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Bert Leuridan[1] and Thomas Lodewyckx[1]

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Abstract

Mechanistic approaches are very common in the causal interpretation of biological and neuroscientific experimental work in today's philosophy of science. In the mechanistic literature a strict distinction is often made between (intralevel) causal relations and (interlevel) constitutive relations, where the latter cannot be causal. One of the typical reasons for this strict distinction is that constitutive relations are supposedly synchronic whereas most if not all causal relations are diachronic. This strict distinction gives rise to a number of problems, however. Our end goal in this paper is to argue that it should be given up, at least in the context of the biological and the psychological sciences. To that effect, we argue that constitutive relations in this context are diachronic, thus undermining the aforementioned reason. We offer two cases from scientific practice in which constitutive relations are regarded as both diachronic and causally efficacious, review three existing ways of dealing with the apparent diachronic nature of interlevel relations in mechanisms and propose a new account of diachronic, causal constitutive relevance.

1. Introduction

Mechanistic approaches are near ubiquitous in the causal interpretation of biological and neuroscientific experimental work in today's philosophy of science (see Glennan 1996, 2002; Machamer, Darden and Craver 2000; Bechtel and Abrahamsen 2005; Leuridan 2010; and Illari and Williamson 2012). It is often claimed that any causal interaction in a mechanism is exclusively intralevel, i.e. that causal relations obtain only between objects, events or processes on the same mechanistic level. The interlevel relations between a component part and the behaviour of the mechanism in which it figures as a whole, are defined as constitutive relations and are explicitly seen as non-causal.

There are three well-known reasons offered by Carl Craver, both separately (2007: p.153-154) and in his work with William Bechtel (2007: p.552-554), why these constitutive relations must be non-causal: first, the token behaviours of a component part and of the whole in which it figures are logically dependent, whereas cause and effect are typically required to be logically independent; second, a causal relationship is generally taken to be asymmetric, while Craver and Bechtel consider the constitutive relation to be symmetric;[2] third, constitutive relations are seen as synchronic, whereas causal relations are mostly assumed to be diachronic.

[1] University of Antwerp, Centre for Philosophical Psychology. The research for this paper was supported by the Research Foundation Flanders (FWO), research project G056616N.

[2] Craver explicitly commits to constitutive relationships being symmetrical, which may lead to problems for his account. This has already been addressed by Samuel Schindler (2013). According to Kistler (2009, p.603-604), this symmetry seems to imply that Craver and Bechtel believe constitution to be an identity relation. Rea

These three reasons notwithstanding, a strict distinction between constitutive and causal relations may be considered problematic (see Leuridan 2012). Below, we will expand on these problems in more detail as they are the source of inspiration for the present paper. Following Leuridan (2012), our end goal in this paper is to argue that the strict distinction in question should be given up, at least in the context of the biological and the psychological sciences. To that effect, we will focus mainly on the third reason listed above, viz. that constitutive relations are seen as synchronic whereas causal relations are mostly assumed to be diachronic.

One way to counter that reason would be to focus on the possibility of synchronic causation. In several approaches to causation, causes are expected to precede their effects, yet this diachronic interpretation is not without its critics and some accounts of causation do explicitly abandon the requirement for temporal asymmetry in causation (see Huemer and Kovitz 2003; see also footnote 5). In a similar vein, Leuridan (2012: p.420) offers an example of synchronic causation, viz. a simple pendulum.

In this paper, however, we will take a different route towards our end goal. While we side with the standard view that most causal relations are in fact diachronic, we argue against a strictly synchronic interpretation of constitutive relations. This is our intermediate goal.

In section 2, we start by further discussing the notions of 'mechanism' and 'mechanistic level', and by explicating the strict distinction drawn by Craver (2007) between causal intralevel and constitutive interlevel relations. We discuss Craver's mutual manipulability account, and its use in this article, in section 3. In section 4, we briefly summarize some of Leuridan's (2012) arguments against that strict distinction and motivate our present endeavour. In section 5, we make further room for this endeavour by addressing the issue of logical dependence among constitutive relata. Then, in section 6, we begin developing our argument by examining scientific case studies in which constitutive relations are regarded as both diachronic and causally efficacious. These include a case from the literature on gene manipulation and its effects on long-term potentiation (LTP) and spatial memory (Kandel 2000), as well as a case on the coupling of perception and action in the context of cognition (Vernon et al. 2015). The causal relations in these examples will be cashed out in terms of Woodward's interventionist theory of causality (2003), which inspired Craver (2007) in his treatment of constitutive relevance. As we will see, the synchronic account of constitutive relevance quickly deteriorates if one takes a closer look at what is actually going on in these case studies. In section 7, we analyze three different approaches that, each in their own way and to a different degree, aim to explain the often-overlooked temporal dimension to constitutive relations. These include the constraint relation, as suggested by Kistler (2009) and Bechtel (2017), a stringently defined notion of temporal parts, as defended by Kaiser and Krickel (2017) and Krickel (2017; 2018), and Kirchhoff's (2015) turn towards process ontology, inspired by Seibt (2009). Each of these approaches, though fruitful, faces its own problems. In section 8 we propose our own account of diachronic causal constitution to circumvent these issues. We conclude this paper in section 9.

2. Mechanisms, mechanistic levels, interlevel constitutive relations and constitutive relevance

Let us first look at the prevailing conception of mechanisms and interlevel relations promoted by, among others, Craver (2007) and Craver and Bechtel (2007). Mechanisms are defined as collections of parts or components[3] and their activities, organized such that they exhibit the phenomenon to be explained (Craver, 2007: p.5, and Craver and Bechtel, 2007: p.549). Relative to a given mechanism, Craver defines mechanistic

(1997) and Kistler (2009) explicitly doubt that constitutive relations are identity relations and believe constitution to be an asymmetrical relation. Kirchhoff (2015) acknowledges symmetry but similarly argues against a strict identity relation. See section 7 for a more detailed discussion of the work of Kistler (2009) and Kirchhoff (2015). In this paper, we will leave the symmetry argument untouched.

[3] Unless specified otherwise, the terms 'component' and 'part', though not strictly interchangeable, will be employed as such in this article.

levels as follows.[4] An item X's φ-ing, for instance the conversion of information from incoming light to a pattern of neural activity by the optic nerve, is at a lower level than S's ψ-ing, in this case the visual perception by the eye, if and only if X's φ-ing is a component in the mechanism for S's ψ-ing (Craver, 2007: p.153 and p.188-195). X's φ-ing is a component in that mechanism if and only if it is one of the entities-and-activities organized such that S ψ's. In other words, the optic nerve plus its activity is a component of the eye in its particular activity, as it helps to ensure that it can convert information from incoming light (Craver and Bechtel, 2007: p.549). The levels of a mechanism are connected by interlevel relations between the components and the macro-level phenomenon. As the organized behaviours of the components 'constitute' this phenomenon, i.e. the behaviour of the mechanism as a whole, they are referred to as constitutive relations (Craver, 2007: p.153-154). Constitutive relations are further spelled out in terms of 'mutual manipulability' (see section 3 for more details).

Craver and Bechtel, as well as several other authors, treat the constitutive relation and the causal relation as completely distinct concepts. In their view, there is no such a thing as interlevel causation: "[t]here are no causal interactions beyond those at a level" (Craver and Bechtel, 2007: p.561). Causation is treated as entirely intralevel. Apparent cases of interlevel causation are said to be mechanistically mediated effects, which are hybrids of interlevel constitutive and intralevel causal relations (Craver and Bechtel, 2007: p.547-548).

One of Craver and Bechtel's main arguments for this view is, as we mentioned above, that constitutive relations are supposedly synchronic. In Craver's words: "If one is committed to the idea that causes must precede their effects, then constitutive relationships are not causal relationships" (2007, p.154). Take for example those theories of causation that require some sort of physical interaction or exchange between cause and effect (see for instance Skyrms, 1980; Reichenbach 1956/1971; Salmon, 1994; Dowe, 2000; and Beebee, 2004). Any such theory appears to preclude the possibility of interlevel causality in mechanisms, as it is a part of their concept of causation that causes must be spatially and temporally distinct, meaning that they cannot have any spatial or temporal parts in common.[5] In Craver and Bechtel's words: "Given the compositional relations between mechanisms and their components, the space-time path of the mechanism includes the space-time path of its components. They coexist with one another, and so there is no possibility of their coming to spatio-temporally intersect with one another" (2007: p.552).

Our end goal in this paper, i.e. undermining the strict causal-constitutive distinction, then threatens to lead us to the following inconsistent triad.

> I. Causal relations are diachronic. (This is typically assumed.)
>
> II. Constitutive relevance relations are synchronic. (This is what Craver and Bechtel claim.)
>
> III. Constitutive relevance relations may be considered causal, at least in certain contexts. (This is what we intend to argue.)

[4] The mechanistic conception of levels has been criticized, see for instance Potochnik and McGill (2012), Eronen (2013) and Potochnik (forthcoming).

[5] It is often assumed that the common sense idea, that causes must precede their effects, is fairly widespread in the philosophical literature. A typology of causal accounts, as posited by Leuridan and Lodewyckx (2019), reveals however that the kind of 'time-first' accounts that support this common sense idea are more of an exception than a general rule. The currently leading accounts are almost invariably 'time-independent' and often make explicit room for cases involving instantaneous and/or backward causation, even though they acknowledge that in fact most causes precede their effects. Some influential theories by contrast demand causation itself to be completely instantaneous.

The problem is obvious. How could a synchronic relation act diachronically? To repeat, it is not our intention to address this problem by arguing on behalf of synchronic causality. Instead, we aim to escape the inconsistency by presenting a diachronic reinterpretation of constitutive relevance (this being our intermediate goal).

