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Reconciling the No Decoupling Approach and the Inbetweenness Approach to Constitutive Relevance Relation

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Abstract

Mechanistic explanations in neurobiology require an account of constitutive relevance: the relation between a phenomenon and the components of its underlying mechanism. Two recent accounts of this relation, the 'no decoupling' (NDC) approach and the 'inbetweenness' approach, are widely treated as rivals. This paper argues instead for a reconciliation. I first show that the two approaches rest on different conceptual pictures and variable-based representations of the explanandum phenomenon: NDC represents the phenomenon with a single variable, whereas inbetweenness represents it as a pair of causally connected input and output variables. Despite this conceptual difference, I argue that, given some widely accepted interventionist and new-mechanist assumptions, the metaphysical and epistemic theses of the two approaches are compatible, and that they always generate converging constitutive judgements when applied to the same phenomenon. Turning to case studies of the circadian clock in *Drosophila*, I then show that NDC and inbetweenness are each best suited to reconstructing and guiding different stages of mechanistic discovery, depending on how researchers conceptualise and represent the phenomenon at that stage. I conclude that, rather than competing theories, NDC and inbetweenness are better understood as complementary conceptual tools for navigating different episodes of mechanistic discovery.

1. Introduction

Explanations in biological sciences are often said to be mechanistic: they explain a phenomenon by describing the underlying mechanism in terms of organised component entities and activities (Machamer et al., 2000; Glennan, 2002; Bechtel and Abrahamsen, 2005). It is crucial for a mechanistic explanation to describe only the entities and activities that are relevant to the phenomenon to be explained. The notion ‘constitutive relevance’ is hence coined to capture the relevance relation between a phenomenon and the components of its underlying mechanism (see Craver, 2007, Chap. 4). For philosophers of science, the problem of constitutive relevance is threefold: *conceptually*, we ask how to conceptualise a phenomenon, its components, and the relation between them; *metaphysically*, we inquire into the nature of the constitutive relevance relation – that is, the truthmaker(s) of claims about such a relation; *epistemically*, we seek to understand cases of mechanistic discovery in scientific practice – that is, the process by which researchers identify a phenomenon’s components through empirical investigation. To better understand the sciences of mechanisms, it is also crucial to further articulate the relationship between these three aspects of the problem of constitutive relevance (Craver et al., 2021; Craver et al., 2024).

The best-known analysis of constitutive relevance is perhaps Craver’s (2007) ‘mutual manipulability (MM)’ account. Drawing on Woodward’s (2003) interventionist theory of causal relevance, the MM account introduces interlevel experiments as the primary method for assessing claims about constitutive relevance. However, the MM account has received extensive criticism (e.g. Leuridan, 2012; Romero, 2015; Baumgartner & Gebharter, 2016). These challenges have spurred the development of alternative accounts of constitutive relevance. Among these, two main approaches have emerged: the

‘no decoupling (NDC)’ approach, which characterises the relation as an unbreakable common-cause coupling between the phenomenon and its components (Romero, 2015; Baumgartner and Gebharter, 2016; Baumgartner and Casini, 2017), and the ‘inbetweenness’ approach, which views a component as causally situated between the input and output of the phenomenon (Menzies, 2012; Harinen, 2018; Krickel, 2018a; 2018b; Prychitko, 2021; Craver et al. 2021). Both approaches retain the interventionist spirit found in the MM account, yet their characterisations of constitutive relevance differ in all three aforementioned aspects (more details later).

The NDC and inbetweenness approaches to constitutive relevance are often regarded as competing theories that form the basis of an ongoing debate (e.g. Krickel 2018b; Baumgartner & Casini 2025). In contrast, this paper argues for a reconciliation between the two approaches. Specifically, I contend that the two approaches rest on distinct conceptual pictures of constitutive relevance, which give rise to different variable-based representations of the explanandum phenomenon: the NDC approach assumes that the phenomenon is represented by a single variable, whilst the inbetweenness approach posits that the phenomenon is represented by a pair of causally related variables. By highlighting the conceptual and representational differences, I argue that given certain shared assumptions, the two approaches should always yield converging constitutive judgements when applied to the same phenomenon. Further, I argue that which approach can more aptly reconstruct and guide a given instance of mechanistic discovery depends on how the phenomenon is conceptualised and represented in the empirical context. Drawing on case studies from chronobiology, I show that the same research programme evoked different variable-based representations for the different ‘sub-phenomena’ studied at different research stages, and different approaches to constitutive relevance could be applied accordingly. I therefore propose a pluralist view of constitutive relevance, arguing that these approaches are not rival theories. Rather, different accounts of constitutive relevance are best understood as conceptual tools that guide and describe different cases of mechanistic discovery.

Note that my discussion sets aside another line of accounts of constitutive relevance, namely the regularity approach (Couch 2011; 2023; see also Harbecke 2010, 2015). Roughly, the regularity account of constitutive relevance draws on Mackie’s (1980) ‘INUS’ theory of causation and characterises a component of a phenomenon as a non-redundant part of a sufficient but non-necessary condition for the phenomenon. One thing that distinguishes the regularity approach from the NDC and inbetweenness approaches is that the former refrains from the interventionist framework in its analysis, and perhaps as a result, the conceptual framework provided by the regularity approach makes no explicit reference to variables (e.g. Couch, 2011; Harbecke, 2010). While this does not undermine the regularity theory as an account of constitutive relevance, it is difficult to compare the account with the interventionism-inspired accounts, given my focus on the variable-based representations and their implications for experimental practice. This is the main reason why this approach will not be discussed in the present paper.[1]

The remainder of the paper proceeds as follows. After introducing some preliminaries concerning the MM account (Section 2), I present the NDC and inbetweenness approaches to constitutive relevance in greater detail (Section 3). I then argue for a reconciliation of the two approaches, showing that they yield

converging constitutive judgements if appropriately applied to the same case (Section 4). Drawing on case studies about the circadian rhythm in *Drosophila*, I argue that different accounts of constitutive relevance are better suited to guiding and reconstructing different stages of the mechanistic discovery of circadian phenomena, depending on how scientists conceptualise and model the target system (Section 5). Finally, I contend that these distinct accounts provide valuable conceptual tools for navigating different cases of mechanistic discovery, thereby motivating a pluralist view of constitutive relevance (Section 6).

