaviour*, each of which is often the result of a different underlying mechanism (see Kaiser [2015], [unpublished (a)]). For example, cells not only undergo mitosis (i.e. cell division), but also produce proteins, replicate their genome, grow, and die. Organisms such as mice not only navigate through the Morris Water Maze (i.e. memorize spatially), but also reproduce, survive, defend themselves, and so on. If an object exhibits more than one characteristic behaviour it (at least) consists of all those component objects whose occurrents are relevant to bringing about these different behaviours. It does not merely consist of those component objects that are relevant to the *one* behaviour that is to be explained.²⁹ Cells that divide, for instance, do not merely consist of those component objects that constitute the mechanism for cell division (e.g. chromosomes and centrioles). They are also composed of objects (e.g. ribosomes, tRNAs, and amino acids) that are relevant to other characteristic behaviours of cells, such as protein synthesis or apoptosis (cell death).³⁰ In contrast, mechanisms are always for *one* specific phenomenon and are composed of only those component objects that are relevant to this phenomenon.

²⁹ Of course, how exactly the notion of relevance can be spelled out (i.e. under which conditions an object is a part of another object) is an urgent question. Answering this question amounts to providing an account of (biological) parthood, which is the task for a separate paper (see Kaiser [unpublished (a)]).

³⁰ This is the reason why the phenomenon-box in Figure 6 is larger/higher than the mechanism-box.

Second, the objects involved in mechanistic phenomena are *individuated differently* from the collection of all component objects that constitute a given mechanism. Spatial boundaries, such as the cell membrane, the skin of an organism, or the blood-brain barrier are very important to the demarcation of objects from their environment (see Kaiser [2015], [unpublished (a)]). This is not true for mechanisms because mechanisms ‘frequently transgress compartmental [physical] boundaries’ (Craver [2007], p. 141). The mechanism for action potential, for instance, consists not only of ion channels, the neuronal membrane, and ions that are located inside of the neuron. In addition, ions that are located outside of the neuron are also components of the mechanism. Another example is the mechanism for muscle contraction that includes an incoming, external neuronal signal (i.e. neurotransmitters that bind to receptor molecules outside of the muscle fibre). Hence, a mechanism can have objects as components that are not (or at least not all of the time)³¹ parts of the object or system that shows the behaviour that is explained by this mechanism. In short, mechanisms can encompass *external* objects.³²

These considerations reveal an important distinction: generally speaking, the conditions under which something is a *component* in a mechanism (hereinafter ‘componency’) differ from the conditions for being a *part* of an object (hereinafter ‘parthood’). The centrioles, for example, are parts of the cell, but not components in the mechanism for protein synthesis because their activity is irrelevant to the synthesis of proteins, but relevant to another characteristic behaviour of the cell, namely cell division. The distinction between componency and parthood is already implicit in Craver’s account of constitutive relevance ([2007], pp. 139–60), according to which mechanisms are composed of all and only those objects and occurrents (X ’s ϕ -ing) that satisfy *parthood* and *mutual manipulability* (recall Section 2.3). According to this account, componency presupposes parthood.

Still, the distinction between componency and parthood encounters at least two problems in the context of Craver’s approach to constitutive relevance. First, Craver seems to think that phenomena are behaviours of mechanisms as wholes (S ’s ψ -ings). Hence, the system (the ‘ S ’) that is referred to in the parthood condition must be the mechanism as a whole. But this obviously blurs the distinction between parthood and componency and it renders the approach

³¹ This is a point of divergence. One of us thinks that components of mechanisms have to be spatial parts of the phenomenon-OIO at least at some time during the occurrence of the mechanism (where spatial parthood here is understood as an object occupying a sub-region of the spatio-temporal region occupied by another object; Leuridan [2012]; Krickel [unpublished]). The other claims that something can be a component of a mechanism even if it is never a spatial part of the phenomenon-OIO (Kaiser [2015], [unpublished (a)]).

³² David M. Kaplan seems to rely on a similar assumption when he argues that ‘the gecko adhesion mechanism is spatially distributed to include *external* components spanning the boundary between the gecko and its environment’ ([2012], p. 552; our emphasis).

to constitutive relevance circular. We might solve this problem by modifying Craver's approach: the system mentioned in the parthood condition might not be the mechanism as a whole, but rather a larger object or system (in the sense characterized in Section 4.1) that is engaged in the behaviour-to-be-explained (the ψ -ing).