3. Mutual manipulability as an account of constitutive relevance – modulo two caveats

3.1. Constitution versus constitutive relevance

So far, we have not made explicit what account of constitutive relevance we adhere to in this paper. Before doing that, we should draw attention to the important distinction between constitution and constitutive relevance. Constitution holds between the behaviour of the mechanism as a whole and all of its constitutively relevant parts. Hence the constitution relation is the sum of manifold constitutive relevance relations. Constitutive relevance holds between changes to the behaviour of a mechanism as a whole and changes to that of one of its parts (Craver, 2007: p.153). Our efforts in this paper are focused mostly on constitutive relevance, though for ease of exposition we oftentimes write 'constitutive relations' instead of 'constitutive relevance relations'.

3.2. Defining constitutive relevance

One of the most prominent accounts of constitutive relevance today is Craver's mutual manipulability (MM) account. In treating intralevel causal relations, Craver adopts Woodward's manipulationist account of causation (2007: chapter 3). Intralevel relations are causal if and only if they are invariant under some range of ideal *etiological* interventions.[6] Interlevel constitutive relations are treated in a similar, yet slightly different fashion by Craver (2007: chapter 4). A component is constitutively relevant to the behaviour of the mechanism as a whole, according to MM, if it is possible to wiggle the behaviour of the whole by wiggling the behaviour of the component and if - vice versa - it is possible to wiggle the behaviour of the component by wiggling the behaviour of the whole (Craver, 2007: p.153). More formally:

> (i) X is part of S; (ii) in the conditions relevant to the request for explanation there is some change to X's φ-ing that changes S's ψ-ing; and (iii) in the conditions relevant to the request for explanation there is some change to S's ψ-ing that changes X's φ-ing. (Craver, 2007: p.153)

Craver then offers a more stringent notion of ideal *interlevel* interventions, defined in terms that are very similar to Woodward's manipulationist theory of causation, to explicate 'wiggling' and 'some change' (2007: p.154).

Short of two caveats, we endorse Craver's notion of mechanism level and his mutual manipulability account. We will treat it primarily as an account of type constitutive relevance (e.g., LTP is constitutively relevant for spatial memory, see section 6.1). It can be used to talk about token constitutive relevance as well (e.g., a particular occurrence of LTP in a particular mouse is constitutively relevant for that mouse's spatial memory during a given experiment).

That MM can be used both at the type-level and at the token-level should sound familiar. MM is modelled along the lines of Woodward's manipulationist account, which defines causation both at the type-level (see Woodward 2003: p.59) and, derivatively, at the token-level (p.84). The parthood condition in MM should not

[6] The term 'etiological' is adapted from Leuridan (2012), who uses it to distinguish etiological from interlevel interventions.

pose any problems in this respect. It is possible to conceive of parthood relations both at the type-level (e.g., the retina is part of the eye) and at the token-level (e.g., this retina is part of this eye). Craver explicitly leaves room for both token- and type-readings of constitutive relevance, though he finds token-readings more straightforward, as type-readings may stand in need of disambiguation (2007: p.191-192).

The first caveat is the following. In the past decade, MM has been scrutinized in several ways. One point of discussion is the parthood condition (i). Craver does not offer a definition of parthood. Leuridan (2012: p.410) has suggested that a definition in terms of spatio-temporal inclusion,

(STI) *X* is part of *S* iff the spatio-temporal region occupied by *X* is contained in the spatio-temporal region occupied by *S*,

would be intuitively appealing, yet argued that with (STI) it becomes hard to distinguish between causal intralevel relations and supposedly non-causal constitutive interlevel relations. It is natural to think of (STI) in a 'snapshot' fashion: *X* and *S* satisfy (STI) if and only if every time-slice of *X* is contained in a time-slice of *S* occurring at the same instant. As will become clear in section 7.3, however, biological and psychological phenomena should not be approached in a snapshot fashion. At the end of this paper, we will move towards a more processual approach to MM, including a new definition of parthood.

The second caveat can be dealt with very quickly. Craver intended MM to be an account of constitutive relevance as a strictly non-causal relation, whereas we will argue to the contrary.

Yet apart from these two caveats, we endorse MM.

4. Motivating our endeavour

The inconsistency at the end of section 2 only arises if one insists that the strict distinction between causal and constitutive relations must be given up; see clause III. of our inconsistent triad. Why would one do so? Before we proceed, let us motivate our endeavour in more detail. Despite Craver and Bechtel's arguments, we see four related reasons for arguing against the strict distinction in question. We should warn that the sole purpose of this section is to provide *reasons for arguing* against the strict distinction in question. No conclusive arguments should be expected yet.

A first reason is given by Leuridan (2012: p.424). The *central manipulationist idea*, which serves as the basis for several theories of causation, most notably Woodward's interventionist account, is that causal relationships are distinctive in that they are potentially exploitable for the purposes of manipulation and control. From that perspective, it is hard to hold on to the view that constitutive relations, which are characterized in terms of mutual *manipulability*, are not causal. If one wishes to affect the behaviour of a mechanism as a whole, a good strategy is to manipulate its parts; and vice versa.

A second reason, also given by Leuridan (2012: p.413), is a technical elaboration of the previous one. MM couches interlevel relations in Woodwardian terms, thereby raising the question why constitutive relevance would not simply entail causal relevance.[7] Leuridan (2012: p.406-407) argues that when the conditions for ideal interlevel interventions given by Craver are satisfied, it follows that the conditions set for ideal etiological interventions are all satisfied as well. Leuridan notes that there is a slight difference in the way ideal etiological

[7] As one reviewer correctly remarked, Woodward's framework is not intended to apply to models in which some variables are *non-causally* dependent on each other (see Woodward, 2011: p.21-27, and the references in footnote 16). Yet the point of our paper, and to a certain extent of Leuridan (2012), is precisely to show that interlevel relations in mechanisms are causal after all. Hence the question whether Woodwardian interventionism is applicable to mechanistic interlevel relations should be bracketed here.

interventions are defined by Woodward andCraver respectively. Craver seems to formulate his clauses for an ideal etiological intervention as necessary conditions, while Woodward regards his subtly different clauses as both necessary and sufficient conditions. This leaves room for Craver to argue that causal relevance does not follow deductively from constitutive relevance. However, to ensure his point, that no constitutive relations are also causal relations, he would have to supply one or more conclusive reasons why ideal interlevel interventions, that satisfy the relevant necessary conditions, could not rightly be regarded as ideal etiological interventions.

In view of these two reasons, we will explicate interlevel causal relations using ordinary Woodwardian interventions (see footnotes 7 and 16 for a legitimation of this approach).

A third reason is that some leading practicing scientists do not seem to distinguish between causation and constitution, at least in the biological and psychological sciences. This will be illustrated in more detail in section 6. Much of the mechanistic literature is naturalistic in the sense that it awards a lot of attention to empirical details. Craver's *Explaining the Brain*, for instance, is so interesting, in part, because it involves extensive case studies. We endorse that approach to philosophical questions and wonder what can be learnt from scientific practice.

These three reasons give rise to a fourth consideration. If causal and constitutive relevance are so similar, why should we stick to two distinct notions instead of one? Metaphysical notions should not be multiplied beyond necessity.

Keeping these four motivations in mind, it is our endeavour and end goal in this article to argue in favour of causally efficacious constitutive relations by reexamining, as our intermediate goal, the supposed need for these relations to be synchronic.

5. Challenging the logical independence argument

Although it is our aim in this paper to counter the synchronicity problem, some attention should be awarded to the issue of logical dependence among the constitutive relata, i.e. Craver and Bechtel's first reason mentioned in the introduction.[8] This is perhaps the main reason why it is assumed in the literature that parts and wholes cannot be causally related. If it is decisively shown that constitutive relations cannot be causal, we should give up our present endeavor.[9]

Craver and Bechtel (2007, p.552) cite David Lewis who writes the following:

> C and E must be distinct events – and distinct not only in the sense of *nonidentity* but also in the sense of *nonoverlap* and *nonimplication*. It won't do to say that my speaking this sentence causes my speaking this sentence or that my speaking the whole of it causes my speaking the first half of it; or that my speaking causes my speaking it loudly, or vice versa. (2000, p.78; our emphasis)

We will not challenge Lewis's claim here, except with respect to nonoverlap, but we do doubt that it is relevant to interlevel relations in mechanisms. For ease of exposition and in opposition to the intended intermediate conclusion of this paper, we will assume in this section that constitutive relations are synchronic and that it makes sense to think of the constitutive relata as time-slices, i.e. in a snapshot fashion. This makes it possible

[8] We are grateful to an anonymous reviewer for pressing us on this issue.

[9] It is important to note that we do not intend to deliver an exhaustive argument to undermine this reason here. That would take another article.

to model them loosely along Kim's account of events.[10] We will come back to these assumptions in footnote 13.

Consider the following two events:

- S's ψ-ing at time *t* (or: a change in S's ψ-ing at time *t*)
- X's φ-ing at time *t* (or: a change in X's φ-ing at time *t*)

Note first that these events are *not identical*: S ≠ X and ψ-ing ≠ φ-ing. Moreover, as we will argue in the rest of this paper, these events in fact may take place at different times t ≠ t'. Second, they may *overlap* spatio-temporally, yet we doubt that this by itself is a good reason to deny them the status of cause and effect in a Woodwardian fashion. This can be illustrated by means of two examples: the simple pendulum and the ideal gas law.[11] The length l of a simple pendulum is regarded as a cause of that pendulum's period T. By intervening to change l, one changes T (Woodward, 2003: p.197). Consider the following two events, where x is a simple pendulum:

- x's having length l at time t (or: a change in x's length l at time t)
- x's having period T at time t (or: a change in x's period T at time t)

These two events overlap spatio-temporally and even involve the same, identical object x. If *they* are not denied the status of cause and effect, *a fortiori* we cannot deny a mechanism's interlevel relata that status, pending a solution to the synchronicity problem of course.