2. The rise and fall of the mutual manipulability account

A primary goal of Craver's MM account of constitutive relevance is to uncover the norms of mechanistic explanations implicit in the experimental strategies employed by practicing scientists (Craver, 2007, p.144). In his terminology, "S's ?-ing" represents the explanandum phenomenon, which is a behaviour (?) of the whole system (S); on the other hand, 'X's f-ing' denotes the activity (f) of an entity (X), which potentially acts as a component of the phenomenon. If X's f-ing is a component of S's ?-ing, the latter is said to stand at a higher mechanistic level than the former. Graphically, Craver (2007) uses a large 'bubble' to represent the phenomenon, which is projected onto several interconnected smaller 'bubbles' representing the components – this is what I call the *'superimposed bubbles'* conceptual picture of constitutive relevance (Fig. 1).

Craver (2007) argues that the evidence for claims of constitutive relevance are usually provided by experiments that are *interlevel* in nature: in bottom-up experiments, researchers manipulate the lower-level activity and detect change in the higher-level behaviour; in top-down experiments, researchers manipulate the higher-level behaviour and detect change in the lower-level activity. Inspired by Woodward's (2003) interventionist framework of causal relevance relation, Craver (2007) uses the notion of ideal intervention to characterise the manipulations required in the interlevel experiments. According to Woodward, roughly, an ideal intervention on X with respect to Y is a manipulation of X which results in a change in Y only through this change in X and not in any other way (Woodward, 2003, p.98). An ideal intervention in the context of constitutive mechanistic explanations is one that changes the activity at one level only through changing the activity at the other level. More specifically, according to the MM criterion, X's ?-ing is a component of S's ?-ing if it can be established '(i) that the putative component is spatially within S, (ii) that some ideal interventions on the putative component (X's ?-ing) change the phenomenon (S's ?-ing), and (iii) that some ideal interventions on S's ?-ing change X's ?-ing' (as phrased by Craver et al. [2024]).

Importantly, MM also adopts from Woodward's interventionist theory its way of articulating relations in terms of *variables*. According to Woodward (2003), variables are the relata of the causal relation. In parallel, MM holds that the relata of the constitutive relevance relation, namely the phenomenon S's ?-ing and its component X's ?-ing, are likewise to be understood as variables. What exactly are variables? Unfortunately, the term 'variable' is not without ambiguity. Woodward states that variables are properties, magnitudes etc. that can take more than one value (Woodward, 2003, p.14; 2008, p.222; 2010, p.290). To

serve as the relata of causal relation, variables are not merely numbers or other abstracta (Woodward, 2003, p.14). However, Woodward also uses 'variable' to refer to the representations of such properties, magnitudes, etc. in causal models (e.g. Woodward 2003, pp.39, 83, 344).[2] This usage aligns with the intuition that the same property (e.g. happiness) can be represented using different variables (e.g. a binary variable or a continuous variable). This sense of the term 'variable' also aligns with the discussions on the problem of variable choice, which is an emerging topic in the literature on causal modelling (see Woodward, 2016). To avoid confusion, in what follows I use 'variables' solely to refer to the variable-based representations of properties, magnitudes, etc. (rather than the properties etc. themselves or the measurement process of properties, magnitudes, etc.).[3]

Back to the MM criterion. Despite its apparent success in answering empirical questions about constitutive relevance, MM stumbles on metaphysical issues. In particular, many argue that the notion of ideal intervention leads to incoherence when applied to interlevel cases (see Leuridan, 2012; Romero, 2015; Baumgartner & Gebharter, 2016; Baumgartner & Casini 2017; Harinen, 2018). According to Baumgartner and Gebharter (2016), the phenomenon *supervenes* on its constituents (given a certain mechanistic organisation). This means that every change in a phenomenon is necessarily accompanied by a change in its constitutive parts. Therefore, it is impossible to intervene ideally on S's ?-ing with respect to its X_i's $?_i$-ings, rendering the MM criterion unsatisfiable. If the definition of ideal intervention is modified in a way that makes such intervention possible, and if X's ?-ing and S's ?-ing are mutually manipulable, then X's ?-ing is also a cause of S's ?-ing, and S's ?-ing a cause of X's ?-ing (Romero, 2015). Such a consequence is undesirable, since it is widely held that a phenomenon and its component cannot stand in a bidirectional causal relation. Thus, MM unavoidably steps into a metaphysical quandary.

In agreement with these objections, I shall not consider MM as a viable account of constitutive relevance. In response to MM's failure, philosophers have proposed several alternatives that work within the interventionist framework whilst avoiding the problems of interlevel ideal intervention. In particular, these accounts share the interventionist commitments to characterising the phenomenon and putative components in terms of variables, and to grounding constitutive judgements in the results of experimental interventions on those variables. I now turn to examine these recent approaches to constitutive relevance.

3. The no decoupling approach and the inbetweenness approach

3.1 The no decoupling approach

Romero (2015) and Baumgartner and Gebharter (2016) are among the first who identified the problems associated with interlevel intervention embedded in MM. According to both critics, rather than ideal, the interventions involved in interlevel experiments are *fat-handed* in nature. A fat-handed intervention I on X with respect to Y is one that '[affects] not just X and other variables lying on the route from I to X to Y, but also variables that are not on this route and that affect Y' (Woodward, 2008, p.209). In interlevel cases, interventions are fat-handed because the phenomenon and its components, due to the supervenience

relation, share all their causes as common causes (see Fig. 2). Based on this insight, Romero (2015, p.3746) argues that if X's ?-ing is a component of S's ?-ing, then any intervention on X's ?-ing is necessarily an intervention on S's ?-ing; moreover, any intervention on S's ?-ing is necessarily an intervention on at least one of its components Xi's ?i-ing. Baumgartner and Gebharter (2016) make a similar argument with a focus on a set of putative components rather than single components. Conceptually, both proposals inherit from MM the 'superimposed-bubbles' conceptual picture of constitutive relevance relation. Based on this conceptual picture, both proposals follow MM in assuming that a phenomenon is represented by a single variable (S's ?-ing).[4]

Building on these proposals, Baumgartner and Casini (2017) offer a more refined formulation of constitutive relevance which they term the No Decoupling (NDC) theory. Sparing the formal details, the NDC theory presents a well-defined metaphysical thesis of constitutive relevance, according to which a phenomenon (S's ?-ing) and the set of all its components **?(X)** = {X_1's ?$_1$-ing, …, X_n's ?$_n$-ing} are *unbreakably* coupled via common causes in a redundancy free manner.[5] The common cause coupling is unbreakable in the sense that any cause of the phenomenon acts as a common cause for at least one of its components. This metaphysical thesis is naturally followed by an epistemic regimen for mechanistic discovery. Specifically, Baumgartner and Casini (2017) argue that since common causes can be found between the phenomenon and a non-component, positive results of interlevel experiments cannot decisively confirm claims of constitutive relevance. Rather, they argue, constitutive relevance relations can only be inferred in an *abductive* way – that is, if and only if S's ?-ing and set **?(X)** remain common-cause coupled after accounting for an extensive list of causes of S's ?-ing, then **?(X)** can be abductively confirmed as *unbreakably* coupled with and hence constitutively relevant to S's ?-ing.

