Diachronic Constitution

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Abstract: It is often argued that constitution and causation are different kinds of metaphysical relations. Constitution, like other grounding relations, is assumed to be synchronic (it happens at a time), while causation is diachronic (it happens over time). It is this synchronic-diachronic division that, more than other difference-makers, is argued to distinguish grounding relations such as constitution from causation. This paper develops an account of a species of constitution that happens over time. We call this type of constitution, *diachronic constitution*. We show how diachronic constitution is a consequence of a common type of causation, often ignored in metaphysical discussions of causation: continuous reciprocal causation. Hence, constitution is not only sometimes like causation; it can also be a form of causation. We argue that temporalising the constitution relation is neither as remarkable nor as problematic as it might initially seem. It is inevitable, given local interactions between microscale and macroscale states in dynamical systems.

Keywords: diachronic constitution; material constitution; mechanistic constitution; metaphysical dependence; reciprocal causation; dynamical systems

Introduction

It is often assumed that *grounding* relations such as constitution must be a distinct kind of relation from causation. We challenge this assumption. We focus on the constitution relation as a species of grounding in what follows. We do so for two reasons: (i) to target how smaller things *produce* or *make up* larger things; and (ii) to show that when considered in the context of dynamical systems, the constitution relation *is* a kind of causal relation: continuous and reciprocal causation between microscale and macroscale dynamics unfolding over different timescales.[1]

There are similarities between grounding relations such as constitution and causation (Schaffer 2016). Nevertheless, it has been argued that these similarities are merely superficial. In particular, it has been argued that the similarities between these relations do not support the claim that constitution (or grounding) is a kind of causation (Bernstein 2016).

[1] There is a separate discussion on the notion of 'grounding' in metaphysics (many of the references in our introduction are prominent figures in this discussion). We shall not enter directly into this debate. Yet, we think that when the concept of grounding is used to track how certain things are produced or made up by other things, the argument of this paper for construing constitution as a diachronic relation of dependence applies (*mutatis mutandis*) to grounding. In other words, grounding as applied to dynamical systems should be thought of as a diachronic metaphysical relation.

We begin by highlighting what we take to be an important similarity between constitution and causation.

Constitution and causation both back *explanation*. Why is the water boiling? One answer might be that I am heating the water to steam some vegetables. A different answer would have to do with thermal instability in the fluid dynamics. As Dasgupta (2017) notes: the first kind of answer is a causal answer, in the sense that it tracks a causal history of events. The second answer is an example of constitutive explanation: it explains why the molecular base of the water makes it the case that water has reached boiling point. Moreover, constitution and causation both back these different kinds of explanation by appeal to '*because*' and '*in virtue o*f' structures (Bernstein 2016). As Schaffer (2016) points out, "it is apt to use causative verbs like 'making' in glossing grounding relations. Likewise it is apt to invoke general notions like 'dependence' in glossing both causal and grounding relations." (2016, p. 54)

Many philosophers have supposed that similarities like these are relatively superficial, outweighed by a more substantial difference that distinguishes constitution from causation.[2] These philosophers have endorsed what we will call the '*synchronic assumption*':

- Constitution is *synchronic* (it is a part-whole relation that holds at an instant in time), while causation is *diachronic* (it is a relation between cause and effect that unfolds over time).

It is possible to challenge this picture. One option is to argue that causation can be non-diachronic. Wilson (2018) argues that grounding is equal to *metaphysical causation*, and says that "metaphysical causal dependencies are not mediated by any laws of nature .... it is to be expected that [they] should by and large be synchronic." (2018, p. 730)

We reject the synchronic assumption on different grounds. We argue that constitution, as a species of grounding relation, can sometimes be diachronic. We call this species of constitution, *diachronic constitution*. We will argue that for a class of systems, most notably *dynamical systems*, constitution is a type of causation: continuous and reciprocal causation. Dynamical systems are systems that exhibit changes over time in their microscopic elements and macroscopic organisation. In dynamical systems, constitution is a temporal relation of dependence between macroscopic structures and

[2] Not everyone agrees. See e.g. Leuridan & Lodewyckx (2020) for reasons for challenging what we will call the synchronic assumption that focuses on the use of this assumption in the literature on mechanistic explanation. They pursue a different path from our paper, as we consider the concept of constitution more broadly construed as a grounding relation. However there are some convergences in our argument. Leuridan and Lodewyckx (building on Kirchhoff 2015) argue against a causation-constitution distinction on the grounds that both causation and constitution are best thought of as interlevel relations.

microscopic elements. Micro- and macroscale dynamics are distinguished by the timescales over which their dynamics unfold. Thus the parts of a dynamical system are processes that exhibit change over time. Crucially, a diachronic view of constitution makes it possible to account for how processes at the microscopic scale of a system can interact to make up or produce macroscopic processes at the organisational scale of the system as a whole. Some have argued that the constitution relation cannot take processes as relata (e.g., Ylikoski 2013). We show that this view is mistaken: the elements of which a dynamical system is composed are processes. This is to say that the elements have an existence that is continuous time-dependent.

A second popular reason for taking constitution and causation to be metaphysically distinct types of relation has to do with a widely received view that constitution is a dependence relation that holds between parts and wholes. Dependence relations are standardly taken to be asymmetric - the whole depends on the parts but the parts do not depend on the whole (Barnes 2018). We will call this the '*dependence is asymmetric assumption*':

- Constitution is a part-whole relation and the whole depends on the parts but the parts do not depend on the whole.