Similarly, the ideal gas law states that the pressure P, volume V, and temperature T of a sample of an ideal gas are related as follows: $PV = nRT$, where n is the number of moles of the gas and R is the universal gas constant. Each of the different variables V, P and T can take up the role of cause or effect from an interventionist standpoint (see Woodward 2003, passim). Again the following events are spatio-temporally overlapping and even involve the same, identical sample of gas x:

- x's having pressure P at time t (or: a change in x's pressure P at time t)
- x's having volume V at time t (or: a change in x's volume V at time t)
- x's having temperature T at time t (or: a change in x's temperature T at time t)

To repeat, if *they* can be causes and effects, why can't S's ψ-ing and X's φ-ing?

Third, unlike Lewis's examples, S's ψ-ing and X's φ-ing do *not logically imply* each other.[12] Given a few plausible assumptions about the meaning of "my speaking this sentence" and the meaning of "my speaking the first half of it", the first implies the second. The relation between S's ψ-ing (e.g., the visual perception by the eye) and X's φ-ing (e.g., the conversion of information from incoming light to a pattern of neural activity by the optic nerve), by contrast, is not a matter of semantic assumptions and/or logical implication. Constitutive relevance

[10] Kim writes: "Event [x, P, t] exists just in case substance x has property P at time t" (Kim, 1976: p.9). Note that the notion of 'event' is compatible with the process-based view we will discuss further on (see section 7.3 and 8). Note also that Lewis had his own theory of events. The differences between his account and Kim's, however, do not matter for our purposes.

[11] For a third example (aphids and *Buchnera*), see Leuridan 2012, section 6.

[12] Lewis, in the quoted passage, merely talks about 'nonimplication'. Craver writes that "in the constitutive relation, a token instance of the property ψ is, in part, constituted by an instance of the property φ; as such, the tokening of φ is *not logically independent* of the tokening of ψ." (2007, p.153, our emphasis) Hence we take it that it is *logical* implication which is at stake.

relations in mechanisms are not defined or assumed, but discovered empirically by means of interlevel experiments (Craver 2007; Bechtel 2004). Our focus – like Craver's and Bechtel's – is on empirical neuroscience and related disciplines, not on armchair neuroscience.

To conclude: Lewis may perhaps be right that my speaking this sentence cannot be the cause of my speaking the first half of it, but from that it does not follow that S's ψ-ing and X's φ-ing cannot be causally related. Nonidentity and nonimplication do not apply here. Nonoverlap is not required for causation. It would of course take more than this section to establish this in full detail. Yet we submit that this line of reasoning should suffice to make room for pursuing our intermediate goal.[13] So let us proceed.

6. Scientific examples of interlevel causal processes in mechanisms

Metaphysical discussions in the philosophy of science are best informed by scientific case studies. Contrary to the philosophical quasi-consensus, much of the experimental work in neuroscience and psychology seems to have progressed under the assumption that it is *causally* relevant to a whole when its parts are manipulated or that – vice versa – manipulating the whole *causally* leads to changes in the workings of its parts.

Both bottom-up and top-down experiments[14] in these disciplines seem to be freely interpreted in causal terms.[15] Bottom-up experiments involve the manipulation of certain properties of parts of the mechanism to affect a change to the behaviour of the mechanism as a whole. Examples are gene manipulation, the use of added transgenes, the knocking-out of other specific genes, and optogenetics, a method of neuromodulation that uses light to intervene on the workings of living cells that have been genetically modified to express light-sensitive ion channels (Han et al., 2017). Top-down experiments consist of an intervention on the behaviour of the mechanism as a whole to induce some change in its parts. Scientific research of this kind usually features an experimental set-up in which the environment or the state of the mechanism is altered in some explicit way to observe the impact on some or all of the relevant components (Bremner, 2006).

We present two sets of examples: neuroscientific examples, specifically experiments carried out by Mark Mayford et al. (1996), which Eric Kandel discusses in terms of interlevel causation (section 6.1); and a psychological example by David Vernon et al. (2015), which the authors present as containing elements of bidirectional causation between the levels of a mechanism (section 6.2).

6.1. Interlevel causation between the processes underlying spatial memory

Kandel describes a number of bottom-up experiments and explicitly terms them as cases involving interlevel causation:

> Biological analysis of learning requires the *establishment of a causal relation between specific molecules and learning*. This relationship, which has been difficult to demonstrate in mammals, can now be studied in mice either by the use of transgenes or the selective knockout of genes. (2000: p.1272; italics added)

[13] If we reach our intermediate goal, the double assumption which we started from in the current section, viz. that (1) the constitutive relation is synchronic and (2) that it makes sense to think of the constitutive relata as time-slices, should be given up. Giving up (1) only strengthens the arguments just presented. Giving up (2) does not undermine them.

[14] Craver (2007, p.145-162) provides a detailed account of the different varieties of such experiments.

[15] Craver and Bechtel (2007: p.556-562) analyze and explain away several cases of supposed bottom-up and top-down interlevel causation.

More specifically, Kandel (2000: p.1265-1273) describes a series of experiments on the importance of associative long-term potentiation (LTP) for the functioning of spatial memory in mice (see also Squire and Kandel, 2000). In the context of spatial memory, LTP is a synaptic mechanism responsible for maintaining a coherent spatial map over time. This synaptic activity persistently strengthens the signal transmission between neurons in the hippocampus. It is thought that this synaptic plasticity is responsible for encoding learning and memory. Hence any defects in LTP should be expected to interfere with spatial memory. Experiments are explicitly designed to investigate the effect of controlling the gene expression in genetically modified mice in regards to their ability to perform rudimentary spatial tasks. The expression of a specifically prepared transgene is selectively turned on or off, by administering a drug. In a specific case, by Mayford et al. (1996), the expression of the persistently active form of the Ca^{2+}/calmodulin-dependent protein kinase gene in a genetically modified mouse was shown to interfere selectively with LTP, resulting in an instability in the hippocampal place cells. The mutated mouse was unable to form an adequate place field, which is an internal representation of the animal's location within its surroundings and the basis for the spatial map needed for spatial memory. As a result, the mouse was hard-pressed to complete spatial tasks. When, by administering a specific set of drugs, the transgene was turned off, the LTP of the mutant mouse gradually (!) returned to normal and the animal's capability for spatial memory was restored.

In order for these bottom-up experiments to fit our purposes, as relevant instances of interlevel causation, they must meet the conditions for an ideal etiological intervention, as determined by Woodward (2003).

It is not particularly difficult to think of these interactions in Woodwardian terms, provided one does not, by assumption or stipulation, rule out a causal interpretation from the start (see footnotes 7 and 16). The expression of the Ca^{2+}/calmodulin-dependent protein kinase gene, and its relevance to the stability and coherence of the spatial map, conforms to the minimum requirement for a cause in Woodward's sense:

> C is a genuine cause of E if, given the appropriate background conditions, there is a possible manipulation of the cause C such that this is also a way of manipulating or changing the effect E. (Woodward, 2003: p.16)

Changes in the expression of the gene lead to changes in the workings of the LTP, and ultimately in spatial memory. This case also satisfies Woodward's definitions for interventions and intervention variables (2003: p.98). We focus on his notion of intervention variables.[16] His first two conditions are met:

> (I1) *I* causes *X.*
>
> (I2) *I* acts as a switch for all other variables that cause *X*. When *I* attains certain values, *X* ceases to depend on the values of other variables that cause *X* and instead depends only on the value taken by *I*. (Woodward, 2003: p.98)

The changes to the gene (*X*) are caused, and completely controlled, by the researchers' actions (*I*). The third and fourth conditions proceed as follows:

> (I3) Any directed path from *I* to *Y*, goes through *X*. *I* does not directly cause *Y* and is not a cause of any causes of *Y* that are distinct from *Y*, except for those built into the connection *I* - *X*-*Y* itself.

[16] It may again be objected that we are misapplying Woodward's framework. See the interesting work of, among others, Romero (2015), Baumgartner and Gebharter (2016) and Baumgartner and Casini (2017). These authors have criticized the application of Woodward's interventionist framework in the context of mechanistic interlevel relations. These criticisms all share a crucial assumption, however, viz. that constitutive relevance is not causal. Therefore, their results by themselves cannot be used to undermine our argument. But if our proposal fails, this would add to the importance of their endeavour. See also footnote 7.

(I4) *I* is independent of any variable *Z* that causes *Y* and is on a directed path that does not go through *X*. (Woodward, 2003: p.98)

An intervention on the gene expression is by no means a direct intervention on spatial memory (*Y*), just like a direct intervention on a simple pendulum's length is not a direct intervention on its period (see section 5). Still, there is an influence on spatial memory of the intervention on gene expression, via the intermediary of LTP. Moreover, the experimenters' intervention on the gene expression is independent of any other possible causes, unaffiliated with gene expression, of spatial memory.[17] Additionally, this relation may be deemed invariant, as it retains quite some stability under a range of possible testing interventions. We can thus conclude that in the experiment under consideration, the expression of the Ca^{2+}/calmodulin-dependent protein kinase gene is causally relevant to spatial memory.

This case has been extensively treated by Craver (2007). Following his work, there is a quasi-consensus in the philosophical literature that LTP is constitutively relevant for spatial memory. We do not dispute this constitutive interpretation. Yet, even though Woodward may not have meant for his account to include interlevel causation, Craver opened the door – for the good, we would say – for a causal interpretation when he couched his mutual manipulability account of constitutive relevance in Woodwardian terms.