Baumgartner and Casini's (2017) NDC account focuses on the constitutive status of sets of components rather than individual components. This, in my view, is due to the possibility of multiple realisation in mechanisms. When multiple realisation is present, changes in the supervenience base need not produce changes in the supervening property. Since the phenomenon supervenes on its components but not vice versa, altering a single component may leave the phenomenon unchanged. This renders 'bottom-up' experiments – namely, the experiments that intervene on the lower-level variable and observe changes in the higher-level variable – unhelpful for mechanistic discovery. However, actual cases of mechanistic discovery usually proceed in a piece-meal, step-by-step fashion, focusing on one putative component at a time. In such cases, researchers do not work from pre-determined component sets. Can the NDC approach be extended to guide such scenarios? I believe it can, provided multiple realisation is (assumed to be) absent. When multiple realisation is absent, altering a component must also change the phenomenon. In other words, if S's ?-ing is not multiply realised – more precisely, if S's ?-ing is not realised by any mechanism that does not contain X's ?-ing – then any cause of X's ?-ing should act as a common-cause for S's ?-ing.[6]

Notably, it is also impossible for a non-component to share all its causes with S's ?-ing as common causes. Here is why: suppose that all the causes of W's ?-ing are causes of S's ?-ing. Since all the causes of S's ?-ing are causes of some of its components, there must be a subset of the components of S's ?-

ing – call it set **A** ∈ **?(X)** – that is coupled with W's ?-ing via common causes. In other words, any cause of W's ?-ing acts as a common cause of at least one member of **A**. We can express the rest of the components of S's ?-ing using the complement set $\mathbf{A^c}$ = {Xi's ?i-ing ∈ **?(X)** | Xi's ?i-ing ∉ **A}.** Importantly, the set formed by W's ?-ing and members of $\mathbf{A^c}$ (namely, {W's ?-ing} ∪ $\mathbf{A^c}$) is common-cause coupled with S's ?-ing – all the causes of S's ?-ing are causes of some members of the set. As a member of this set, W's ?-ing a component of S's ?-ing.[7]

Therefore, barring multiple realisation, X's ?-ing is a component of S's ?-ing *if and only if* any cause of X's ?-ing acts as a common cause of S's ?-ing. Epistemically, individual components can be identified abductively through experiments that exploit lower-level causes. If the causes of X's ?-ing continue to be confirmed as common causes of S's ?-ing across diverse manipulations and background conditions, the best explanation is thus that X's ?-ing is constitutively relevant to S's ?-ing.[8] In what follows, I take this corollary as part of the NDC approach, guiding the discovery of individual components in certain experimental conditions.

3.2 The inbetweenness approach

Meanwhile, another approach to modifying MM and accounting for constitutive relevance has been under development. In particular, some have begun to question the conceptual picture underlying the MM account. For instance, Krickel (2018b) argues that a single variable cannot properly do justice to the fact that phenomena are usually processes that involve different changes over time. On the other hand, Menzies (2012) stresses that explanandum phenomena for mechanistic explanations are usually captured by causal counterfactuals connecting some input and output conditions. According to this line of reasoning, the phenomenon should be represented as a causal pathway that begins with an input variable, $?_{in}$, and terminates with an output variable, $?_{out}$. Between these endpoints lies a chain of variables representing the causally connected components of the phenomenon. This conceptual picture – what I call the 'chain of nodes' (Fig. 3) – differs from the 'superimposed bubbles' picture employed by MM and NDC. Further, the variables $?_{in}$ and $?_{out}$ are distinct from the overarching phenomenon variable S's ?-ing posited in MM and NDC representations. In other words, the NDC and inbetweenness approaches employ different variables to represent the explanandum phenomenon.

Given this conceptual framework, these authors argue that constitutive relevance amounts to a sort of *causal inbetweenness* – that is, a component is constitutively relevant to a phenomenon if and only if it lies on a causal pathway between the input and the output that define the phenomenon (Menzies, 2012; Harinen, 2018; Krickel, 2018a; 2018b; Prychitko, 2021; Craver et al., 2021).[9] This captures the core metaphysical commitment of the inbetweenness approach to constitutive relevance. Consequently, the epistemic problem of constitutive relevance boils down to the problem of identifying the components causally bridging $?_{in}$ and $?_{out}$. This provides a new interpretation of 'top-down' and 'bottom-up' experiments. According to Harinen (2018, p.48–49), a top-down experiment manipulates the input variable $?_{in}$ and observes whether changes occur in the component variable X's ?-ing, whilst a bottom-up experiment intervenes on X's ?-ing and observes changes in the output variable $?_{out}$. Since $?_{in}$ and $?_{out}$ are

not constituted by X's ?-ing, no interlevel ideal intervention is required by the inbetweenness approach. When both experiments yield positive results, one can conclude that X's ?-ing causally mediates $?_{in}$ and $?_{out}$, and thus that X's ?-ing is a component of the phenomenon in question. The inbetweenness approach hence highlights the use of causal reasonings in mechanistic discovery.

Note that the inbetweenness approach, along with the chain-of-nodes conceptual picture, applies only to phenomena with *definitive* inputs and outputs. A definitive input is a cause of the phenomenon that marks the activation or initiation of the phenomenon in certain background conditions. For example, the phenomenon of memory is initiated by a learning task in suitable experimental conditions. Importantly, when there is no multiple realisation in the mechanism, the definitive input activates all the components of the phenomenon.[10] This can be derived from the inbetweenness commitment that all components lie causally between the input and output; this notion of the definitive input also aligns with the widely accepted assumption that mechanistic components are non-static occurrences concurrent with the phenomenon.[11] Likewise, barring multiple realisation, a definitive output is one that marks the termination of a phenomenon in certain conditions, which also serves as a downstream effect of all its components. In contrast, phenomena without definitive inputs or outputs – arguably including certain oscillatory phenomena – fall outside the scope of the inbetweenness approach.

In sum, the two recent approaches to constitutive relevance differ in many respects. The NDC approach inherits from the MM account the 'superimposed-bubbles' conceptual picture, represents the phenomenon with a single variable, and therefore maintains that the phenomenon and its components are unbreakably coupled by common causes. On the other hand, the inbetweenness approach adopts the 'chain of nodes' conceptual picture, represents the phenomenon as the transition between a pair of input and output variables, and hence treats constitutive relevance as a kind of causal mediation. Both approaches adopt the interventionist framework and offer interconnected answers to the conceptual, metaphysical, and epistemic problems of constitutive relevance. I take both accounts to offer viable solutions for at least some cases of mechanistic discovery. How, then, should we understand the relationship between them?