We will reject the 'dependence is asymmetric' assumption. In dynamical systems the parts and the whole stand in a relation of *simultaneously co-evolving* over time such that the macroscale dynamics depend on the dynamics at the microscale, while, at the same time, the microscale dynamics are constrained by the ensemble behavior of the whole.

A related, but different, intuition that might back treating constitution and causation in dissimilar terms has to do with the existence conditions of the relata in constitution and causation, respectively. We will call this the '*wholly distinct relata assumption*':

- Constitution holds between relata that are not wholly distinct (they spatio-temporally and materially co-exist), whereas causation holds between relata that are wholly distinct in the sense that they do not overlap spatially and temporally.

We will also reject the 'wholly distinct relata' assumption on two grounds. First, the relation between cause and effect in dynamical systems is continuous, reciprocal and ongoing. Thus, the idea of causes and effects as always wholly distinct events is incorrect. Dynamical systems are counterexamples. Second, diachronic constitution implies that the processes involved in continuous, reciprocal causation are not wholly

distinct; they co-exist in virtue of their co- dependence in the here-and-now and over time.[3]

The structure of this paper is as follows. In section 1 we lay out reasons philosophers have given for the synchronic assumption: the assumption that constitution is synchronic, whereas causation is diachronic. In section 2 we distinguish between two species of constitution: the well-known view of constitution as material constitution and constitution as diachronic constitution. We will show that only diachronic constitution is applicable to dynamical systems. This will be done by focusing on important differences in constitution when examining two examples: Michelangelo's David (a case of material constitution) and the Rayleigh- Bénard convection system in physics (a case of diachronic constitution). In section 3, we look at new work in the mechanistic literature seeking to salvage the distinction between causation as diachronic and constitution as synchronic. We highlight three problems with this mechanistic account of constitution; all of which can be avoided if constitution is understood as a diachronic dependence relation. We end, in section 4, by highlighting several important points about why diachronic constitution is still a kind of constitution.

1. The synchronic assumption

We start with the following observation: in certain circumstances, smaller things *make up* larger things in the specific sense that the smaller things ground the existence of the larger things. In analytical philosophy, the notion of *grounding* at play here is usually cast in the following (technical) ways:[4]

- X (or the Xs) constitutes Y. *Constitution* is an atemporal (synchronic) one-one relation between (typically) materially and spatially co-located objects that differ in their kind membership - it holds, for example, between a lump of clay or marble and a statue (Baker 2000).

- The Xs compose Y. *Composition* is a synchronic relation that holds between many spatially non-overlapping elements, and the whole that is made-up of

[3] The notion of 'here-and-now' is itself a temporal notion because processes co-evolve in the here-and-now, as well as over longer timescales.

[4] There is now a lively discussion concerning the notion of 'grounding' itself. As already noted in footnote 1, we suspect that our treatment of constitution as diachronic will have implications for how to think of the grounding relation as well. Indeed, some, like Wilson (2018), argue that grounding is a species of causation. He argues that grounding is equal to metaphysical causation, distinguishing this kind of causation from nomological causation. If we are correct in our argument for a diachronic view of constitution as a form of causation, i.e., continuous, reciprocal causation, then it becomes possible to think of nomological notions of causation in terms of constitution. This is a topic we will return to in future work.

those elements - it holds, for example, between a house and many bricks or between different molecules and water (Gillett 2007; Hawley 2006).

- Y is realised by X (or the Xs). *Realisation* is typically taken to be a synchronic relation that holds between property instances such that for X to realise Y at some instant is for X to play the Y-role - e.g., certain patterns of neuronal activity realise memory at some time in virtue of instantiating the functional role of memory at that time (e.g., Polger 2006).

- Y properties supervene on X properties. *Supervenience* is a synchronic relation between (typically) properties of different kind - e.g., mental properties are said to supervene on physical properties such that for any mental property, *M*, if anything has *M* at t, there is a physical property at t that *M* supervenes on (Kim 1998).

In all of these examples, the *main* reason for thinking that there is a deep dissimilarity between grounding relations like constitution and non-grounding relations such as causation is the synchronic assumption. Here are some illustrative examples:

> Building relations do not unfold over time. If property *P* realizes property *Q*, it does so at some time t; if these molecules compose that table, they do so at some time t; if these time slices compose that persisting object, they do so *simpliciter*. Causation, in contrast, is paradigmatically *diachronic*, and that idea is frequently invoked to distinguish causation from relations like composition, constitution, or supervenience — relations that I am calling kinds of building. (Bennett 2011, pp. 93-94)

> The verb 'compose' in the predicate 'the *xs* compose *y*' is to be understood as being in the present tense, and the same point applies to 'are' in 'are parts of'. Thus, 'are parts of' and 'compose' should be read 'are *now* parts of' and '*now* compose'. Strictly speaking […], our *definiendum* should have been 'the *xs* compose *y* at *t*', and our "primitive" mereological predicate should have been '*x* is a part of *y* at *t*. (van Inwagen 1990, p. 29; italics in original)