This suggests that we are in fact presented with a *causal* constitutive relation. As Kandel writes:

> Together, these experiments provide insight into the genetic chain of *causation* that connects molecules to LTP, LTP to place cells, and place cells to the outward behavior of the animal as reflected in both short- and long-term spatial memory. (2000: p.1273; italics added)

As constitutive relations supposedly are instantaneous, the question now becomes: is the causal relation in question synchronic?

Interpreting this particular case as involving concrete processes, rather than abstract variables, shows that in a wet and messy biological context some time elapses before any effects actually arise. Interfering with LTP via an intervention on the gene expression does not lead to an immediate destabilization of the resulting place field:

> In both types of mutants the interference with LTP does not prevent the formation of place fields. Although the place fields formed in the absence of LTP are larger and fuzzier in outline than normal, LTP is not required for the basic transformation of sensory information into place fields. *LTP is required for fine-tuning the properties of place cells and ensuring their stability over time*. (Kandel, 2000: p.1266-1267; our emphasis)

The processes in question are of a complex, continuous character, and they need time to unfold and develop across the different levels of the mechanism. This seems to be the case for many, if not most, biological and neuroscientific mechanisms. More on this in sections 7.3 and 8.

6.2. The bidirectional causal relation between the perceptuo-motor coupling and cognition

Similar to the field of biology, and perhaps even more strikingly, psychological scientific practice hinges on the possibility of interlevel causation. Psychotherapy operates under the assumption that social interventions can change or alter brain chemistry or neuronal plasticity in some causally significant way. We have touched upon

[17] We acknowledge, as does Craver (2007: p.103), that such experiments are much less clear in the real world. In the history of LTP research, it has been hard to determine which of the many interactions are relevant to the occurrence of LTP, making it difficult to perform the required *ideal* interventions.

this when referring to top-down experiments in neuroscientific research. Moreover, many neuroscientists, including Kandel (2013), consider case studies in psychological research featuring downward causation unproblematic. Consequently, there are many experiments that straddle the divide between both these disciplines. Specific examples include the effect of abacus training on neural pathways (Li et al., 2016) or the influence of high-stress environments on neurochemical responses (Bremner, 2006). What is interesting about such cases is that they do not merely indicate the existence of downward causation, but seem to additionally recognize the existence of a *bidirectional* causal link. Changes to neural connections influence the act of, or capacity for, learning.

The psychological case detailed here deals with such a bidirectional connection between the lower-level coupling of perception and action on the one hand, and higher-level cognition on the other hand. As evidenced by a number of neuroscientific and psychological experiments, there is a clear – intralevel – reciprocal causal relationship between perception and action.[18] In all these cases, perception is understood to influence actions and – vice versa – actions are bound to have an impact on perception. According to Vernon et al. (2015: p.3-5), this relation between action and perception is constitutively relevant to the autonomous system of a cognitive agent. What they term 'constitutive autonomy' is the ability of the system to act as an autonomous entity via self-organization, self-production and self-maintenance, in short: self-regulation. In an autonomous agent, these processes can be described as far-from-equilibrium processes: they require continuous fine-tuning to function properly and maintain the balance of the system. A popular example of such a far-from-equilibrium process is an animal's internal temperature regulation (see, for instance, Recordati and Bellini, 2003: p.28-30). Maintaining optimal body temperature depends on a feedback loop that allows the system, or body, to regulate the values of certain parameters around a set point.[19] Given this continuous fine-tuning and the far-from-equilibrium nature of the processes involved, the interlevel relation should not be treated as synchronic. The limbic system relays signals related to sustaining the viability of the organism while being entrained by the prefrontal cortex. The latter, in turn, is connected to the neocortex. Together they facilitate adaptive behaviour or self-regulation. The limbic system relays signals to parts of the brain that in time become relevant to the overarching process of self-regulation, and ultimately to cognition.

Vernon et al. argue that in cognitive agents the global system may anticipate certain environmental events and actively prepare for them. In the case of internal temperature, the cognitive agent may decide to seek out some shade to help regulate its body temperature. This preemptive action or predictive self-regulation is a fundamental far-from-equilibrium process known as allostasis. It is achieved via a degree of centralized control exerted by the higher-level cognitive function on the lower-level coupling, or subsystem, of action and perception. The parts and the whole in this context are labeled by Vernon et al. as local and global factors respectively; the interactions at the different levels are referred to as local and global system dynamics. The relation between the global and the local level is explicitly termed *constitutive*; the global level is constituted by the organized local factors (Vernon et al., 2015: p.5). Yet it is also taken by the authors to be circularly *causal*:

> Thus, circular causality exists between levels of a hierarchy of system and sub-system. This influence of macroscopic levels on microscopic levels in a system is captured in the term downward causation i.e. that global-to-local or macroscopic-to-microscopic aspect of circular causality whereby the global system behaviour causally influences the individual

[18] Vernon et al. (2015) point to Rizzollatti et al. (1996), Rizzollatti and Fadiga (1998), Rizzollatti and Craighero (2004) and Thill et al. (2013).

[19] Although the term is seldom used in biological research, it is generally agreed that a true equilibrium with respect to body core temperatures in homeothermic mammals is only attained when the heart ceases to function. In other words, only in death will biological systems ever reach a state of true thermal and mechanical equilibrium with the external environment.

> system components. In circularly causal systems, global system behaviour influences the local behaviour of the system components and yet it is the local interaction between the components that determines the global behaviour. Thus, […] the degree of participation of the components of a system is determined by the global behaviour which, in turn, is determined by the interactions among the components through causal reciprocal feedback loops. (Vernon et al., 2015: p.5; bibliographical references omitted)

The relations described in this example are not just taken to be causal by the researchers themselves. They are also causal in a Woodwardian manipulationist sense – again provided one does not, by assumption or stipulation, rule out a causal interpretation from the start. Interventions on the perceptuo-motor level influence cognitive processes, and conversely, intervening in cognitive processes has an effect on specific bodily functions. In the latter case, this is borne out by several psychological methods of cognitive behaviour therapy, such as thought stopping, which are often employed with measurable impact in disrupting the physiological effects of anger or anxiety attacks (e.g., the associated rise in blood pressure and heart rate – see Putri and Kurniawan (2016)). From an interventionist point of view, this is reasonable evidence for a causal relationship. For reasons of space, we will not further explicate this case using Woodward's conditions (I1)–(I4).

7. Temporality, processes and the constitutive relation

The scientific cases in section 6 suggest that constitutive relations can be causal and should not necessarily be viewed as synchronic. More often than not, they harbor a delay between action and reaction, which we believe is not adequately accounted for in Craver and Bechtel's view.

In the present section, we will look at a number of views on constitutive relations, mechanisms and interlevel causation that can help us to reinterpret our case studies. Each, in its own way, functions as an attempt to reconcile the temporality present in constitutive relations. First, we will examine the possibility of adding a constraint relation to our conceptual framework, as suggested by Max Kistler (2009) and William Bechtel (2017). Second is an account based on temporal parts in acting entities, defended by Marie Kaiser and Beate Krickel (2017). Finally, we will discuss Michael Kirchhoff's (2015) turn towards process ontology, a radical paradigm change inspired by Johanna Seibt (2009).[20] We will delineate our own position further in section 8.

7.1. Downward causality and the constraint relation

In searching for an explanation of supposed cases of downward causation in mechanisms, and the apparent diachronic activity underlying it, both Kistler (2009) and Bechtel (2017) have argued for adding a constraint relation to the mechanists' toolbox.

The relation between a whole and its parts is not one of strict identity. Parts may break down or be removed without affecting the operations of the whole, and – vice versa – the properties of the whole may change without that having to affect all of its parts. Mirroring this fact, a constraint reduces the number of ways in which the system may evolve or change. It limits the number of outcomes at the different levels of a complex mechanism, and consequentially, partially determines them. Again, consider the example of homeostatic equilibrium, which is also employed by Kistler: "An animal's body temperature corresponds to a degree of

[20] Another interesting critique of the strict distinction between causal and constitutive relations which draws on the temporality of processes is given by Mc Manus (2012). Since he focuses on the subdomain of developmental biology, we will not review his arguments in detail here.

freedom subject to the constraint of remaining within limits imposed by a regulatory mechanism at the level of the organism" (2009: p.603).

Following the earlier work of Craver and Bechtel, both Kistler (2009) and Bechtel (2017) take interlevel causation to consist of intralevel causal and interlevel non-causal relations. Yet, they differ in some important respects.

Kistler (2009) discusses LTP and spatial memory as we did in section 6.1. He acknowledges the possibility of downward causation under certain conditions:

> […] the judgment that a given lower-level property *e* of a part of a mechanism is causally influenced in a "downward" way by a higher level property *C* of the whole mechanism, can be empirically justified [if certain conditions are satisfied]. (2009: p.607)

He is unwilling, however, to take the possibility of synchronic causation seriously and acknowledges the possibility of a delay or time lag in a causal interpretation of interlevel relations (Kistler, 2009: p.602-607). Enter the constraint notion. Focusing on the top-down direction, he writes:

> Top-down causation is conceivable if it is understood in terms of the influence of a higher level property *C* of a whole mechanism at time t_1 on a property *e* of a lower-level part at some later time t_2. If a higher-level law imposes a constraint on the state of system *S*, a higher-level property of *S* at time t_1 can be (partly) causally responsible for a lower-level property that one of the components of *S* has at some later time t_2. (Kistler, 2009: p.604)

Bechtel (2017) has a different view of constraint. Whereas Kistler's relation may be regarded as causal – at least in some cases – by virtue of its temporal asymmetry, Bechtel's constraints are synchronic and therefore non-causal:

> But in the moment when the mechanism receives causal input from outside by having the state of one or more of its parts altered, the relation between the parts and the mechanism as a whole is not diachronic but synchronic. At a given time, the mechanism is constituted of its various parts. The natural language to use to talk about how synchronically the parts are affected by the whole is that of *constraint*—being situated in the mechanism constrains the behavior of the part. (2017: p.271)

In short, although the propagation of effects by the constrained system as a whole may involve the kind of diachronic activity we saw in our examples in section 6, the interlevel constraint by the whole of the mechanism on its parts always occurs synchronically. It is realized through organizational effects between the components at the same instant in time (Bechtel, 2017: p.256).