4. Reconciling the two approaches

The NDC and inbetweenness approaches to constitutive relevance are often regarded as rival accounts (e.g., Krickel, 2018b; Baumgartner & Casini, 2025). However, I argue that the two approaches are complementary rather than conflicting. My argument rests on two points. First, given certain common grounds, the NDC and inbetweenness approaches are compatible with one another – a claim I develop in this section. Second, which approach best guides mechanistic discovery depends on how scientists conceptualise and model target phenomena in practice. Depending on these choices, different approaches are suitable for reconstructing and guiding different stages of mechanistic discovery – I elaborate this with case studies in the next section.

As suggested above, the NDC approach represents the phenomenon with a single variable corresponding to the upper bubble in the 'superimposed-bubbles' picture, whereas the inbetweenness approach represents the phenomenon as the causal transition between two variables, reflecting the 'chain-of-nodes' picture. A pressing question is hence whether the same phenomenon can be appropriately represented by both frameworks. If every phenomenon is subject to only one variable-based representation, then the NDC and inbetweenness accounts should always be applied to different phenomena. In that case, the two approaches to constitutive relevance do not conflict, as they would never yield verdicts about the same phenomenon.

However, it seems to me that nothing prohibits the representation of the same phenomenon in two different ways. In particular, a phenomenon characterised as a transition between input and output conditions can be represented by a single variable as long as the transition varies in magnitude. Conversely, a phenomenon captured by a single variable can equally be represented by an input-output pair as long as it has definitive input and output conditions.[12] Therefore, I assume that at least some explanandum phenomena are amenable to both variable-based representations and hence subject to the analyses of both NDC and inbetweenness accounts.[13] The pressing question thus becomes: would the two accounts yield converging judgments regarding the component status of the same element regarding the same phenomenon?

Here, I argue that, given some widely accepted interventionist and new-mechanist assumptions, the NDC and inbetweenness accounts always generate converging judgements about constitutive relevance when applied to the mechanistic discovery of the same phenomenon. To see this, we need to first ensure that the two aforementioned variable-based representations genuinely capture the same phenomenon. It is thus helpful to illustrate the overarching phenomenon variable posited by the NDC account, S's ?-ing, and the input and output variables adopted by the inbetweenness account, $?_{in}$, and $?_{out}$, in the same causal diagram. Based on what has been said about the two accounts, we know that S's ?-ing corresponds to the causal process between $?_{in}$, and $?_{out}$. In other words, $?_{in}$ is a cause variable of S's ?-ing, while $?_{out}$ is an effect variable of S's ?-ing (see Fig. 4).

In this diagram, the explanandum phenomenon is represented both by S's ?-ing and by the input-output pair ?in and ?out. Recall that the chain-of-nodes representation applies only when $?_{in}$ and $?_{out}$ are the definitive input and output of the phenomenon. As noted above, a definitive input causes all components of the phenomenon, whilst a definitive output results from all components. I treat this characterisation of the definitive input/output as independent of the inbetweenness approach. In particular, it is widely accepted among new mechanist philosophers that mechanistic components are not static parts but occurrences concurrent with the phenomenon when the initiating condition is present. If NDC theorists accept this assumption, they should also accept that the initiating condition – the definitive input – causes all components of the phenomenon. Similarly, new mechanists generally hold that components are effective occurrences contributing to the phenomenon's output. If NDC theorists endorse this view, they should agree that the definitive output is caused by all components of the phenomenon. Rejecting

these two mechanist commitments – that components are non-static and effective – would require substantial argument. I see no reason why NDC theorists should object to either assumption.

Now, suppose that X_5's $?_5$-ing is a component of S's ?-ing judged by the NDC theory, and that there is no multiple realisation in the mechanism. I argue that the inbetweenness theorist will likewise rule that X_5's $?_5$-ing is a component of the phenomenon. Given the assumptions above, $?_{in}$ is a cause and $?_{out}$ an effect of X_5's $?_5$-ing. Since $?_{in}$ is a cause of X_5's $?_5$-ing, manipulations on $?_{in}$ will result in changes in X_5's $?_5$-ing in top-down experiments. In bottom-up experiments, since $?_{out}$ is an effect of X_5's $?_5$-ing, manipulations on X_5's $?_5$-ing will change $?_{out}$. Therefore, the inbetweenness theorist will conclude that X_5's $?_5$-ing lies on the causal chain between $?_{in}$ and $?_{out}$, hence serves as a component of the phenomenon in question.

Suppose that the inbetweenness theorist judges X_6's $?_6$-ing to be a component of the phenomenon because it causally bridges ?in and ?out. Assume also that no multiple realisation is in the picture. I argue that the NDC account will reach the same conclusion. This follows from an intuitive assumption about the identity of causal processes: barring multiple realisation, altering an element forming a causal process changes the process itself. In particular, since X_6's $?_6$-ing is part of the causal process bridging $?_{in}$ and $?_{out}$ (with no multiple realisation), any factor that changes X_6's $?_6$-ing would make a difference to this causal process by altering the input-output relation. Given this assumption, any cause of X_6's $?_6$-ing must be a common cause shared by the causal process in question, namely S's ?-ing. As discussed in Section 3, the NDC account rules that only components of S's ?-ing share all their causes with S's ?-ing as common causes. Therefore, the NDC theorist should conclude that X_6's $?_6$-ing is constitutively relevant to S's ?-ing.

What if the mechanism exhibits multiple realisation – that is, if the same phenomenon type can be realised by different mechanisms involving distinct components across different instances? Importantly, multiple realisation is a property of phenomenon types, not tokens. The reasoning above therefore still applies to each individual instance of the phenomenon; both NDC and inbetweenness theorists should reach the same constitutive judgements at the token level. However, complications arise when making constitutive claims at the type level, particularly when attempting to generalise from experiments in the presence of multiple realisation. In terms of the NDC approach, when a component of S's ?-ing is removed, the common-cause coupling between S's ?-ing and the remaining components may persist due to the involvement of a back-up component. In terms of the inbetweenness approach, top-down or bottom-up experiments may yield negative results for a component when an alternative causal pathway between ?in and ?out exists. Faced with divergent experimental results, researchers can adopt at least three strategies: (a) claim that multiple mechanism types underlie the same phenomenon type, (b) subdivide the phenomenon type into distinct categories each corresponding to one mechanism type, or (c) introduce a new component variable that subsumes both the original and back-up components, thereby merging the mechanism types. Depending on various factors, different researchers may pursue different options (see Colaço [2020] for a discussion). However, such choices are irrelevant to the accounts of constitutive relevance. In other words, when multiple realisation occurs in experimental

contexts, both NDC and inbetweenness theorists face uncertainty. Yet their respective approaches do not determine which strategies researchers adopt when explaining multiply realised phenomena. Therefore, if two researchers differ only in adopting either the NDC or inbetweenness approach, their constitutive judgements should converge even when multiple realisation occurs.