> At least since Hume, many philosophers have held that causes and effects must be logically independent. If one endorses this restriction on causal relations, then one should balk at positing a causal relationship between constitutively [or compositionally] related properties. Finally, because the [composition] relationship is synchronic, *Φ's* taking on a particular value is not temporally prior to *Ψ's* taking on its value. (Craver 2007, p. 153)

> [Supervenience is primarily] used non-temporally [*viz*., synchronically], to signify a metaphysical and/or conceptual determination-relation; […], the idea being that something supervenient […] – is "grounded by" – that on which it supervenes. (Horgan 1993, p. 555)

We agree there is something correct about the reasoning these quotes exemplify for carefully chosen examples of grounding. For example, it seems correct to think that the rules of chess constitute how the game is to be played at each instant in time in which the game is played. Moreover, we shall not dispute that enduring entities like tables and statues can be argued to be constituted synchronically. We take the notion of *material* constitution to apply to the constitution of enduring entities (more on this in section 2). However, we will argue that dynamical systems - systems found throughout the natural and social worlds - are systems whose organisation is diachronically constituted. The synchronic assumption does not generalise to all cases of constitution. We develop this argument in the next section by contrasting material constitution with diachronic constitution.

2 Two Species of Constitution

2.1. Material Constitution: Michelangelo's David

Michelangelo's *David* is constituted by a particular piece of marble, *Piece*. The metal chain I use to lock my bicycle is constituted by steel links knotted together. These are familiar examples of what is called *material constitution* in metaphysics.

Material constitution is standardly taken to be a *synchronic* one-one relation of determination that holds between spatially and materially co-located objects of different kinds. This view of constitution is popular, and has been defended by Baker (2000), Fine (2003), Lowe (1995), Shoemaker (1999), Simons (1985), and others.

The constitution relation can be framed in terms of how to fill out the following schema: X (or the Xs) constitutes Y at *t* if and only if _____? (Wasserman 2004, p. 694) It is widely agreed that a necessary condition for X (or the Xs) to constitute Y is that the relation of constitution that holds between X (or the Xs) and Y involves two *coincidence* conditions. First, material constitution requires *spatial and temporal coincidence*: X (or the Xs) constitutes Y at *t* only if X (or the Xs) and Y have the same spatial location at *t*. Second, material constitution requires *material coincidence*: X (or the Xs) constitutes Y at *t* only if X (or the Xs) and Y share all the same material parts at *t* (Wasserman 2004, p. 694).

In addition to these coincidence conditions, we can also say something about the formal properties of the constitution relation. Material constitution is often taken to

be *transitive* and *irreflexive*. Moreover, material constitution is usually considered to be *asymmetric*. Defenders of constitution want to say that *Piece* constitutes *David*, but not *vice versa*. Adding the formal properties of irreflexivity and asymmetry entail a specific view of the constitution relation, that "*constitution is not mere coincidence*," (Wasserman 2004, p. 694; italics in original) for coincidence is both symmetric (i.e., $\forall x (Pxx)$) and reflexive (i.e., $\forall xy (x = y)$). As Wasserman says: "This is a substantial commitment, but it is also welcomed by most constitution theorists." (2004, p. 694)[5]

Finally, material constitution is commonly thought to hold between *enduring* relata; constituting elements that are *wholly present* whenever they exist (Wasserman 2004, p. 708, fn. 3). Lewis (1986) defines 'wholly present' as follows: "Let us say something […] *endures* iff it persists by being wholly present at more than one time." (1986, p. 202; italics in original).

Table 1 summarises the key properties of material constitution.

Material Constitution
Michelangelo's David
- Synchronicity (atemporality)
- Asymmetry
- Object-based (endurance)
- Non-causal

2.2. Diachronic Constitution: Rayleigh-Bénard Convection Rolls

Now contrast the case of David with an example of self-organised pattern formation in an open (i.e. non-equilibrium steady-state) dynamical system: the Rayleigh-Bénard convection system. Open dynamical systems are examples of *interaction-dominant systems*; systems in which the constituent elements constrain each other's dynamics in such a way as to act as single coherent units (Anderson et al. 2012). We use this example as it is a well-documented case of an interaction-dominant system (the brain would be a different and much more complex system).

Bénard cells form when fluid is heated between two planes in a gravitational field. The formation of Bénard cells depends on several things such as the type of fluid, its depth,

[5] Nor is the constitution relation equivalent to identity since identity (like coincidence) also has the formal properties of being reflexive and symmetrical. One reason these differences are welcomed by constitution theorists is because material constitution thereby provides a core concept for a non-reductive materialist metaphysics (see e.g. Rudder-Baker 1997).

and the temperature gradient. The latter is central. If the temperature gradient is below a certain value (a function of the Rayleigh number), then the fluid will remain stable despite its natural tendency to move given its viscosity and thermal diffusivity. However, when the temperature gradient exceeds a certain critical value, then thermal instability occurs. As Chemero and Silberstein (2008) put it: as the temperature gradient reaches its critical value, "there is a breakup of the stable conductive state and large scale rotating structures resembling a series of parallel cylinders called Bénard cells are eventually produced." (2008, p. 20) All this is to say that one starts to see fluctuations in the density of the fluid given a specific temperature threshold from which large-scale structures start to arise - a convection roll.