A hidden advantage of the constraint solution is that it not only can account for cases, or apparent cases, of downward causation, as Kistler and Bechtel do, but also for upward causation (as an anonymous reviewer has helpfully pointed out). Constraints can work both ways. The mechanism as a whole constrains the parts; but the parts also constrain the whole.

These constraint accounts face a number of problems, however. A disadvantage of Kistler's proposal is that it leads to a tension or perhaps even an inconsistency. Consider the following propositions which he subscribes to:

(A) Levels in mechanisms are constitutively related.

(B) Constitution is synchronic and not causal.

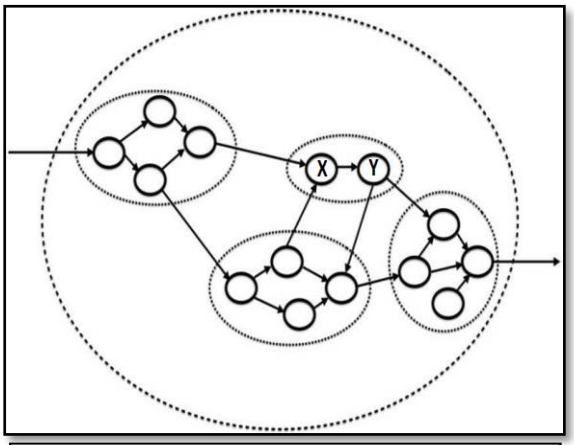
(C) These same levels are also related via a constraint relation.

(D) The constraint relation may be considered as diachronic and causal under the right circumstances.

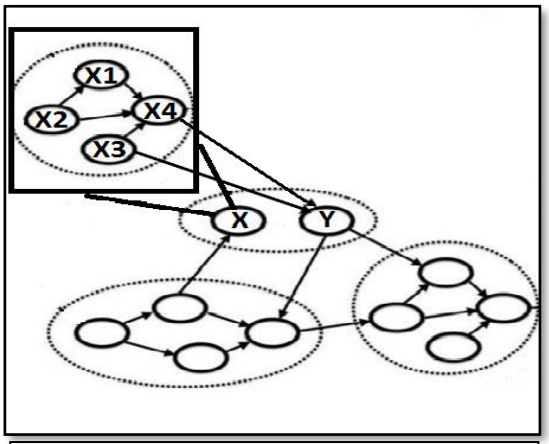
(B) can be interpreted in a strong or in a weak sense. In the strong sense, (B) says that if *x* and *y* are related constitutively, they cannot be related causally. Following this strong interpretation, (A)-(D) are inconsistent. In the weak sense, (B) says that if *x* and *y* are related constitutively, that token relation is not causal, leaving open the possibility that *x* and *y* are *also* related via another, causal, constraint relation. This would lead to a tension however; *x* and *y* would be related by two different relations – one causal, the other non-causal, one synchronic, the other diachronic – which nonetheless work together smoothly. That would call for further explanation.

Bechtel faces a different problem: epiphenomenalism (perspectival or genuine). In order to tackle the question how to delineate mechanisms, i.e. when entities constitute a higher-level mechanism, Bechtel appeals to graph-theoretic representations of biological networks (2017). In these representations, mechanistic levels are flattened: they only comprise nodes denoting entities and edges denoting causal influences.[21] Higher-level mechanisms are not depicted as such; they are equated with highly interconnected clusters of nodes involving complex dynamic behaviour, due to their complex organization including feedback loops (2017: section 3). Due to their complex organization, these mechanisms as interconnected modules constrain their parts.

As any representational tool, graph-theoretic representations are subject to pragmatic choices pertaining to the preferred level of description (2017: p.270-271). This in itself is unproblematic. Nodes may represent molecules, or neurons, or complexes of neurons, … Researchers are free to choose "the entities at which the graph representation bottoms out" (p.270). They may choose to decompose some mechanisms while deliberately representing others as a single node. As a result, "[t]he graph representation will show the components into which the one mechanism has been decomposed interacting with the other mechanisms that have not been decomposed" (2017: p. 270).



Graph (1): *Flattened redrawing of Craver's diagram, with dotted ovals grouping nodes at the middle and top levels of the original diagram (cf. Bechtel, 2017: p.262).*



Graph (2): *Decomposition of a module X into a highly interconnected, complexly organized set of nodes X_1, X_2, X_3 and X_4. Note that there is no edge from X to Y.*

But here's the rub. Suppose that in a first graph, X and Y are two nodes such that X $\rightarrow$ Y. In other words, X causes Y according to graph (1). Consider now a second graph (2) in which Y is left unchanged (it is still a node), but X is decomposed into a highly interconnected, complexly organized set of nodes X_1, X_2, X_3, … Some of these, say X_3 and X_4, are causes of Y, the others are not. X is no longer in the picture as a node, but as a module, and there is no edge from X as such to Y. X constrains X_3 and X_4, but since the constraint relation is said to be non-causal, X is in itself not a cause of Y according to graph (2).

[21] Edges in graph-theoretic network representations may denote different types of relations, yet in his discussion of mechanisms Bechtel treats them as causal (2017: p.263).

How should we make sense of the disappearance of the X-to-Y causal relation? One way would be to say that whether X causes Y indeed depends on our choice of representation. X is epiphenomenal from one perspective, but not from the other. This conflicts with the central manipulationist idea, however. Whether changing X is a potential tool for the purpose of manipulating and controlling Y, does not depend on how we depict X and Y.[22] Hence this perspectival epiphenomenalism is to be rejected. Another way would be to say that X was never a cause of Y after all and that its decomposition into X_1, X_2, X_3, … made this clear. But that could be said about all mechanistically decomposable phenomena, leading to genuine epiphenomenalism with respect to all higher level phenomena. In our opinion, this genuine epiphenomenalism is to be rejected too.[23]

Finally, Kistler and Bechtel share one more problem. Instead of reducing the number of metaphysical relations, they add a new one, 'constraint', to the old pair 'causal relevance' and 'constitutive relevance', in a single context, i.e. to tackle a single case study. As we will see, the more preferable and parsimonious approaches discussed in the next sections commit to a reinterpretation of constitution instead of offering a new relation on top.

7.2. Temporal parts in entity-involving-occurrents

Recent work by Beate Krickel, based on earlier work with Marie Kaiser, presents a possible explanation for interlevel causation which utilizes the notion of temporal parts in acting entities.

Kaiser and Krickel (2017) attempt to resolve the problems with part-whole causation by acknowledging certain spatial and temporal parts in the phenomena explained by mechanisms. These so termed OIOs (*object-involving occurrents*), which Krickel (2017) renames as EIOs[24] (*entity-involving occurrents*), are processes, events or states causally engaged in the system, or the object, under consideration.[25] A specific example of an

[22] There is a partly analogous phenomenon in the causal modelling literature. Suppose that (variable) X is a cause of (variable) Y. Whether X is a direct cause or an indirect cause of Y in a causal graph depends on which other variables besides X and Y are included. This relativity of the direct/indirect causation distinction is innocuous and does not conflict with the central manipulationist idea.

[23] It deserves to be mentioned that Bechtel explicitly touches upon the problem of epiphenomenalism and claims that his graph theoretic account is not guilty of it (2017: p. 269-270). He offers three reasons. The first is that "the nodes in a network need not belong to a common level in any of the standard senses" (p. 270), such as levels of size, or levels of types of entity. Levels can only be distinguished locally, he adds, within a mechanism. Hence if a graph comprises several modules or mechanisms, one cannot treat its nodes as at a common level. That is true, but leaves our argument about graphs 1 and 2 unaffected, as it does not hinge on the assumption that there is such an all-encompassing common level. Bechtel's second and third reason we have already mentioned. These are that researchers can always choose for a finer-grained or a more coarse-grained level of description respectively. Again, that is true, but leaves our argument unaffected as well. It is precisely the (true) fact that researchers can switch between levels of description that (inadvertently) gives rise to said epiphenomenalism within Bechtel's framework.
That Bechtel opposes epiphenomenalism can also be seen in his work with Jason Winning, in which he defends emergent causal powers. Although the constraint relation itself is not causal, it does "enable objects to have novel, emergent behaviors, this is tantamount to the emergence of causal powers… The ways that mechanisms and their parts are constrained explains why both mechanisms and their components are intrinsically productive; by means of possessing such emergent powers, mechanisms and components causally produce the effects they do" (Winning and Bechtel, 2018 :p. 294).

[24] We will use the term EIO from here on.

[25] Objects are, for example, organisms, brains, cells, or ion channels. The objects engaged in constitutive-mechanistic phenomena typically have quite clear spatial boundaries (such as membranes) which allow a distinction between inside and outside (see Kaiser 2015). The notion of an object is also supposed to refer to systems. Systems are typically composed of more than one object and most biological systems—such as gene

EIO would be a muscle fibre contracting, seen as an object or entity (= muscle fibre) displaying an activity or behaviour (= contracting), or an entity involving an occurrent (Kaiser and Krickel, 2017: p.768-770). EIOs have spatial as well as temporal parts, defined as follows (Krickel 2018: p.64):

(temporal EIO-part) An acting entity E_1 is a temporal EIO-part of another acting entity E_2 iff:

(i) the entity involved in E_1 is identical with the entity involved in E_2;
(ii) the activity involved in E_1 begins later and ends earlier than the activity involved in E_2, or the former begins simultaneously with the latter and ends earlier than the latter, or the former begins later than the latter and ends simultaneously with the latter.