In this case, a second problem occurs: if the parthood condition is supposed to be a *necessary* condition for being a mechanistic component, this contradicts the claim that some mechanisms transgress spatial boundaries and include occurring objects/acting entities that are *external* to the object or system whose behaviour is to be explained (see Kaiser [2015], [unpublished (a)]). Component objects that are located outside of the spatial boundary of a (higher-level) object are not parts of it and thus cannot be components of mechanisms that are responsible for behaviours of these objects. Consider, for example, the action potential mechanism. This mechanism is responsible for the firing behaviour of neurons. Hence, the object or system that is referred to in the parthood condition is the neuron. For neurons to fire it is crucial that certain ions at a certain point of time diffuse *out* of the neuron. Now, if constitutive relevance requires that the components of the mechanism for the firing of the neuron are parts of the neuron, these ions could not be considered components of the mechanism because they are not parts of the neuron. A plausible way to solve this problem is to weaken the parthood condition and require only the *majority* of components of a mechanism to be parts of the corresponding object or system.

4.3 The adequacy of option (5)

In this section we show how the view that mechanistic phenomena (tokens) are object-involving occurrences (OIOs) meets the three criteria of adequacy that we introduced in Section 2. We will elaborate on these points in turn.

First, as the various examples that we have discussed indicate, option (5) captures paradigmatic examples of the phenomena of constitutive MExs, such as the contraction of a muscle fibre, the firing of a neuron, cell division, the cell synthesizing proteins, growing, dying, and replicating DNA, the navigation of a mouse through the Morris Water Maze, or the vision of a mammal. Hence, our approach to constitutive mechanistic phenomena satisfies (C1).

Second, criterion of adequacy (C3) states that constitutive mechanistic phenomena have to be such that they can plausibly be constituted by mechanisms. We have argued that this implies (at least) that constitutive mechanistic phenomena must be such that they can have spatial parts, and that they must be temporally extended. OIOs satisfy this criterion:

occurrents are extended in time. Objects are extended in space. OIOs inherit these features. Thus, phenomena as OIOs meet the third criterion of adequacy (C3).

Third, concerning (C2) one might object that our analysis reveals that the ontological natures of constitutive and etiological mechanistic phenomena are not that different. Etiological MExs describe phenomena as being caused by mechanisms. If one assumes that the relata of causation are events, it is plausible to assume that *etiological* mechanistic phenomena are *events*. One might further argue that events are not that different from our OIOs—depending on what one takes events to be, either all OIOs are events or at least some OIOs are events. This would imply that the phenomena involved in etiological MExs are of the same or a similar ontological kind as those involved in constitutive MExs (contra Ylikoski [2013]). This is not a problematic consequence since our analysis reveals that the difference between constitutive and etiological mechanistic phenomena lies somewhere else, namely in their *relation to mechanisms*. In a nutshell, in etiological MExs the phenomenon occurs temporally after the mechanism has occurred. In constitutive MExs the phenomenon (i) occurs *at the same time* as the mechanism occurs and (ii) most components of constitutive mechanisms are *spatially contained* in the object or system that constitutes the OIO that is the phenomenon. Etiological mechanisms might, but need not be spatially contained in the object or system that constitutes the phenomenon.

Let us enter into further details. Consider spatial relations first. As we have argued in Section 4.2, it is plausible to assume that the majority of the components of constitutive mechanisms are *spatially contained* in (i.e. located inside of the spatial boundary of) the object or system *S* whose behaviour (ψ -ing) is to be explained. For example, the mechanism for muscle contraction consists of actin and myosin filaments, sarcoplasmic reticula, calcium ions, and so on, which are all located inside of the cell membrane of the muscle fibre. Constitutive mechanisms may also encompass component objects that are external to the phenomenon-object (e.g. the neuronal signal is external to the muscle fibre), but the majority of the components are parts of the phenomenon-object and thus spatially contained within it. With respect to etiological mechanisms there exists no requirement of this kind. Components of etiological mechanisms may or may not be spatially contained in the phenomenon-object or system whose behaviour is to be explained. For example, the etiological explanation of why a certain phenotypic trait (e.g. brown skin colour) became prevalent in a population of mice refers not only to parts of the members of the population (and their genetic constituency), but also and in particular to environmental factors (such as the plants that grow

in the area where the mice live) that are not spatially contained in the object whose state is to be explained (i.e. the prevalence of mice with brown skin colour in the population).³³

Furthermore, for constitutive MEXs spatial parthood between mechanisms (more precisely, their component objects) and phenomena (more precisely, the object involved in the phenomenon) is *not sufficient*. Temporal relations between the occurrences, in which the phenomenon-object is involved, and the component occurrents, which constitute the mechanism, must be taken into account as well (in addition to relevance relations that are supposed to be covered by the mutual manipulability requirement). In the case of constitutive mechanisms the occurrents that are components of the mechanism *occur during* the explanandum phenomenon's taking place (recall Section 2.3). For example, the release of calcium ions from the endoplasmic reticulum into the cytosol (a component of the mechanism for muscle contraction) occurs during the contraction of the muscle fibre (the phenomenon to be explained). By contrast, etiological mechanisms *occur earlier* than the phenomena they explain. For example, the etiological mechanism that causes the prevalence of mice with brown skin colour in a population and that describes the interactions between brown and non-brown mice with the environment (e.g. that brown mice are better hidden from predators) occurs *before* the event that the brown colour trait is prevalent in a population occurs.