In sum, I argue that for phenomena amenable to the constitutive analyses of both the NDC and inbetweenness approaches, the two approaches always yield converging results and identify the same set of elements as constituting the mechanism. This conclusion relies on both parties endorsing certain assumptions, including the definition of definitive input/output and the identity of causal processes. These assumptions are widely accepted among new mechanist philosophers, and I see no reason to reject them. Absent objection to these assumptions, I argue that the NDC and inbetweenness approaches to constitutive relevance are compatible despite their differences.[14]

5. The case of the circadian clock

In the previous section, I focused on the compatibility of the NDC and inbetweenness approaches. In this section, I turn to their practical application in concrete case studies. Drawing on the circadian rhythm research, I demonstrate that the NDC and inbetweenness approaches are suitable for reconstructing and guiding different stages of mechanistic discovery. Specifically, I show that at different stages of investigating the circadian rhythm in *Drosophila*, researchers adopt different conceptual pictures and employ distinct variables to represent their target phenomena. These choices depend on the nature of the target phenomena as well as pragmatic factors including research questions and available resources. Depending on these choices, the NDC and inbetweenness methodologies are applied to the 'localising' and 'enriching' stages of mechanistic discovery, respectively. I therefore argue that the NDC and inbetweenness accounts serve different explanatory functions and do not conflict in practice. Note that this argument does not rely on the compatibility argument developed in Section 4. Even if NDC and inbetweenness theorists reject the shared assumptions and make conflicting metaphysical claims about constitutive relevance, both accounts can still serve as useful tools for scientists navigating different empirical scenarios.

5.1 The ‘localising’ stage and the NDC approach

It is long recognised that many physiological and behavioural phenomena in organisms are circadian in nature – that is, they oscillate in an approximately 24-hour cycle. These circadian phenomena are explained by the existence of a biological oscillator, namely the circadian clock within the organisms. Such explanations are well-known examples of mechanistic constitutive explanations (which has been extensively discussed by William Bechtel, e.g. Bechtel 2015a; 2015b; 2016; Bechtel & Abrahamsen, 2010; 2011; see also Robins and Craver, 2009). However, how are the components of the circadian clock determined? Which theory of constitutive relevance best accounts for the explanatory projects of circadian rhythms? To answer these questions, we need to take a closer look at the process of mechanistic discovery of the circadian clock.

As with most explanatory projects in the biological sciences, the mechanistic explanation of the circadian rhythm began with an examination of the explanandum phenomena. The notion 'circadian rhythm' does not refer to a single phenomenon, but a wide range of behavioural and physiological patterns in different organisms, each deserves a tailored mechanistic explanation. Yet, a crucial milestone in the phenomenon-level studies was the confirmation of the endogeneity of these circadian phenomena. To establish the endogenous nature of a circadian phenomenon, researchers typically try to eliminate all external input factors to the system (the *zeitgebers*) and assess whether the circadian rhythm persists in their absence. For example, De Mairan (1729) was among the first who observed that the diurnal leaf movements of plants could last for days in constant darkness. However, it was not until the 1960s that a consensus among scientists eventually emerged, recognising that most if not all circadian rhythms are endogenous phenomena.

As mentioned, a phenomenon being endogenous means that external inputs are not necessary for the sustenance of the phenomenon. However, some initiating conditions must be present for the phenomenon to occur. Environmental cues, for instance, are critical for entraining circadian rhythms during time zone changes or in the infancy of animals (see Vallone et al., 2006). Internal inputs such as metabolic energy are likewise essential for circadian oscillators to function. Nevertheless, given a focus on the stable, ongoing circadian rhythms of adult organisms, researchers typically excluded input conditions from their characterisation of the circadian phenomena at the outset of the explanatory programme.

Once the phenomenon is well characterised, researchers begin investigating its underlying mechanism. As argued by Bechtel and Richardson (1993/2010), a common heuristic at this stage is to identify a *locus of control* of the phenomenon. A locus of control for a phenomenon is assumed to be a localised component within the system that is essential for the phenomenon. In the case of circadian rhythm, the locus of control was labelled metaphorically as *the clock*. With the conviction that there must be a circadian clock, scientists set off to look for the clock mechanism. We can call this stage the *'localising' stage* of the mechanistic discovery for circadian phenomena.

Now we have a clearer picture of the situation confronted by the researchers at this stage: the phenomenon of interest was the circadian behaviour of a certain species (e.g., the diurnal locomotion of *Drosophila*); moreover, since the phenomenon was endogenous, the inputs to the system were excluded from consideration; finally, the phenomenon was assumed to be generated by a localised system within the organism, i.e., the clock. Given this situation, which account of constitutive relevance can best serve as a guidance for the mechanistic discovery? Well, the inbetweenness account does not seem to be a good choice – without a definitive input, the phenomenon cannot be conceptualised as a causal chain.[15] In contrast, the NDC approach fits well with this picture. The circadian phenomenon was straightforwardly represented by a single variable – for instance, the behaviour of *Drosophila* was usually represented by a binary variable capturing the presence of locomotor activities detected by infrared light beams. Moreover, multiple realisation was not a major concern at this stage of research. Given the

clock's role as the locus of control, clock components were assumed to be essential and irreplaceable. Thus, the NDC approach could be applied to identify individual clock components.

Indeed, the NDC approach offers a tailored reconstruction of the experimental works conducted during this phase of research on circadian rhythm. According to Bünning (1964[1958]), the functioning of various anatomical structures were investigated in this period. These clock candidates included the secretion of the fasciculus opticus (a hormonal gland) in crustaceans and the secretion of the adrenal gland and the pituitary gland in vertebrates. Knockout experiments served as a major method for examining the role played by these putative clock components, whereby the putative components were manipulated, and changes in the circadian behaviour were detected. I believe that this method can be understood through the NDC account – that is, as tests for the common cause coupling between the component and the phenomenon when multiple realisation is absent. According to the NDC account, any change to an essential component should be accompanied by a change to the phenomenon. Thus, if manipulation on the putative clock component resulted in changes in the circadian behaviour across a wide range of conditions, this would be evidence for the claim that all causes of the putative component act as a common cause of the phenomenon, and hence for the constitutive status of the putative component.