(spatial EIO-part) An acting entity E_1 is a spatial EIO-part of another acting entity E_2 iff:

(i) the entity involved in E_1 occupies a proper sub-region of the spatiotemporal region occupied by the entity involved in E_2;
(ii) the activity involved in E_1 occurs during the activity involved in E_2.

Krickel (2018: p.64) regards constitutive relevance as a synchronous relation involving a diachronic dependency relation. Because of this, mutual manipulability can indeed involve causal dependency, and hence interlevel causal relations. Constitutive relevance relations synchronically relate the whole EIO with its proper spatial EIO-parts (i.e., à la Craver and Bechtel). A constitutively relevant spatial EIO-part of a phenomenon exists, however, for an arguably shorter time span than the phenomenon. A temporal EIO-part of the whole can therefore be diachronically causally relevant to a spatial EIO-part and vice versa. More specifically, causal dependency is taken to hold between a component of the mechanism and a chronologically later temporal EIO-part of the phenomenon, or between a temporal EIO-part of the phenomenon and a chronologically later component.

In the case of LTP and spatial memory, Krickel (2018) distinguishes a number of EIOs, including: the mouse navigating its surroundings, the spatial map generated by the hippocampus, and LTP inducing neuron activity. She states that the hippocampus is a proper spatio-temporal part of the mouse and that the generation of the spatial maps occurs within the time frame of the navigation behaviour. Hence the hippocampus and its generating spatial maps form a spatial EIO-part of the mouse and its navigating behaviour. According to Krickel they are mutually and causally dependent. Take for example the mouse navigating its surroundings, and employ the definition given for temporal EIO-parts. The navigating mouse is trivially identical to the navigating mouse. If the mouse turns left at t_1, this will cause the activity in the hippocampus at t_2, which in turn will cause the mouse's turning right at t_3. And so on. The causal dependency holds between a component of the mechanism (e.g., the hippocampus generating spatial maps) and a chronologically later temporal EIO-part of the phenomenon (e.g., the mouse turning right at t_3 during navigation).

This description of events incorporates a dual relationship, as Krickel (2018) combines a synchronous constitutive relevance relation with diachronic causal dependency. This gives rise to a tension similar to the one found in Kistler's framework:

Let X_i (for $i \in \{1, \ldots, n\}$) and S be EIO's[26] and let the former be components in the mechanism for the latter. Let superscripts 1 and 2 be time indices. These refer to two distinct, nonoverlapping time frames which are extended in time, not time points or time slices, where 2 is later than 1. Hence X_i^1 and S^1 occur simultaneously

regulatory networks, the immune system, populations, or ecosystems—have less clear spatial boundaries than objects (Kaiser and Krickel, 2017: p.768).

[26] We will leave out explicit reference to the activities (φ-ing and ψ-ing) in question, but only in the interest of readability. Hence S and the X_i are not to be taken as objects or entities. They are entity-involving occurrences.

at t_1; X_i^2 and S^2 occur simultaneously at a later time t_2. X_i^j is a proper spatial EIO-part of S^j, for each $i \in \{1, \ldots, n\}$ and for each $j \in \{1, 2\}$. As is common in the literature, all these EIO's can be conceived of as variables which may take different values. For ease of exposition, we will talk about the states which they are in or even leave the states unmentioned. Now consider the following relations which we think should hold according to Krickel (2018):

1. The state of S^1 is determined constitutively and hence synchronically by the states of the X_i^1. Once the latter states are fixed, the state of S^1 is fixed as well.
2a. The state of an EIO at a later time is partly determined – or co-determined – by the state of that same EIO at an earlier time; hence S^1 co-determines S^2 …
2b. and X_i^1 co-determines X_i^2 for each $i \in \{1, \ldots, n\}$.[27]
3. Causal dependency holds between a component of the mechanism and a chronologically later temporal EIO-part of the phenomenon. Hence X_i^1 co-determines, in the sense of causally influences, S^2, for at least some $i \in \{1, \ldots, n\}$.
4. Causal dependency also holds between a temporal EIO-part of the phenomenon and a chronologically later component. Hence S^1 co-determines, in the sense of causally influences, X_i^2, for at least some $i \in \{1, \ldots, n\}$.

From 2a. and 3. it follows that the state of S^2 is co-determined by both S^1 and some or all of the X_i^1. Analogously it follows from 2b. and 4. that each of the X_i^2 is co-determined by the corresponding X_i^1 and some also by S^1. But there is no wiggle room for the state of S^2 once those of the X_i^2 are fixed, because the following holds in analogy to 1.:

5. The state of S^2 is determined constitutively and hence synchronically by the states of the X_i^2. Once the latter states are fixed, the state of S^2 is fixed as well.

It would be a miracle if all these relations were to work together this smoothly. That would call for further explanation.

To this we would like to add that, from our perspective, it is preferable for reasons of parsimony, and arguably more in line with our case studies, to subscribe to a single causally efficacious constitutive relation instead of two different ones, diachronic causality and synchronic constitution, in a single context or case study. We come a little closer to such a single relation in the next section.

7.3. **The primacy of processes**

The interlevel relata in both our case studies are inherently temporal. Perhaps a turn towards a process-view of reality can make sense of the dynamical systems represented by our cases.

An important proponent of such a process-view is Johanna Seibt. She has argued (2009) that one specific axiom of the prevailing substance paradigm has proven particularly troublesome. This is the assumption that all concrete individuals or entities, i.e. all the basic constituents of nature, (i) each have a determinate unique spacetime location and (ii) have this location necessarily since they are individuated in terms of their location. According to Seibt, such a conception glosses over subject-less activities, which are those activities that are not the doings of persons or things. Examples are 'it is snowing, not raining,' 'the radiation has decreased by 50%,' or 'there's water in the next valley' (2009: p.484). She recommends replacing this assumption, thus advocating a radical change in ontological paradigm:

[27] We leave it an open question whether the relation between an EIO at t_1 and that same EIO at t_2 is a causal relation or some other form of co-determination.

> We can replace the particularist conception of individuals with a view of individuality that focuses not on location but rather on 'specificity-in-functioning' in the widest sense of 'functioning,' i.e., focuses on the dynamic role of an entity (e.g., an activity) within a certain dynamic context. (2009: p.484-485)

In other words,

> whatever we talk about in common sense and science is an individual the distinctness of which does not derive from its unique placement (which it may but need not have) but from 'what it does' or 'how it interacts,' i.e., from its mereological relationships to other processes.[28] (Seibt, 2009: p.496)

Seibt uses the aforementioned subject-less activities to model processes in her general process theory (GPT). According to GPT:

> […] the world is "the ongoing tissue of goings-on" - the entities of any domain of a language or theory are best described as general processes, i.e., as individuals which are (i) concrete or spatio-temporally occurrent but do not necessarily occur in a determinate bounded region, (ii) more or less specific or determinate, (iii) more or less spatially and/or temporally recurrent, and (iv) more or less complex. (Seibt, 2009: p.495)

General processes are described as independent, individual, concrete, spatio-temporally extended, non-particular, non-countable, determinable, and dynamic entities. Even though subject-less activities serve as the model for general processes, the notion of 'general processes' is much more encompassing. Such processes

> […] are the ontological counterparts not only of statements about subjectless activities but also of statements about things, stuffs, events, properties, actions, relations, persons, etc. In other words, any concrete individual is a general process, since the logical differences between statements about, say, things and stuffs, or activities and events, can be accounted for in terms of ontological differences among varieties of general processes. (Seibt, 2009: p.486)

In the prevailing substance paradigm, non-countable, non-particular stuffs and activities (e.g. water, snowing) have been analysed in terms of countable and uniquely located entities (e.g. 'this puddle of water') or bounded developments (e.g. 'snow flake's S_1's moving from p_1 to p_2'). GPT, by contrast, treats the countable as a sub-form of the non-countable (Seibt 2009: p. 488).

Seibt's proposal, though radical, has some interesting consequences for our paper.

First, it offers a unique argument to further undermine the logical independence argument (cf. section 5). The supposed logical dependence between constitutive relata emanates from treating them in an STI-fashion, i.e. as being spatio-temporally included. If, following Seibt, it no longer makes sense to individuate constitutive relata in terms of their spatio-temporal location, the problem of logical dependence vanishes. Constitutive relata may still be related mereologically in terms of their specificity-in-functioning, more on this below, but that relation is a contingent one. LTP plays a role in spatial memory, but not per definition. To repeat, our focus – like Craver's and Bechtel's – is on empirical neuroscience and related disciplines, not on armchair neuroscience.

Second, Seibt deliberately uses the somewhat vague sense of function as expressing a 'dynamic role' in the specificity-in-functioning criterion, and hence *consciously* blurs, she writes, the distinctions between

[28] Seibt's general process mereology is not based on spatio-temporal inclusion. See below.

constitutive dynamic components, characteristic activities, and causal consequences of a dynamic (Seibt, 2009: p.503). In that sense, she helps to break down the distinction between constitutive and causal relations.

Seibt does not explore the issue of causation versus constitution in her work, yet starting from the radical changes she proposed, Michael Kirchhoff (2015), has explicitly argued against a *fundamental* distinction between causality and constitution. As we will see, however, his opposition to this distinction is not yet radical enough and ultimately incoherent.