To sum up, what characterizes constitutive mechanisms and distinguishes them from etiological ones is that, first, the *majority* of the components of constitutive mechanisms (but not necessarily all of them) are *spatially contained* in the phenomenon-object, and second, that constitutive mechanisms *occur during the same time span* as the phenomena they explain. Hence, our account of the ontological nature of mechanistic phenomena it is in line with and makes sense of the difference between etiological and constitutive mechanisms (C2).

5 Conclusion

In this paper, we have developed an account of the ontological nature of phenomena that are explained by constitutive MEXs. This account fills a gap in the mechanistic literature because the metaphysics of constitutive mechanistic phenomena has not been specified yet. Filling this gap is important because three claims that lie at the heart of the New Mechanistic approach crucially hinge on the notion of a constitutive phenomenon: mechanisms are supposed to constitutively *explain* phenomena, they do so because they *constitute* phenomena, and

³³ Of course, one could doubt that this is a *mechanistic* explanation at all. But defending this claim is the task of the New Mechanists, not ours. Furthermore, one could also question whether this is an *etiological* MEX (rather than a constitutive one). However, if this were a constitutive MEX the explanandum phenomenon would have to be different: the *change* of allele frequencies in the population, and not the prevalence of a certain trait in a population, would have to be the phenomenon to be explained.

phenomena are said to *determine the individuation* of the mechanisms that constitute them. Only if we know what constitutive mechanistic phenomena are can we make sense of these three major claims.

According to our approach, phenomena explained by constitutive MExs can best be understood as object-involving occurrents (OIOs), which are objects or systems that are involved in a certain process or event, or are in a certain state. Typically, the phenomena that are investigated by the life sciences are organisms or parts/groups of organisms, which are engaged in certain behaviours or activities. Understanding constitutive mechanistic phenomena as OIOs enables us to make sense of the three claims of the New Mechanists. First, in constitutive MExs mechanisms explain the *behaviours of objects*. Second, the difference between etiological and constitutive MExs consists in the fact that the components of constitutive mechanisms occur *during the same time span* in which the phenomenon occurs, whereas etiological mechanisms occur *before* the phenomena they explain. Furthermore, in constitutive mechanisms *most* of the components are *spatially contained* in the OIO that constitutes the phenomenon, whereas etiological mechanisms are not spatially restricted. Hence, according to our view, a necessary condition for mechanistic constitution is the following: a mechanism constitutes a phenomenon only if every component of the mechanism occurs during the phenomenon's occurrence, and most of the components are spatially contained in the phenomenon. Finally, our approach also clarifies the individuation-claim. A mechanism is composed of only those objects and occurrents that are constitutively relevant to the phenomenon that the mechanism is supposed to explain. According to our approach, this implies that a component of a mechanism must be relevant to a particular *behaviour of an object*, where it must be the case that the component-occurrent occurs during the phenomenon-occurrent, and the component-object is a spatial part of the phenomenon-object (at least most of them). Of course, this is only a necessary condition—we still have to specify when a putative component is *relevant* to the phenomenon. This is an urgent question, but an answer goes beyond the scope of this paper.

We are confident that our analysis of the metaphysics of mechanistic phenomena can be used to enrich and clarify other questions in the mechanistic literature, for instance: What is the mechanistic level relation, and what are its relata? What are higher-level interventions, in contrast to lower-level interventions? Are phenomena multiply realizable (or rather multiply constitutable) by different mechanisms?

Funding

This work was partially supported by the Deutsche Forschungsgemeinschaft (DFG) [FOR-1063].

Acknowledgements

We would like to thank the members of the Kolloquium zur theoretischen Philosophie (Universität zu Köln), of the Lake Geneva Biological Interest Group (IgBIG, Université de Genève), and of the Lehrstuhlkolloquium of Prof. Keil (Humboldt-Universität zu Berlin) for comments on earlier drafts. Our thanks also go to Kelley Schiffman and Tim Steeger for proof reading and formatting.