Notably, almost all of the component candidates under investigation shared some common causes with the respective circadian behaviours – that is, there were always some causes that could change the activity of the candidate structure and the circadian behaviour altogether. However, as predicted by the NDC approach, the scientists did not close the case upon several positive results – after all, common cause coupling could exist between the phenomenon and non-components. Rather, scientists kept testing different manipulations to see if role of the putative component regarding the circadian phenomenon – or in NDC's terminology, the common cause coupling between them – was robust enough for constitutive claims. Sadly, it turned out that the coupling for most clock candidates appeared broken after further investigation – for example, when the fasciculi optici was removed from crabs, the diurnal fluctuations in oxygen consumption continued (Brown et al., 1954); when the pituitary gland was removed from rats, the rhythm disappeared at first but re-appeared slowly after a few days (Levinson et al., 1941). The search for the circadian clock proved to be a prolonged battle.

As a turning point of this research period, a genetic locus of circadian rhythm was identified in *Drosophila*. In particular, Konopka and Benzer (1971) found three types of mutants with different phenotypes of the circadian locomotive behaviour in the flies (one arrhythmic, one with a shorter circadian period, and one with a longer period). All three mutants have mutations in the same functional gene named *period (per)*. Following studies showed that the functioning of *per* plays a crucial role for the circadian behaviour in *Drosophila*– a nonsense mutation[16] in *per* led to the absence of rhythmic behaviour, while increased and decreased numbers of normal *per* alleles led to shortened and lengthened circadian periods, respectively (see Hall & Rosbash [1987] for a review). In terms of the NDC theory, the common-cause coupling between *per* functioning (X's ?-ing) and the circadian phenomenon (S's ?-ing) was strong: all the various causes of the former that were tested proved to be causes of the

latter. Based on these findings, researchers argued that *per* forms an important component of the circadian clock in *Drosophila*. The discovery of the first genetic locus of the clock thus marked a milestone in the mechanistic discovery of circadian phenomena.

5.2 The ‘enriching’ stage and the inbetweenness approach

The discovery of *per* gene initiated the era of chronogenetics. Using genetic screening technologies, researchers identified more genetic loci of circadian rhythms at the turn of the 21st century (see Cermakian & Sassone-Corsi [2000] for a review). Given these clock components, researchers wanted to know *how* they gave rise to the circadian phenomena. In other words, a crucial next step for the mechanistic discovery was to fill in the details that were left blank in the mechanistic model – or the ‘mechanism sketch’ in Craver’s (2007) term. Call this next stage the ‘enriching’ stage of the mechanistic discovery of circadian rhythms.

How could a mechanistic model be enriched? The NDC account proposed by Baumgartner and Casini (2017) starts with the assumption that we already have a set of putative components in mind. The account says nothing about where to find more component candidates or how to enrich the set. On the other hand, the inbetweenness approach offers a practical guideline for filling in the blanks in an incomplete mechanistic model. In particular, two causally related components can be viewed as forming an input-output structure, and the elements on the causal path between the two can be identified using the causal betweenness reasoning. In other words, by zooming in on the causal transition between two known components of the broader mechanism, researchers can use the inbetweenness approach to further the mechanistic discovery. Therefore, I argue that the ‘enriching’ stage of the mechanistic discovery of the circadian rhythm can be fruitfully reconstructed by the inbetweenness account of constitutive relevance.

Regarding the function of *per* in *Drosophila*, Hardin and colleagues (1990) proposed a negative feedback loop between *per* mRNA and its translation product PER protein. According to their hypothesis, the PER protein inhibits the transcription of its own gene, resulting in an oscillation of its expression, thereby controlling the circadian rhythm. However, a problem emerged: the PER protein lacked any DNA-binding domain, so some other factor would need to mediate this inhibitory effect. How does the PER protein inhibit the transcription of gene *per*? This became a crucial research question at this stage. Note that the phenomenon in question differs from the behavioural level pattern studied at the localising stage of the research programme – the former can be understood as a distinct segment or ‘sub-phenomenon’ of the broader subject matter of circadian rhythms. In this sub-phenomenon, PER protein production (i.e. per mRNA translation) serves as the input condition, *per* DNA transcription as the output condition, and the question concerns how the former inhibits the latter. Thus, even if the behavioural-level circadian phenomenon lacks definitive initiating or terminating conditions, this sub-phenomenon remains subject to causal-betweenness reasoning.

Although PER does not have DNA binding motifs, it contains a sequence that can support binding with another protein. A potential binding partner for PER was believed to be the TIM protein. In particular, the

timeless (tim) gene is another genetic locus of circadian rhythm, and its product mRNA and product protein TIM are involved in a negative feedback loop similar to PER. It was therefore proposed that TIM mediates the inhibitory effect in the per feedback loop. To test this hypothesis, Sehgal and colleagues (1995) conducted a series of manipulationist experiments. In particular, they measured the levels of TIM and *tim* mRNA in nonsense *per* mutants, and found out that the absence of PER ($?_{in}$) abolished the oscillation of TIM, thereby altering its activity. In the terms of the inbetweenness approach, this counts as a top-down experiment On the other hand, the level of *per* mRNA was measured in nonsense *tim* mutants, and it turned out that the absence of TIM also eliminates the oscillation of *per* mRNA. In other words, TIM enabled the change in the *per* transcription ($?_{out}$), hence passing the test of a bottom-up experiment. Therefore, the activity of TIM could be said to causally mediate the changes in the level of per translation and transcription (Fig. 5). Based on further evidence, Sehgal and colleagues concluded that TIM plays the role of dimerizing with PER and transporting it into the nucleus where the DNAs are located. The mechanistic model of the circadian clock in *Drosophila* was therefore enriched.

More blank spaces remained to be fulfilled. In particular, it remained unclear how the PER-TIM dimer regulates the transcription of its target genes in *Drosophila* (after all, TIM also lacks a DNA-binding domain). Meanwhile, research on mammalian circadian mechanisms offered insight into this problem. In particular, it was found in mice that the product protein of gene *clock* could bind the *per* gene. Darlington and colleagues (1998) hence hypothesised that a homolog of *clock* exists in flies which can activate the transcription of *per* and *tim*. After identifying a *clock* homolog gene in *Drosophila*, *dclock*, Darlington and colleagues set off to investigate the role played by *dclock* and its product protein dCLOCK. They transfected a construct expressing *dclock* into a cell line that did not express *dclock*, *per*, or *tim*. It was found that dCLOCK causes significant induction of the promoters of *per* and *tim* – that is, the presence of dCLOCK activates the transcription of *per* and *tim* (bottom-up experiment). Moreover, by transfecting *per* and *tim* into the cells, they observed that the dCLOCK-mediated induction of *per* and *tim* was inhibited by the presence of PER and TIM proteins (top-down experiment). On the other hand, PER and TIM exhibited no negative effect on the expression of *per* and *tim* when dCLOCK was excluded. Therefore, the researchers concluded that dCLOCK was the missing puzzle causally connecting the negative feedback between the production of PER-TIM dimer ($?_{in}$) and the transcription level of *per* and *tim* ($?_{out}$). As they put it, 'dCLOCK closes the feedback loop of *Drosophila* circadian oscillator' (Darlington et al., 1998, p.1602).