We have seen above how philosophers have standardly distinguished constitution from causation on the grounds of two assumptions: the synchronic and causal asymmetry assumptions. We will argue next that both assumptions fail for the constitution of Bénard cells.

2.2.1. The synchronic assumption fails in the case of Bénard cells

There is an immediate complication with trying to shoehorn the concept of material constitution (as defined above) to fit self-organising dynamical systems. One could try to impose the properties of synchronic constitution onto the Rayleigh-Bénard convection system. But, this would be akin to attempting to wear shoes on one's hands - "you can do it, but gloves fit a whole lot better." (van Gelder & Port 1995, p. 2)

First, it is not plausible to ask whether the formation of Bénard cells is such that its constitutive elements constitute the ensemble behavior (the observed rolling motion of the liquid) at an atemporal instant *t*. Or, differently put, one cannot begin by framing this phenomenon and its constitutive base in terms of how to fill out the schema (above): X or the Xs constitutes Y at an atemporal instant *t* if and only if _____? The same holds if one were to invoke other grounding relations such as composition, realisation or supervenience. The reason why this schema does not fit is that the formation of Bénard cells is inherently temporal, or *diachronic*.

Second, at the spatial scale of molecular dynamics, time is *continuous*, in the precise sense that temporality cannot be broken down into discrete quanta. So if one were to claim that the system in question is in a particular 'state', *X*, at a particular point in time, this would be an approximation - it would "boil down to saying that the average of the system's states during that period of time was *X*." (Spivey 2007, p. 30) Hence, the explanatory basis of the formation of Bénard cells is diachronic.

Finally, Bénard cells and their molecular constituents are *processes*. Processes are temporally spread out in nature, which implies that a process cannot be wholly present

at any given point in time. To insist that processes can be described as being present at some synchronic point in time is possible only by taking an average of the states the process goes through over a period of time. To see this more clearly, consider what Ladyman & Ross (2007) say about the relation between water and H_20. Under the synchronic model of constitution, if H_2O composes or constitutes water at some point in time *t*, or at each temporal stage over $t_1 \ldots t_n$, then both of the hydrogen molecules and the oxygen molecule must be entirely present at that point in time or at each moment over $t_1 \ldots t_n$. According to Ladyman & Ross, this synchronic view is however mistaken. Water is constituted "by oxygen and hydrogen in various polymeric forms, such as $(H_2O)_2$, $(H_2O)_3$), and so on, that are *constantly forming*, *dissipating*, and *reforming* over short time periods in such a way as to give rise to the familiar properties of the macroscopic kind water." (2007, p. 21; italics added) Because water is constituted in a complex dynamical system it "makes no sense to imagine it having its familiar properties *synchronically*." (Ross & Ladyman 2010, p. 160; italics added) To claim that a dynamical process has the properties it has at some point in time is *an abstraction*; it is an abstraction that should not be mistaken for how the properties of dynamical processes manifest themselves over time. In other words, from the fact that a system can be described synchronically, it does not follow that it has any of its special characteristics synchronically.

Ylikoski (2013) however suggests that questions of constitution *abstract away* from such details. He says:

> The constitutive questions abstract away from the behavior and orchestrated activities of the parts, and ask how the system has a capacity for this kind of behavior ... One could say that the question only addresses a *synchronous time-slice* of the system. Of course, *this is a heavy abstraction*, but it helps in articulating an important explanatory question. (2013, p. 4; italics added)

We agree talk of a *synchronic time-slice* of a system *is* indeed "a heavy abstraction". However, it is too heavy of an abstraction if one takes the constitution relation (or any kind of grounding relation) to be about the nature of a system. Now, it is not problematic to say that a system is in some particular *synchronic* state, X, if by this claim one is making such a claim for epistemic, explanatory purposes to measure the approximate values of a system at some *measured* point in time. Such a measure may well answer "important explanatory questions" (Ylikoski 2013, p. 4). It is equivalent to saying that a system's states over some period of time were on average, X. There is no reason to think that this epistemic claim is unhelpful. As Spivey (2007) reminds us: "This kind of coarse averaging measurement is often a practical necessity in science, but should not be mistaken as genuine evidence for the system actually resting in a discrete stable state." (2007, p. 30) However, it is a problem if one takes such an epistemic claim to imply that the microscale processes that constitute the dynamical

structure of interest do so instantaneously at some discrete point in time. Water is not constituted by H_2O at any given instant in time *t*, but is diachronically constituted by oxygen and hydrogen forming different polymeric forms over time. Hence, the claim that talk of constitution is a form of abstract explaining of a system at a synchronic instant *t* is only meaningful if taken solely as an epistemic principle of approximation. Yet, to confuse the epistemic side of the constitutive coin for its metaphysical side is, we submit, a *fallacy*. It is the fallacy of mistaking claims about a system's behaviour that might be epistemologically useful in certain explanatory contexts, for metaphysical facts about such an inherently diachronic system.

Unlike the material notion of constitution, which is best-suited to an object-based ontology, the rolling motion of Bénard cells are best captured within a broadly speaking process-based ontology.