References

- Andersen, H. [2012]: ‘The Case for Regularity in Mechanistic Causal Explanation’, *Synthese*, **189**, pp. 415–32.
- Baker, L. R. [1997]: ‘Why Constitution is Not Identity’, *The Journal of Philosophy*, **94**: 599–621.
- Barros, B. [2008]: ‘Natural Selection as a Mechanism’, *Philosophy of Science*, **75**, pp. 306–322.
- Baumgartner, M. and Gebharder, A. [2015]: ‘Constitutive Relevance, Mutual Manipulability, and Fat-Handedness’, *The British Journal for the Philosophy of Science*.
- Bechtel, W. [2005]: ‘The Challenge of Characterizing Operations in the Mechanisms underlying Behaviour’, *Journal of the Experimental Analysis of Behaviour*, **84**[3], pp. 313–25.
- Bechtel, W. [2006]: *Discovering Cell Mechanisms. The Creation of Modern Cell Biology*, Cambridge: Cambridge University Press.
- Bechtel, W. [2008]: *Mental Mechanisms. Philosophical Perspectives on Cognitive Neuroscience*, New York and London: Taylor and Francis Group.
- Bechtel, W. [2011]: ‘Mechanism and Biological Explanation’, *Philosophy of Science*, **78**, pp. 533–57.
- Bechtel, W. and Abrahamsen, A. [2005]: ‘Explanation: a mechanist alternative’, *Stud. Hist. Phil. Biol. & Biomed. Sci.*, **36**, pp.421–41.
- Bennett, M. and Hacker, P. [2003]: *Philosophical Foundations of Neuroscience*. Oxford and Malden, Mass.: Wiley-Blackwell.

- Bechtel, W. and Richardson, R.C. [2010]: *Discovering Complexity. Decomposition and Localization as Strategies in Scientific Research*, Cambridge: MIT Press.
- Bogen, J. [2005]: ‘Regularities and Causality; Generalizations and Causal Explanations’, *Studies in History and Philosophy of Biological and Biomedical Sciences*, **36**, pp. 397–420.
- Bogen, J. [2008]: ‘Causally Productive Activities’, *Studies in History and Philosophy of Science*, **39**, pp. 112–23.
- Campaner, R. [2006]: ‘Mechanisms and Counterfactuals: A Different Glimpse of the (Secret?) Connexion’, *Philosophica*, **77**, pp. 15–44.
- Callender, C. [2011]: ‘Philosophy of Science and Metaphysics’, in S. French and J. Saatsi (eds), *Continuum Companion to the Philosophy of Science*, Continuum, pp. 33–54.
- Craver, C. [2007]: *Explaining the Brain*, Oxford: Oxford University Press.
- Craver, C. [2014]: ‘The Ontic Account of Scientific Explanation’, in M. I. Kaiser, O. Scholz, D. Plenge, and A. Hüttemann (eds), *Explanation in the Special Sciences – The Case of Biology and History* [Synthese Library], Dordrecht: Springer, pp. 27–52.
- Craver, C. F. and Bechtel, W. [2007]: ‘Top-down Causation without Top-down Causes’, *Biology and Philosophy*, **22**, pp. 547–63.
- Craver, C. F. and Darden, L. [2001]: ‘Discovering Mechanisms in Neurobiology: The Case of Spatial Memory’, in P. Machamer, R. Grush, P. McLaughlin (eds), *Theory and Method in Neuroscience*, Pittsburgh: University of Pittsburgh Press, pp. 112–37.
- Craver, C. F. and Darden, L. [2013]: *In Search of Mechanisms. Discoveries across the Life Sciences*, Chicago/London: University of Chicago Press.
- Craver, C. F. and Kaiser, M. I. [2013]: ‘Mechanisms and Laws: Clarifying the Debate’, in H. - K. Chao, S.-T. Chen, and R. L. Millstein (eds), *Mechanism and Causality in Biology and Economics*, Dordrecht: Springer, pp. 125–45.
- Cummins, R. [1983]: *The Nature of Psychological Explanation*. Cambridge, MA: Bradford and MIT Press.
- Darden, L. [2002]: ‘Strategies for Discovering Mechanisms: Schema Instantiation, Modular Subassembly, Forward/Backward Chaining’, *Philosophy of Science*, **69**[3], Supplement: Proceedings of the 2000 Biennial Meeting of the Philosophy of Science Association. Part II: Symposia Papers. (Sep., 2002), pp. 354–65.