In the two examples above, two clock components – namely the functioning of TIM and dCLOCK – were identified using causal-betweenness reasoning as prescribed by the inbetweenness approach. In particular, their constitutive relevance to the clock mechanism was confirmed by their roles in the causal pathways between known clock components, which constitute the broader clock mechanism. In each case, the previously identified components served as the definitive input and output variables of the sub-phenomena in question, and the causal role of the putative component was established by both top-down and bottom-up experiments. Therefore, I argue that the inbetweenness approach aptly captures the methodologies guiding mechanistic discovery during the 'enriching' stage of the research.

6. The upshot: a pluralist view of accounts of constitutive relevance

The preceding case studies have shown that the NDC approach to constitutive relevance is more suitable to describe the 'localising' stage of the mechanistic discovery of the circadian rhythm, whereas the inbetweenness approach is more suitable for the 'enriching' stage of the mechanistic discovery. Thus, rather than being rivals, the two frameworks work in tandem in guiding the mechanistic research programme on circadian phenomena in *Drosophila*. Such a conclusion can be generalised by attending to the ubiquity of endogenous, oscillatory phenomena in biology and neuroscience. In particular, endogenously active biological oscillators are commonplace in biological systems. These oscillators support various biologically significant phenomena, ranging from motor behaviours (Calabrese & Marder, 2024) to cognitive processes (Ward, 2003).[17] I suggest that the narrative I presented for chronobiology at least applies to many other oscillatory phenomena.

Although both episodes of research contribute to the mechanistic explanation of the same subject matter – namely, the circadian rhythm in *Drosophila* – I argue that it is reasonable to interpret them as targeting two sub-phenomena labelled by the same overarching concept within the same research programme.[18] In particular, at the 'localising' stage, researchers asked what is the source of the endogenous circadian behaviour at the organism level, whereas at the 'enriching' stage, the question became how the PER protein inhibits the transcription of the *per* gene. These two questions address two distinct aspects of the circadian rhythm, targeted at different stages of the mechanistic research. Further, researchers employed different forms of variable-based representations to capture these two sub-phenomena. At the localising stage of circadian research, no known input factor could usefully demarcate the sub-phenomenon; hence, the sub-phenomenon was represented by a single variable and conceptualised in line with the 'superimposed bubble' picture. By contrast, during the enriching stage, elements within the mechanism sketch served as the input and output factors for further mechanistic discovery; accordingly, the sub-phenomenon was represented as a chain of causally connected variables. Importantly, these two conceptual and representational schemes do not conflict. Rather, they exemplify a process of reconceptualisation of the explanandum phenomenon during the mechanistic discovery.[19] If my reconstructions are accurate, the case study of the circadian rhythm illustrates that both the target sub-phenomena and the variable-based representations employed for a given subject matter can change over the course of mechanistic discovery.

As a result of this transformation, different accounts of constitutive relevance, embedded with different conceptual pictures, are evoked to guide the mechanistic discovery accordingly. In particular, in the 'localising' stage of circadian studies, the sub-phenomenon was represented as a single, overarching variable. Consequently, the NDC account and the abductive reasoning were applied in order to localise the circadian pacemaker. In the 'enriching' stage, the sub-phenomenon was represented as a causal chain. As a result, the inbetweenness account and causal analyses were applied to fill in the mechanistic details. More generally, I argue that scientists routinely adjust their approach to constitutive relevance and methodologies for mechanistic discovery according to the present goals and resources of their investigation. Here, I invite the reader to think of accounts of constitutive relevance and their

corresponding methodologies as tools for navigating different cases of mechanistic discovery. As different physical environments demand different physical tools, so too do different 'conceptual environments' favour different conceptual tools.

Thus, my argument is not limited to the oscillatory cases, as all cases of mechanistic discovery involve variable representations and conceptual assumptions that might fare well with some accounts of constitutive relevance but not others, which call for case-by-case analyses. To account for a plurality of cases, we should embrace a plurality of theories of constitutive relevance, including both the NDC and inbetweenness approaches, their variants, and even other distinct accounts[20]. I believe that such a pluralist viewpoint is philosophically fruitful – it untethers philosophical endeavours from the ambitious goal of providing a universal theory of constitutive relevance, and frees accounts of constitutive relevance from a debate that is unlikely to be decisively resolved. Armed with the pluralist view, philosophers can offer more tailored advice to practicing scientists by identifying the philosophical tool most suitable for the empirical investigation at hand. Moreover, many intriguing questions remain to be answered. For instance, what factors influence the choice of variables in mechanistic models? Which factors are involved in the 'conceptual environment' of an inquiry? Do researchers manipulate and control this 'conceptual environment' in ways analogous to how they manipulate and control the physical environment? Adopting a pluralist view of constitutive relevance opens the door to a wide range of fruitful philosophical discussions.

7. Conclusion

In conclusion, in this paper I contend that the NDC approach and the inbetweenness approach to constitutive relevance should not be viewed as rival accounts. Given certain common assumptions, I argue that the NDC and inbetweenness approaches are compatible and that they generate converging constitutive judgements when applied to the same cases. Based on the case study of explaining circadian phenomena, I argued that the two approaches are suitable for guiding and reconstructing different stages of mechanistic discovery given how the explanandum phenomena are conceptualised in practice. Therefore, I proposed that we should think of different approaches to constitutive relevance as providing tools for navigating different cases of mechanistic discovery. By attending to the conceptual problems, our understanding of constitutive relevance and mechanistic explanations can be sharpened and better align with actual scientific reasoning.

Declarations

Author Contribution

The author prepared all the work for the manuscript.