According to Kirchhoff, causation and constitution, though not the same, should be conceived of as more akin than is traditionally assumed. The traditional conception of constitution, he contends, does not adequately account for biological systems. That traditional conception, which includes Craver and Bechtel's (2007) iteration, is a synchronic relation between spatio-temporally coincidental events or objects (2015: p.320-321). The classic example concerns the statue of David and Piece, the piece of marble that constitutes the statue. Any change to one of the two comes down to an immediate (instantaneous, synchronic) change to the other. Biological systems, by contrast, involve processes where change in time and temporal unfolding are essential. [29,30]

Kirchhoff does not fully adopt Seibt's GPT, but his approach shares some kinship with process ontologies. This kinship can be fleshed out in terms of perdurance, as opposed to endurance (2015: p.330-331). Let us return to the example of David and Piece. At any point in time *t*, David and Piece can be determined to exist, as they do not depend on any unfolding or evolution to determine their identity. Their existential persistence can be described as *endurance*. This is not the case with processes (2015: p.324-325). Processes at every mechanistic level are time continuous, an idea he derives from Hofweber and Velleman (2011: p.56). Moreover, these processes occur and develop in different time-scales. The time-scales on which neural modulations progress are, for instance, different from the time-scale of a higher-level process such as memory. These scales do not necessarily coincide with mechanistic levels. A single level of a mechanism can involve multiple different time-scales. Because of this thoroughly dynamic and evolving character, it makes no sense to think of them as simple snapshot instances at some time *t*. Processes are therefore characterized by *perdurance*. In this way, Kirchhoff incorporates the perhaps most important concept from Seibt's ontology of processes: the denial that all concrete individuals occupy a unique spatio-temporal location (Seibt, 2009: p.484).

Because for Kirchhoff the interlevel, constitutive relata are processes which cannot be thought of in a snapshot fashion, synchronic constitution does not genuinely apply here. It would be strange that something so clearly temporal in nature, namely processes at a lower level, synchronically constitute something that is equally

[29] It should be noted that an emphasis on temporal unfolding is present in part of the mechanistic literature. Machamer, Darden and Craver (2000), for example, seem to agree with such a process-based view of mechanisms, especially within a biological context:

> Often, mechanisms are continuous processes that may be treated for convenience as a series of discrete stages or steps. [...] Although we may describe or represent these intermediate activities as stages in the operation of the mechanism, they are more accurately viewed as continuous processes. (Machamer, Darden and Craver, 2000: p.12-13)

Kirchhoff fails to mention this trend in the mechanistic literature. Still, he is right in asserting that the processual nature of mechanistic activities has not yet been sufficiently accounted for and that the standard notion of synchronic constitution is inappropriate when it comes to biological processes. (We would like to thank an anonymous reviewer for pressing us on this issue.)

[30] Another scholar who has stressed the importance of processes in biological science, albeit in opposition to the notion of mechanism, is John Dupré (2012).

temporal, namely processes at a higher level. He does admit, that for pragmatic reasons, we can think in terms of synchronic constitution, yet:

> […] such an application can at best yield snapshots of a linear development. This kind of synchronic modeling or measuring strategy is often a practical necessity in empirical sciences, e.g., cognitive science, but should not be mistaken (or conflated) as genuine evidence for the higher-level processes and its [sic] sub-processes and components as being ontologically synchronic. (2015: p.326)

As an alternative, he proposes diachronic process constitution, a relation which "itself is diachronic and dynamic—just as the relata may be" (Kirchhoff, 2015: p.326). [31]

In Section 8 we will adopt some features of Kirchhoff's process view. Yet our aims, scope and even conclusion differ.

First, Kirchhoff's main aim is to save extended cognition from the causal-constitutive fallacy. But his concepts are not tied to EC and can be applied more widely (witness the LTP-case).[32]

Second, we differ concerning the general idea of the ontological primacy of processes. Though Kirchhoff's ultimate position on this matter is unclear, Seibt argues strongly for a radical change in ontological paradigm. We, however, are not sure that all cases of mechanistic phenomena require a process ontology, or that the substance paradigm should be abandoned wholesale. Therefore, we prefer to be as uncommitted as possible in this respect.

Third, despite Kirchhoff's attempt to argue that causal and constitutive relations are not "fundamentally distinct" (2015: p.342), in that the latter are synchronic and the former diachronic, he still considers the two separate in the following sense: "causal relations are exclusively intralevel, where the constitutive relation is interlevel (2015: p.349). This way, constitutive relations cannot be causal.

He does not provide any arguments for this claim, but just seems to echo Craver and Bechtel. However, Kirchhoff can rely even less on the three arguments (symmetry, logical independence and synchronicity) offered by Craver and Bechtel to ground this strict distinction. Concerning (a) the symmetry argument, he follows Craver in stating that the constitution relation is symmetrical (2015: p.350), but then also claims that the specific mode of causation[33] present in EC-cases can be symmetric as well (2015: p.350-351). He does hold to (b) the logical independence argument. However, this is not a settled issue (see section 5). Moreover, Kirchhoff subscribes to Seibt's specificity-in-functioning, which further undermines the logical argument applied to constitutive relata. This just leaves (c) the synchronicity argument, which as should now be clear, is undermined by Kirchhoff's plea for diachronic process constitution. Even though Kirchhoff seems absolved of all three arguments provided by Craver and Bechtel, he does not give up the entrenched resistance to a causal reading of the constitutive relevance relation. In this sense, his opposition to the fundamental distinction between causality and constitution is not yet radical enough and ultimately incoherent.

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[31] Kirchhoff supplies several real-world examples, e.g., a Watt generator, a Mexican wave or convection rolls, to illustrate his diachronic process constitution, but does not offer detailed accounts of empirical case studies.

[32] Beholden to enactivism and the Extended Cognition thesis in which brain, body and environment are thought of as dynamically coupled in a cognitive system, Kirchhoff challenges the causal-constitutive fallacy, a common objection against Extended Cognition by Adams and Aizawa (2008). Note that Adams and Aizawa's criticism would be undermined if we reach our end goal. Note also that Kirchhoff seems to acknowledge that his conception could also be relevant outside of EC (2015: abstract).

[33] Several adherents to EC, including Vernon et al. (2015), defend continuous reciprocal causation, or CRC, which involves multiple simultaneous interactions and complex feedback loops between causes and their effects.

Again, we are faced with two different relations in a single context. Only, instead of diachronic causality and synchronic constitution we now have diachronic causality and diachronic constitution, leaving us with even less reason to uphold a strict distinction between the two.

8. Diachronic causal constitution

All in all, we propose to analyse our case studies using only a single interlevel relation: constitutive relevance as a bidirectionally causal relation between processes, or diachronic causal constitution for short.

8.1. Parthood as 'functional belonging with'

Let us first take a look at its relata. As we have seen, the relata in our cases are intrinsically temporal. They cannot be thought of apart from their unfolding over time. In Kirchhoff's words, they cannot be conceived of in a snapshot fashion. In Seibt's words, they are non-particular, meaning that they cannot be individuated to a unique spatio-temporal location in the first place. This renders an STI-definition of parthood less apt in the present context. Parts can no longer be thought of as being necessarily spatio-temporally included in the mechanism as a whole. It may even occur that the time frame of a component extends beyond that of the whole mechanism.[34]

Following Seibt and Kirchhoff, mechanistic parts are thus better individuated by their specificity-in-functioning, i.e. in terms of their roles in a dynamic context. Again following Seibt, parthood, or 'is a part of', can be understood as "a highly general relation of functional 'belonging with' […], without implications concerning spatial or temporal containment'' (2009: p.489). We therefore suggest the following definition of parthood for use in a mechanistic context like our cases:

(FBW) P is part of a mechanism W iff P belongs functionally with W.

Notwithstanding their parthood relation, P and W can still be considered appropriately distinct. P has a different specific function, or role to play, than W.

(FBW) individuates parts in a functional fashion. Does it stand up to scrutiny?[35] Krickel (2018b: p.70-71) criticizes the functional approach to the individuation of parts, at least in the version she attributes to Craver (2007: p.190). Notwithstanding the differences between (FBW) and the view she targets, it is useful to check whether our proposal falls victim to her arguments. Krickel's criticism is based on two claims. The first claim is that "scientists often individuate [higher-level] entities before they know what this [higher-level] entity does or how it does what it does" (2018b: p.71). This is undoubtedly true, but it does not undermine (FBW). It only shows that in certain contexts (FBW) is not applicable, at least not epistemically. If it is not known what W does, it cannot be determined whether P belongs functionally with W. That is all. Krickel's second claim is that "[i]f we have to know which parts and which behaviors are crucial for the behavior of the higher-level entity in order to identify it, we end up in an epistemic circle. We need criteria for identifying entities that are independent of the identification of their parts" (2018: p.71). The antecedent of this second claim is clearly false, as is evidenced by Krickel's first claim. In short, Krickel's critique of the functional individuation of parts does not threaten (FBW). And, it would seem, it does not threaten Craver's (2007) account either.

Another criticism can be found in Laura Franklin-Hall's (2016). It is less specific than Krickel's (2018b), as it targets any account of parthood in a mechanistic setting and not just functional ones. Still, it is more threatening. Franklin-Hall emphasizes the new mechanists' failure to develop an adequate answer to the

[34] Take for example our Vernon et al. case. It is theoretically possible for the perceptuo-motor coupling to stay active in some instinctive manner, after higher-level cognition is shut down.

[35] We would like to thank an anonymous reviewer for flagging the two criticisms to be discussed.

carving problem, i.e. to the question how to carve mechanisms 'at their joints' and not in gerrymandered ways. An example of such a gerrymandered carving would be to decompose a neuron in four quarter-neurons. No existing criterion, she claims, rules out this bad carving. This holds for robustness, manipulability, physiological plausibility and (to a large extent) stability, as well as for mutual manipulability. To be honest, (FBW) will not do the trick either, as it may be argued that quarter-neurons belong functionally with their neurons. Yet since (at the time of writing) no adequate solution to Franklin-Hall's carving problem has been published, our account is not worse off than any other mechanistic framework, in particular those which try to force a strict distinction between causal and constitutive relevance. How to solve Franklin-Hall's carving problem is an open research question for the whole mechanistic community.