- Gillett, C. [2013]: ‘Constitution, and Multiple Constitution, in the Sciences: Using the Neuron to Construct a Starting Framework’, *Minds and Machines* **23**[3], pp. 309–37.
- Glennan, S. [1996]: ‘Mechanism and the Nature of Causation’, *Erkenntnis*, **44**, pp. 49–71.
- Glennan, S. [2002]: ‘Rethinking Mechanistic Explanation’, *Philosophy of Science*, **69**, pp. 342–53.
- Glennan, S. [2005]: ‘Modeling Mechanisms’, *Studies in History and Philosophy of Science Part C*, **36**[2], pp. 443–64.
- Glennan, S. [2009]: ‘Productivity, relevance and natural selection’, *Biology & Philosophy*, **24**[3], pp. 325–39.
- Glennan, S. [2010]: ‘Ephemeral Mechanisms and Historical Explanation’, *Erkenntnis*, **72**, 251–66.
- Harbecke, J. [2010]: ‘Mechanistic Constitution in Neurobiological Explanations’, *International Studies in the Philosophy of Science*, **24**, pp. 267–85.
- Illari, P. and Williamson, J. [2013]: ‘In Defense of Activities’, *Journal for General Philosophy of Science*, **44**, pp. 69–83.
- Illari, P. and Williamson, J. [2012]: ‘What is a mechanism? Thinking about mechanisms across the sciences’, *European Journal of Philosophy of Science*, **2**, pp. 119–35.
- Kaiser, M. I. [2015]: *Reductive Explanation in the Biological Sciences*, Dordrecht: Springer.
- Kaiser, M. I. [unpublished (a)]: ‘Individuating Part-Whole Relations in the Biological World’.
- Kaiser, M. I. [unpublished (b)]: ‘Normativity in Philosophy of Science’.
- Kaplan, D. M. [2012]: ‘How to demarcate the boundaries of cognition’, *Biol Philos*, **27**: pp. 545–70.
- Krickel, B. [unpublished]: *The Metaphysics of Mechanisms*, Dissertation, Humboldt-Universität zu Berlin.
- Leuridan, B., [2012]: ‘Three Problems for the Mutual Manipulability Account of Constitutive Relevance in Mechanisms’, *British Journal of Philosophy of Science*, **63**[2], pp. 1–29.
- Lewis, D. K. [1986]: *On the plurality of worlds*, Oxford: Blackwell.
- Machamer, P. [2004]: ‘Activities and Causation: The Metaphysics and Epistemology of Mechanisms’, *International Studies in the Philosophy of Science*, **18**[1], pp. 27–39.
- Machamer, P., Darden, L., and Craver, C. [2000]: ‘Thinking about Mechanisms’, *Philosophy of Science*, **67**, pp. 1–25.
- Maudlin, T. [2007]: *The Metaphysics within Physics*, Oxford: Oxford University Press.

- Psillos, S. [2004]: 'A Glimpse of the Secret Connexion: Harmonizing Mechanisms with Counterfactuals', *Perspectives on Science*, **12**, pp. 288–319.
- Ross, D., Ladyman, J. and Spurrett, D. [2007]: 'In Defence of Scientism,' in D. Ross and J. Ladyman (eds), *Every Thing Must Go. Metaphysics Naturalized*, Oxford: Oxford University Press, pp. 1–65.
- Salmon, W. [1984]: 'Scientific Explanation: Three Basic Conceptions', *PSA: Proceedings of the Biennial Meeting of the Philosophy of Science Association, Volume II: Symposia and Invited Papers*, pp. 293–305.
- Simons, P. M. [1991]: 'On being spread out in time: temporal parts and the problem of change', in W. Spohn, B. van Fraassen, and B. Skyrms (eds), *Existence and Explanation*, Kluwer Academic Publishers, pp. 131–47.
- Skipper, R.A. and Milstein, R.L. [2005]: 'Thinking about evolutionary mechanisms: natural selection', *Studies in History and Philosophy of Biological and Biomedical Sciences*, **36**, 327–47.
- Smith, B. [2012]: 'Classifying Processes: An Essay in Applied Ontology', *Ratio*, **25**, pp.463–88.
- Steel, D. P. [2008]: *Across the Boundaries. Extrapolation in Biology and Social Science*, Oxford/New York: Oxford University Press.
- Tabery, J. [2004]: 'Synthesizing Activities and Interactions in the Concept of a Mechanism', *Philosophy of Science*, **71**, pp. 1–15.
- Torres, P. J. [2008]: 'A Modified Conception of Mechanism', *Erkenntnis*, **71**[2], pp. 233–51.
- Ylikoski, P. [2013]: 'Causal and Constitutive Explanation Compared,' *Erkenntnis*, **78**, pp. 277–97.