Process-based ontologies are proposed as an alternative to substance ontologies that start from self-subsisting entities and their properties. Nor do they presuppose that entities and their activities can be located at discrete points in space-time, as is the case with mechanisms. We return to the differences between processes and mechanisms later in section 3. Process-based ontologies highlight an important shift away from focusing on the material and spatial composition of the whole by its parts in synchronic constitution relations. Instead a process-based ontology aims to make sense of practices of individuating dynamical systems in terms of their behaviour over time in particular contexts. Diachronic constitution therefore shifts our focus away from material elements and their co-location (without denying that this is a part of constitution) to a perspective of dynamical functioning of whole complex non-linear systems.

2.2.2. The dependence is asymmetric assumption fails in the case of Bénard cells

It is correct to say that the rolling motion of the Bénard cell depends on the molecules. In this sense, the rolling motion (the macroscopic behavior) depends on the parts (the behavior at the microscale). From this observation, many would reason that dependence, even in the case under consideration, is asymmetric.

This is the orthodoxy about *dependence* (Barnes 2018). The reason for taking this example to be an instance of this orthodoxy is that it looks like the molecules are prior to or more fundamental than the rolling motion. The rolling motion is the constructed; the non-fundamental. In contrast, the molecules are the elements that construct; they are the fundamentals. As Barnes (2018) observes: "Dependence is the kind of relation that explains the connection between the fundamental and the derivative - it takes us from the derivative (the dependent) to the fundamental (the independent). Any relation that plays this role must be asymmetric. And so dependence must be

asymmetric." (2018, pp. 54-55) We will call this the '*dependence is asymmetric assumption*'.

This view of dependence is however problematic in a range of dynamical systems such as the Rayleigh-Bénard convection system. Barnes (2018) seeks to show why there are cases of dependence that are symmetrical; rather than asymmetrical. She provides a number of examples of symmetrical dependence. It is not our task here to rehearse any of these examples. We take her to have shown that not all examples of dependence relations must exhibit the property of asymmetry. Even if this is not the case, the Rayleigh-Bénard convection system is an example in which the Dependence is Asymmetric Assumption fails.

To see this we return to our flagship example of the Rayleigh-Bénard convection system. Note that once formed, the Bénard cell modifies the configurational degrees of freedom of the molecules such that some possible motions are no longer available (Chemero & Silberstein 2008). If we look at the system over time the relation between the individual molecules and the macroscopic structures they form is not asymmetrical. Insofar as the relation between the microscopic and the macroscopic dynamics is one of dependence, the dependence in question is much more akin to what Barnes (2018) calls symmetric dependence. The macroscopic dynamics depend on the microscopic dynamics, and vice-versa, and this dependence occurs simultaneously between the microscopic and the macroscopic over time.

The Rayleigh-Bénard convection system exemplifies reciprocal causation between dynamics at different timescales of activity. Reciprocal causality is an example of a relation that is symmetrical.[6] The dynamics at the macroscale unfolds over slower timescales than dynamics at the microscale. The macroscale dynamics of the system - convection or conduction - is therefore a consequence of the behaviour of the microscopic parts of the system; it depends for instance on the dissipation of energy by these parts. At the same time, the macroscale dynamics of the system constrains and enslaves the microscale dynamics limiting the degrees of freedom of the molecules of which the Bénard cell is composed. This is what we mean in describing the macro and microscales as standing in a symmetrical relation. Macroscale dynamics form out of microscale dynamics that are in turn, in a circular fashion, constrained and enslaved by the very same macroscale dynamics they form.

2.2.3. *The wholly distinct relata assumption fails in the case of Bénard cells*

[6] This is an observation which coincides with theorems in the physical sciences such as the slaving principle in physics and thermodynamics (Haken 1983). That is, the enslavement of microscale (molecular) by macroscale (ensemble) dynamics is an inevitable result of the delineation of temporal scales, something one can observe in all dynamical systems (Ginzburg & Landau 1950; Hobson & Friston 2014).

The relata of a constitution relation cannot exist independent of one another. In other words, the constitution relation is a dependence relation between parts and wholes. Philosophers have argued on this basis that constitution must be a distinct type of relation from causation, since the relata of a causal relation must always have a distinct and independent existence. Krickel (echoing Craver & Bechtel 2007) for instance writes: "one platitude about causation is that its relata have to be wholly distinct. Thus, it follows that causal relevance and constitutive relevance are mutually exclusive relations." (Krickel 2020, p. 5; cf. Lewis 1986; Salmon 1984)[7]

What makes a causal explanation also count as a constitutive explanation is, we have argued, the relation of reciprocal two-way dependence that holds between micro- and macroscale processes. Microscale interactions among dynamically changing processes account for the formation of a macroscopic structure. At the same time the macroscopic structure limits the degrees of freedom of the microscopic elements. Moreover, in dynamical systems exhibiting reciprocal causality, cause and effect are not wholly distinct relata; they enter into circular, and symmetrical relations with each other as we just described. Once one acknowledges the presence of reciprocal causation in dynamical systems, one must also acknowledge that cause and effect are not always wholly distinct. On the contrary, such an assumption likely only holds in cases of linear causality; not for processes in which microscale and macroscale dynamics stand in a continuous and reciprocal causal relation.

The observation that there is a mutually constraining relation between the micro- and macroscale dynamics of the Rayleigh- Bénard convection system underwrites the idea that the relation between the micro and macro-scale is one of spatial and temporal coincidence. As we argued in the previous sub-section, the molecules and their motion form the constitutive base of the macroscale rolling motion. Yet, once the particular pattern of behavior is manifest at the scale of the ensemble, the macroscale dynamics 'enslave' the microscale dynamics. This enslaving relation makes it the case that the 'distinct existence' condition of causes and effects no longer holds for cases involving continuous and reciprocal causation.