8.2. Diachronic causal constitution defined

(FBW) can now be plugged into condition (i) of the mutual manipulability account of constitutive relevance mentioned in Section 3.2. Manipulability can be treated in an ordinary Woodwardian fashion and the distinction between ideal interlevel and ideal etiological interventions can be dropped (see also footnotes 7 and 16).

The continuous nature of the relata, and the inability to pin down particular unique spatio-temporal locations, also render the standard iteration of synchronic constitution inapt. To capture the intrinsic temporality of the relata, the constitutive relation itself must be diachronic. Here we agree with Kirchhoff.

Summing up, we can talk of diachronic causal constitution iff: (1) the relata are mutually manipulable, (2) the relata are intrinsically temporal such that (3) the interlevel relation must be diachronic as well, and (4) the relata are related in an FBW-fashion, so that despite the part-whole relation between them they can still be considered distinct. In the case of diachronic causal constitution, the constitutive relevance relations are bidirectionally causal.

8.3. Application to our case studies

Let us apply this to our LTP-example. It is clear that (1) it is a case involving mutual manipulability, as it is described this way by Craver (2007). Moreover, the spatial memory of a mouse is constituted by processes evolving over different time-scales: the workings of the LTP, the expression of the Ca^{2+}/calmodulin-dependent protein kinase gene and the formation of a place field formed by hippocampal place cells all occupy different time-intervals in the overall mechanism. In short, they are (2) intrinsically temporal and cannot be individuated to a specific point in time. Hence, following Kirchhoff, (3) the constitutive relation between them must be diachronic as well. This we have seen in section 6.1. LTP is important for the place field's stability and coherence over time. These rely on a continual fine-tuning of the place field's properties. Interfering with the LTP does not prevent the formation of place fields, yet the absence of LTP causes the place field to grow progressively larger and fuzzier. Consequently, an intervention on the LTP will not affect an immediate change to the action capability of the spatial map. It takes a while for the spatial map to get sufficiently deregulated, or conversely to recover enough, to see any difference in the results of subsequent spatial tasks.[36]

It is useful to note that Craver's (2007) examination of this case is strongly different. In his view, as we wrote in section 2, all supposed instances of interlevel causation are composed of intralevel causation and synchronic constitution and the interlevel relata are nondistinct. The time lag is explained away by claiming the following:

[36] Note that this delay between the intervention and the effect on the spatial tasks is different from both the problem of the etiological nature of experimental apparatus and the problem of causal-constitutive propagation discussed by Leuridan (2012, §11).

> Activities at lower […] levels, in contrast, are temporally contained within the activities at higher levels. The formation of spatial maps is not later than the induction of LTP; LTP is part of the process by which spatial maps are formed. LTP does not prepare information for consumption by the hippocampus; it is part of the consumption of information by the hippocampus. (Craver, 2007: p.179)

Doesn't this undermine our analysis? No. Craver's picture only makes sense when one commits to what Seibt referred to as "the most central commitment of the substance paradigm". Following Seibt (2009: p.484), we should abandon spatio-temporal individuation here in favor of specificity-in-functioning.

(4) Employing (FBW), a lower-level component and the mechanism's higher-level phenomenon can be considered appropriately distinct. All four of our conditions are met, meaning we can label the interlevel relation in this case as diachronic causal constitution.

Our psychological case study can be analyzed along the same lines. (1) Perceptuo-motor coupling and cognition are mutually manipulable. Moreover, the processes in question are far-from-equilibrium and require continuous self-regulation to function properly and maintain the balance of the system. The complex patchwork of this self-regulation is lost if we only look at what is happening at single moments in time. These processes are thus (2) intrinsically temporal. The time-scales of the processes comprising the perceptuo-motor coupling charged with, for instance, stimulus response are also not identical to the time-scales of the overarching cognitive processes, such as memory retrieval and learning. The interlevel relation between the two, which underlies the supervising process of allostasis, is unmistakably (3) diachronic. Though it may be argued that the relata in question are not appropriately distinct, spatio-temporally speaking, (4) employing (FBW) we may distinguish them on the basis of their function. Our four conditions are met; again we have a case of diachronic causal constitution.

8.4. Scope and implications for scientific practice

Before we close this section, we would like to restrict the scope of our proposal in two ways. First, as we have mentioned at the end of section 7.3, we are not committed to a full-blown process ontology. The notion of processes is useful to make sense of our case studies, but we leave it an open question whether, in Seibt's words, all 'things, stuffs, events, properties, actions, relations, persons, …' are processes.

Second, we do not mean to insinuate that all constitutive relevance relations are diachronic and causal. There may be cases, such as the example of David and Piece, where synchronic, possibly non-causal constitution may accurately depict what is going on in a snapshot fashion.[37] Yet in some cases, most notably in the wet and messy psychological and neuroscientific contexts prevalent in this paper, and perhaps in biological contexts more broadly, a processual approach emerges as the best fit.

This means that we allow for two different interlevel relations: synchronic, possibly non-causal constitutive relevance on the one hand, diachronic causal constitutive relevance on the other hand. Yet unlike Bechtel and Kistler, Krickel and Kaiser, and Kirchhoff, we do not picture them at work together in one and the same context. We thus avoid the tensions between relations of different kinds that we encountered repeatedly in section 7.

What are the implications of our proposal for scientific practice? As one reviewer put, the distinction between causal relations and constitutive relations does seem to play a role in many scientific discussions, for instance in the debate whether addiction is a brain disease or not, which seems to be a discussion about what

[37] Note that in this case, synchronic causality may still be considered a possibility in the framework of Woodwardian interventionism. Of course, strictly following the processual point of view defended by Seibt, who defines causality following Salmon (1994), this would be impossible.

constitutes the disease as distinct from what may be causing it. Wouldn't such discussions seem pointless if we are to give up the distinction?[38] For several related reasons, the answer is 'No … to the contrary'. First, within the realm of our proposal, the question whether addiction is a brain disease – a disease constituted by changes in the brain – remains a valid empirical question. Second, it also remains a valid empirical question which are the etiological causes of addiction – stress, alienation, … are often cited candidates in the literature. Third, our proposal leaves room for methodological discussions on how the two empirical questions can best be studied. Our claim, that in certain contexts constitution is causal and diachronic, does not imply that etiological and constitutive relations should be studied by the very same means. There are relevant differences between interlevel experiments and same-level experiments, just like there are relevant distinctions to be made among interlevel experiments, among same-level experiments, among other, non-experimental methods for causal discovery etc. Fourth, it also leaves room for practical discussions on how to exploit the answers, if any, to the two empirical questions with an eye toward prevention and treatment. Whether or not addiction is a brain disease – in the sense of diachronic causal constitution – is relevant for treatment. Whether or not alienation is an etiological cause is relevant for both prevention and treatment. In these four senses, our proposal does not detract from the debate at issue. Hence the above answer was 'No …'. Fifth, by steering away from the strong metaphysical claim that causal and constitutive relations are fundamentally different metaphysical categories, our proposal even helps to focus attention on those methodological and practical issues that really matter. Hence the above answer was '… to the contrary'.

9. Conclusion

Our intermediate goal in this paper was to counter the common assertion that constitutive relations must be synchronic. We have described two scientific cases exhibiting interlevel relations, which seem causal in Woodwardian terms and which are interpreted by the researchers themselves as examples of interlevel causality. These relations are arguably not synchronic in nature. In both cases the associated processes exhibit an inherent temporality and time-sensitivity (i.e. they are far-from-equilibrium processes and/or inhabit different time-scales), which affects the interlevel relations between them. Both the constitutive relata and the constitutive relation in these cases are diachronic and dynamic, and thus not accurately represented by the synchronic view on constitution espoused by Craver and Bechtel.

The possibility of such a temporal dimension has received increasing attention in the literature, and we have reviewed three distinct ways in which researchers have tried to explain it. Yet their accounts have proven problematic for our purposes. Adding a constraint relation either gives rise to a tension or inconsistency by combining synchronic constitution with diachronic causal constraints (Kistler), or it gives rise to epiphenomenalism (Bechtel). Kaiser and Krickel's account of temporal parts in acting entities likewise combines synchronic constitution with diachronic interlevel causation, thus also giving rise to a tension. The processual proposal, finally, pays the necessary amount of attention to the intrinsic temporality of our cases, but Kirchhoff holds to a causal-constitutive distinction the arguments for which he – unwantedly – has helped to undermine.

Where does all this lead? To our end goal. It can no longer be argued that (1) a causal interpretation of constitutive relations should be considered impossible on grounds of a supposedly unyielding need for synchronic causality. Add to this that (2) constitutive relevance seems to imply causal relevance (see Leuridan 2012), that (3) the strict distinction between causal and constitutive relations gives rise to problems (see again, among others, Leuridan 2012), that (4) the logical independence argument against causal constitutive relations

[38] We would like to thank the reviewer in question for pressing us on this issue. In our discussion we will leave it an open question whether addiction is a brain disease, although empirical evidence strongly supports the hypothesis that it is – at least in part. Yet we will assume that *if* it is constituted by changes in the brain, the constitutive relevance relations in question are within the scope of our proposal and hence causal. Otherwise, the reviewer's worry would not apply.

is wanting (as section 5 and 7.3 suggest), that (5) renowned scholars in neuroscience and in psychology are not afraid of causal interlevel constitutive relations (see section 6), that (6) their cases apparently fit Woodward's framework (see again section 6), in line with (7) the central manipulationist idea (see section 4), and finally that (8) metaphysical notions should not be multiplied beyond necessity (see again section 4), and you'll come to the conclusion that, in certain contexts, constitutive relevance is nothing more than (a special kind of) causation. Occam would be pleased.

10. References

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