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Footnotes

1. However, Harbecke (2015) offers an inferential method that purports to translate the regularity theory into experimental investigations in terms of variables. If this attempt is successful, future work could explore whether and how my argument may also apply to the regularity approach.
2. This equivocality is explicitly acknowledged by Woodward (2003) in a footnote, where he states '[f]or ease of exposition, I often use "variable" to describe both the properties, magnitudes, and so on related by causal claims and the representations we use to describe such properties. I believe that the resulting conflation of use and mention is (in this context) harmless' (Woodward, 2003, p.377).
3. When I use phrases such as 'an intervention on a variable,' I do so as a shorthand for 'an intervention on an occurrence represented by a variable.'
4. This variable is denoted as 'ψ' by Baumgartner and Casini (2017) and as 'ψ_s' by Romero (2015).
5. The redundancy-free requirement states that no proper subset of the constituting set is common-cause coupled with the phenomenon. This requirement is made to exclude non-constituents such as sterile effects (see Baumgartner and Casini, 2017, p.226). Moreover, a parthood requirement is included in the NDC account to ensure that every instance of Xi's ϕi-ing is a spatiotemporal part of an instance of S's ψ-ing.
6. This characterisation aligns with Romero's (2015, p.3746) account.
7. Note that although now there are two sets that are common-cause coupled with S's ψ-ing, this does not mean that S's ψ-ing is multiply realised. Since W's χ-ing is common-cause coupled with a subset of ϕ(X), it can be understood as a mid-level description of the same components in the subset.
8. This reasoning can be demonstrated by recent papers that attempt to apply the NDC theory to case studies from neuroscience. For instance, Serban and Holm (2020) apply the NDC theory to the case of long-term potentiation (LTP) and memory, arguing that NDC can establish LTP's constitutive relevance to memory through targeted experiments that manipulate LTP. (See van Eck, 2019, for a similar application.)
9. Note that these recent proposals also vary in their commitments to the inbetweenness approach. For instance, Prychitko (2021) develops her account as an epistemic theory of constitutive relevance, not a metaphysical one. Craver and colleagues (2021), on the other hand, argue that their epistemic account constitutes a sufficient but not necessary condition for mechanistic discovery, thereby leaving room for alternative approaches beyond the inbetweenness framework. However, this paper focuses on a version of inbetweenness theory that is both metaphysical and epistemic, and it serves a sufficient and necessary condition for constitutive relevance.

10. When multiple realisation is present, however, there are multiple causal path between the definitive input and output, and a given element on one of the causal path may not be activated by the input.
11. I thereby reject the treatment of the so-called standing conditions as components, which Craver, Glennan, and Povich (2021) defend in their inbetweenness account. Standing conditions are stable structural features necessary for a phenomenon's occurrence – for example, the bracket of a bicycle, which these authors argue constitutes a component of the bicycle's movement. However, Baumgartner and Casini (2025) challenge this view, arguing that since standing conditions are static and do not lie on the causal pathway between input and output conditions, treating them as components conflicts with the inbetweenness approach. I agree with this objection. Such unchanging conditions are better understood as modulators or background conditions rather than as components of the phenomenon.
12. Proponents of the NDC and inbetweenness theories have also cited overlapping case studies to support their respective views. For example, researches on memory and hippocampus activities has been used to support the NDC approach (Serban and Holm, 2020) as well as the inbetweenness approach (Krickel, 2018b).
13. This assumption is compatible with the possibility that the two approaches cannot apply to all phenomena and that they differ in their limitations.
14. One may ask: what accounts for the difference in inferential strategies for mechanistic discovery between the two approaches? Recall that NDC theorists argue that components can only be inferred abductively and inconclusively, whereas inbetweenness theorists believe components can be confirmed conclusively through causal analysis. I contend this difference dissolves upon closer examination. When the inbetweenness theorist lacks knowledge of the definitive input, they must test many input variables and establish the causal betweenness of the putative component across various inputs and the output. This situation permits only inconclusive confirmation of constitutive relevance, mirroring the NDC approach.
15. However, I acknowledge that these circadian phenomena may in principle be conceptualised as a causal chain. As noted above, circadian phenomena are not simply inputless. Rather, it seems plausible that the inputs were idealised away from the representations to highlight the endogenous feature of the phenomena.
16. A nonsense mutation is a mutation in a DNA sequence that results in a nonsense codon or a premature stop codon, which often leads to a complete loss of normal protein function.
17. See also Bechtel and Abrahamsen (2010) for a discussion on the importance of oscillatory organisations in biology.
18. The circadian rhythm thus resembles what Feest (2017; 2025) calls an object of research, which can be associated with multiple different empirical patterns in different studies.
19. The reconceptualisation of explanandum phenomena has been discussed in the new mechanist literature under the label ‘phenomenon reconstitution’ (see Bechtel & Richardson [1993/2010];

Kronfeldner [2015]; Colaço [2020]). Future work may explore how the case studies discussed here align with this literature.

20. For example, Rumana (2024) offers an account of constitutive relevance that is tailored to computational cognitive neuroscience.

Figures

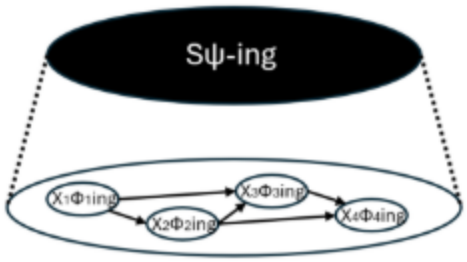


Figure 1

The “superimposed bubbles” conceptual picture of constitutive relevance. Adapted from Craver (2007, p.189)

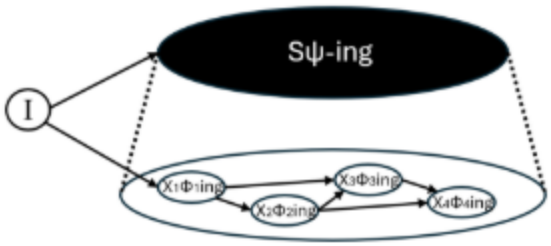


Figure 2

Fat-handed intervention. Intervention I is a common cause of both S’s ψ-ing and at least one of its components. Adapted from Baumgartner and Gebharter (2016, p.750).

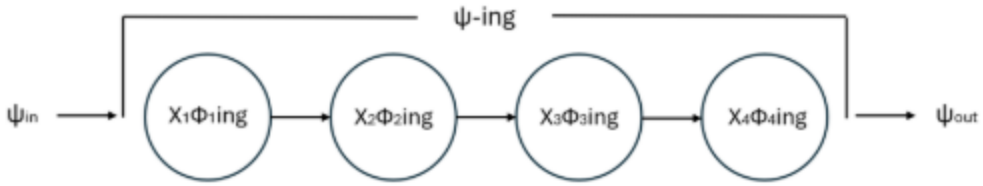


Figure 3

The ‘chain of nodes’ conceptual picture of constitutive relevance. Adapted from Craver et al. (2021, p.8812).



Figure 4

Schematic illustration showing the relationship between S's ψ-ing, ψ_{in}, and ψ_{out}.



Figure 5

Schematic diagram showing the mediating role of TIM in *per* translation and transcription. Arrows represent causal relations.