Now let's turn to the claim that relata that stand in a constitutive relation are not wholly distinct in the sense that they must exhibit what Wassermann (2004) describes as spatial and temporal coincidence. This is to say that the material parts that constitute a whole must occupy the same spatiotemporal region. Our first point is that

[7] It should be noted this is a common assumption in the literature on the metaphysics of causation. See the quote from Craver 2007 in the introduction to this paper, in which he traces this claim back to Hume's famous discussion of causal connections. It is common to read examples like event x - the boy kicking the football caused event y - the glass in the window shattering (e.g. Salmon 1998). We are arguing this feature of causation is absent in cases of reciprocal causality and thus cannot be used to distinguish causation from constitution.

such a feature of the constitution relation cannot be used to distinguish causation as a relation from constitution. This much follows from the failure of the wholly distinct relata assumption. Second, the relata of a constitution relation can sometimes be located at distinct points in time. Thus the co-existence of parts and wholes required for constitution need not be confined to an instant in time.

Table 2 summarises the main differences between the two species of constitution we have discussed so far in this paper: material constitution and diachronic constitution.

Material Constitution	**Diachronic Constitution**
Michelangelo's David	Convection Rolls
- Synchronicity	- Diachronicity
- Asymmetric dependence	- Symmetric dependence (co-dependence)
- Object-based (endurance)	- Process-based (perdurance)
- Non-causal	- Reciprocal causation

This table immediately suggests that synchronic view of material constitution is not the notion of constitution needed for dynamical systems. Moreover, causation and constitution are not distinct relations when it comes to understanding the constitution of dynamical systems. In the next section we will consider a possible attempt at rescuing a sharp distinction between constitution and causation that leverages new work in the literature on mechanistic explanation. We shall suggest this mechanistic view of the relation between causation and constitution has its own problems that can be avoided by adopting a diachronic view of constitution.

3. Mechanistic Constitution: A Non-Causal Proposal

In the recent literature on mechanistic constitution, views can be found that attempt to combine a process-based view of the relata of the constitution relation with an atemporal or synchronic notion of constitution (Harbecke 2010; Kaiser & Krickel 2017; Krickel 2018).[8] Such views attempt to hold onto the distinction between constitution and causation we have been challenging. Mechanists appeal to the notion of a mechanism to account for the constitution of a phenomenon of interest. A mechanism as defined by Machamer et al. (2000) is a structure composed of "entities and activities organised such that they are productive of regular changes from start or

[8] Many thanks to Beate Krickel for (personal) discussion of this possible combination of views.

set-up to finish or termination conditions." (2000, p. 3) The activities and entities are productive of regular changes synchronically at an instant in time.

Mechanistic constitution is standardly understood as a synchronic relation between the entities and activities that compose a mechanism and the phenomenon the mechanism constitutes (see e.g. Craver & Bechtel 2007; Harbecke 2010; Kaiser & Krickel 2017).[9] Harbecke (2016) for instance states: "The idea seems to be that the mechanisms synchronically realize, or instantaneously determine, the initially identified phenomenon such that the relata do not have spatiotemporally distinct instances." (2016, pp. 97-98; see also Craver 2007; Craver & Bechtel 2007) Kaiser & Krickel (2017) say that mechanistic explanation "is grounded in a non-causal relation called (mechanistic) constitution, which is supposed to hold between the mechanism and the phenomenon." (2017, p. 746)

Before looking more specifically at this mechanistic attempt to distinguish sharply between constitution and causation, we emphasise two things we take to be of some importance: (1) similarities between constitution and causation; and (2) the claim that mechanistic constitution is not material constitution.

Despite the aim to show that mechanistic constitution is not causation, mechanists admit there are similarities between the two relations. Harbecke (2016), for example, notes that mechanistic constitution is able to back explanations in the neurosciences for what scientists have in mind when they say that *x* 'is responsible for' *y*, 'gives rise to *y*' or how *x* 'forms the basis of *y*'. In this sense, mechanistic constitution, like causation, back explanations in terms of 'because' structures (a point we highlighted at the start of this paper).

Harbecke (2016) also argues that mechanistic and material constitution are best viewed as distinct kinds of constitution. We argued a similar point by distinguishing material constitution from diachronic constitution. The most powerful consideration Harbecke provides is that mechanistic constitution looks to be well-suited for delivering a concept of constitution that could be applied in science. In discussing the example of David and Piece from earlier, Harbecke quotes Ladyman (2012):

> it is hard even to imagine a way in which science could be relevant to the debate about whether a statue is identical with the lump of clay out of which it is fashioned" (39). The only method that seems to be available to decide about an

[9] Machamer et al. 2000 talk of composition, not constitution. Craver (2007) uses the term "constitutive relevance" (e.g. p.139). However, we take the relation they have in mind to be one of constitution. The notion of mechanistic constitution has recently received discussion in: Harbecke (2010); Kaiser & Krickel (2017) and Gallagher (2018), among others.

> identity or non-identity of the statue and the collection of clay particles is one of conceptual analysis. (2017, p. 110)

Here the puzzle turns on how X and Y can be made of the same material and located in the same space-time region, and yet not be identical. Harbecke agrees with Ladyman that it is hard to see how science could be brought to bear to settle this debate. This looks to be a purely conceptual issue. Mechanistic views of constitution, by contrast, are tailor made to account for constitution as it applies to biological systems, a feature these views share with our view of diachronic constitution.

There are however important differences between mechanistic and diachronic constitution. Specifically, the concept of mechanistic constitution attempts to retain a commitment to all the three assumptions that we have argued fail to hold in self-organising dynamical systems. That is, mechanistic constitution keep intact the following assumptions: (1) the synchronic assumption; (2) the dependence is asymmetric assumption; and (3) the wholly distinct relata assumption.

In the rest of this section, we focus on Krickel's account of mechanistic constitution, as she has done the most work to explain why mechanistic constitution needs to be distinguished from causation (Kaiser & Krickel 2017; Krickel 2018, 2020).

Krickel has argued for a diachronic view of the phenomena constituted by mechanisms. In collaboration with Kaiser, they argue for a view of mechanistically constituted phenomena called *entity involving occurrents* (EIOs). An entity is a thing that endures (i.e. is wholly present at each instant) over time. It is a three-dimensional object that is exhaustively present at any point in time (Krickel 2017). On the other hand, occurrents are taken to be processes, with beginnings and ends, and other temporal parts. The example she gives is of a rat navigating a Morris water maze. The rat is the entity that exhibits a temporally extended navigation behaviour. This behaviour has spatial and temporal parts that are referred to as spatial and temporal EIO-parts. These parts are likewise temporally extended. They include, for instance, activation of the hippocampus, or muscle contractions in the rat as it makes a left-turn in the maze. Temporal EIO-parts are defined as follows:

> An acting entity E1 is a temporal EIO-part of another acting entity E2 iff:
>
> > (i) the entity involved in E1 is identical with the entity involved in E2;
> >
> > (ii) the activity involved in E1 begins later and ends earlier than the activity involved in E2, 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. (Krickel 2018: p.64)

Spatial EIO-parts are defined as sub-regions of the spatiotemporal region occupied by one and the same entity E (Krickel 2018, p. 64). The hippocampus for instance is a spatial EIO-part of the rat. Its firing is a temporal-EIO part of the process by which the rat generates a spatial-map. As we understand the proposal, there are three relevant variables: the phenomenon (S), a spatial part of a mechanism, i.e., an entity and its activity (X_1), and a temporal part of the phenomenon S. The idea is that entities and their activities can be defined at both the level of the mechanism and at the level of the phenomenon as a whole. The key idea is that spatial and temporal EIO-parts can, in principle, "causally interact (if they occur in different space-time regions) …" (2018, p. 7) Assume the rat's navigation behavior lasts from t1 to t4. The rat's turning left at t2 might be a cause of the behavior of the hippocampus starting at t3 (which is a spatial … part of the mouse's navigation behavior (Krickel 2018, p. 7).

This provides the first part of Krickel's account of mechanistic constitution: the claim that spatial and temporal parts of the same phenomenon "can in principle causally interact because they do not necessarily occupy the same space-time region. In other words, they can be wholly distinct." (2018, p. 7) The second part of the account turns on interventionism (cf. Woodward 2003) and states that "if the variables that the intervention is a common cause of are mutually manipulable, then these variables are constitutively related. If they are not mutually manipulable, the intervention is an accidental common cause [and therefore does not identify variables related constitutively]." (Krickel 2018, p. 7)

Mutual manipulation is used here to pick out a relation of constitutive relevance that is distinguished from a relation of causation because it holds synchronically. Thus Kaiser and Krickel write that in causal mechanistic explanations "the phenomenon occurs temporally after the mechanism has occurred." In constitutive mechanistic explanation by contrast "the phenomenon occurs at the same time as the mechanism occurs" and "most components of constitutive mechanisms are spatially contained in the object or system that constitutes the Object Involving Occurrent (OIO) that is the phenomenon" (Kaiser & Krickel 2017: p. 31; all three quotes).[10] The move Kaiser & Krickel are making here to distinguish causal from constitutive mechanistic explanation relies upon the familiar assumption that dependence is asymmetric, which we rejected in making the case for diachronic constitution. We argued that in dynamical systems the relation between microscale and macroscale dynamics can be formulated in terms of continuous and reciprocal causal relations, and that this species of causation is an example of symmetric dependence. Furthermore, we also showed how it is possible to understand causal relations in dynamical systems such that the relata are not always wholly distinct. In cases of continuous reciprocal relation, cause and effect are

[10] Krickel later shifted her terminology to talk of EIOs rather than OIOs.

co-evolving and continuously influencing each other in ways that preclude treating them as distinct events.

The details of how Krickel proposes to use mutual manipulation to determine constitutive relevance, and how she gets round various problems for such a proposal[11] that have been raised previously in the literature are beyond the scope of this article. The point we wish to highlight however is that mutual manipulation requires you to intervene on a system at a point in time. This has the consequence that the relation of constitutive relevance, in Krickel's mechanistic view, holds between temporal and spatial parts of diachronic phenomena. She writes:

> X's φ-ing is constitutively relevant to S's Ψ-ing iff:
>
> 1. X's φ-ing is a spatial EIO-part of S's Ψ-ing,
> 2. There is a temporal EIO-part of S's Ψ-ing that is the cause of X's φ-ing.
> 3. There is a temporal EIO-part of S's Ψ-ing that is the effect of X's φ-ing. (Krickel 2018: p. 7)

Mutual manipulation tells you if conditions 2 and 3 are satisfied. Notice however that to build up an account of what is constitutively relevant to S's Ψ-ing, we need to build up to the whole temporally extended process of rat navigation from a collection of temporal EIO-parts.

However, we have argued that processes cannot be what they are at any synchronic point in time. To persist, in the sense of a process, is to persist as unfolding over time. If the very nature of a process is to unfold over time then how can its existence be determined at an instant? In the case of David and Piece this dilemma does not arise, because the relation of constitution holds between objects and is articulated at a very high degree of abstraction. Objects such as Piece and David, however, have their identity determined at every moment at which they exist.[12] Hence, unlike processes, objects such as David and Piece do not depend for their existence on dynamical unfolding over time. Objects are therefore said to *endure*. By contrast, processes *perdure* (Hofweber & Velleman 2011). With the contrast between endurance and perdurance in place, this makes it hard to see how it is possible to invoke a synchronic notion of constitution, while, at the same time, taking the relata to be diachronic. If the phenomenon of interest is a process, as is the case with dynamical systems, we are dealing with a system that perdures; it is not enduring. Therefore it is no longer possible to treat the system as wholly present at each instance in time. At best all that

[11] We have in mind here objections raised by, e.g., Baumgartner and Gebharter (2015). Krickel (2018) provides a detailed response to these problems.

[12] This of course turns on the assumption that one does not treat even David and Piece as inherently processual. We do not enter this discussion in this paper, leaving it an open question whether all or only some systems are entirely processual, and therefore wholly diachronic.

one finds at an instant is an averaging of the states of the process over time. This, we argued above, is to treat talk of constitution only in an epistemic sense. It cannot, and should not, be mistaken for any metaphysical claim about the constitutive nature of the system under investigation.

Diachronic constitution is therefore not an example of mechanistic constitution. It calls into question the various moves the mechanists make to try to retain a synchronic view of constitution, and a sharp distinction between causal and constitutive mechanistic explanation. If we are correct, then mechanistic constitution cannot be brought to bear to explain constitutive dependence in dynamical systems.

4. Concluding remarks

We have issued a challenge to the following desiderata about the differences between causation and constitution: (1) Constitution is synchronic (it manifests at an instant in time), whereas causation is diachronic (it happens over time); (2) constitution is a dependence relation between parts and wholes, and dependence relations are asymmetric; and (3) constitution holds between relata that co-exist, whereas causation holds between relata that do not co-exist (causes precede their effects).

We have argued, contrary to the first proposition, that the constitution relation can and should, in certain circumstances, be characterised as a diachronic relation of dependence. We did not claim that every constitution relation is diachronic. We limited our argument to dynamical systems - the kind of systems that most clearly take processes as their relata. Second, we argued that the temporal dynamics of microscopic and macroscopic behavior in dynamical systems imply a view of the cause-effect relation as simultaneously co-evolving. Once the behavior of the ensemble is manifest, this behavior enslaves the behavior of the microscale dynamics. It highlights the need to view the cause-effect relation not as a linear relation, but as a continuous and reciprocal relation of dependence. The relata are therefore not wholly distinct. Finally, we showed that in dynamical systems, the relevant dependence relation between the relata is best understood in terms of symmetric dependence. We coined this view of constitutive dependence, diachronic constitution.

We finish this paper by summarising why diachronic constitution *is* still a relation of constitution:

(1) Diachronic constitution in dynamical systems is *productive*. It backs explanation by involving 'because' structures. Production plays a core role in constitution, as it signifies 'bringing something into existence' (even synchronically in the case of Piece and David). In a similar fashion, diachronic constitution explains how

microscopic behavior *makes up* the macroscopic behavior of the system under investigation.

(2) Diachronic constitution in dynamical systems is consistent with the co-existence of microscopic and macroscopic. It goes beyond the mere co-location condition of synchronic constitution by targeting the *co-dependence* of the macroscopic upon the microscopic, and vice-versa.

(3) Diachronic constitution is a relation of non-identity. It is typically assumed that if X (or the Xs) constitutes Y, and if X (or the Xs) are not identical with Y, then the constitution relation between X (or the Xs) and Y is asymmetrical. Diachronic constitution is not an asymmetrical relation of dependence; yet, this does not imply that it is an identity relation, for micro- and macroscale dynamics unfold over different time-scales, as implied by the slaving principle in physics and thermodynamics.

(4) Diachronic constitution can be expressed in metaphysical dependence conditionals: if the molecules did not bond in a particular way, the ensemble dynamics would not come to exist. Causation can also be expressed through metaphysical dependence conditionals of this sort, and so can the synchronic notion of constitution: if Piece had not been formed in such-and-such a way, David would not have existed.

Diachronic constitution tracks continuous and reciprocal causal dependence in dynamical systems over time. Yet, given what we have argued above, this is no reason to say that diachronic constitution is not constitution, for constitution in non-linear dynamical systems just is a kind of causation: continuous reciprocal causation.

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