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The regularity theory of mechanistic constitution and a methodology for constitutive inference

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ABSTRACT

This paper discusses a Boolean method for establishing constitutive regularity statements which, according to the regularity theory of mechanistic constitution, form the core of any mechanistic explanation in neuroscience. After presenting the regularity definition for the constitution relation, the paper develops a set of inference rules allowing one to establish constitutive hypotheses in light of certain kinds of empirical evidence. The general methodology consisting of these rules is characterized as having formed the basis of many successful explanatory projects in neuroscience.

1. Introduction

According to the "mechanistic approach" to theory construction, explanation in neuroscience essentially requires the identification, location, and analysis of the mechanisms underlying a to-be-explained phenomenon on several levels (cf. Bechtel & Richardson, 1993; Craver, 2002, 2007; Machamer, Darden, & Craver, 2000) The definition of a mechanism given by Machamer et al. describes it as consisting of "… entities and activities organized such that they are productive of regular changes from start or set-up to finish or termination conditions." (Machamer et al. 2000, 3). Bechtel and Abrahamsen extend this definition by describing a mechanism as "… a structure performing a function in virtue of its component parts, component operations, and their organization. The orchestrated functioning of the mechanism is responsible for one or more phenomena." (Bechtel & Abrahamsen, 2005, 423)

It is important to distinguish between what Machamer et al. (2000, 3) call "being *productive* of regular changes" and what Bechtel and Abrahamsen (2005, 423) characterize as being "*responsible* for one or more phenomena" (*emphases added*) from *causing* a phenomenon or event. When mechanisms are characterized as producing, or as being responsible for, a phenomenon they are not believed to precede the phenomenon temporally as it is definitional for causes. Rather, the idea is that the mechanisms underlie, realize, or instantaneously determine the initially identified phenomenon. The non-causal and synchronous relation between the phenomena and their mechanisms is now usually referred to as "constitution", "composition", or "constitutive relevance".[1] As mechanisms can sometimes become *explanantia* themselves in the sense that their occurrence is explained by other

[1] The term "composition" has been used by Machamer et al. (2000, 13), Bechtel & Abrahamsen (2005, 426), and Craver (2007, 164); "constitution" occurs in Craver (2007, 153); "constitutive relevance" is found in Craver (2007, 139). It is safe to say that the authors intend these terms widely synonymously. For the sake of terminological unity, from now on we will use the term "constitution" to denote the relation that is referred to by these expressions.

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"lower-level" mechanisms constituting them, the idea of a distinction of "mechanistic levels" has entered the picture.

With the introduction of these two notions, a host of new philosophical puzzles has entered the debate on explanation in neuroscience. One problem to be solved in this context is to offer a satisfactory conceptual analysis of the relation of mechanistic constitution. Call this the "definitional question". Furthermore, certain general questions arise concerning the establishment and discovery of particular mechanistic explanations and hypothesis. This problem corresponds to some extent to questions about causal discovery and inference. As an example of this, John Leslie Mackie (1974) has argued that causation is primarily a second-order relation among types. A cause is a type that is an insufficient but non-redundant part of a condition which is itself unnecessary but sufficient for the occurrence of the effect type. Or in short, a cause is an "INUS"-condition. Even when it is agreed that causation has something to do with INUS-regularities, it is not immediately clear what procedures and inferences allow us to establish a true causal INUS-regularity statement. This puzzle could be called the "methodological question".

This paper sides with the mechanists in their general approach to explanation. It takes the mechanistic framework to be widely adequate for explanation in neuroscience, and it mainly tries to refine the response that the regularity theory of constitution has given to the "definitional question" (cf. Couch, 2011; Harbecke, 2010) by providing new answers to the "methodological" question on the basis of this theory. The aim will be realized by showing how certain inference rules formulated within the regularity framework allow to establish constitutive hypotheses in light of certain kinds of empirical evidence.

The paper is structured as follows. Section 2 sketches an example of a currently accepted explanation in neurobiology that is used as a test case for the subsequent discussions. The regularity theory of mechanistic constitution is presented as an answer to the definitional question in Section 3. Section 4 develops the inference rules that are intended as an answer to the methodological question. An interesting implication of the regularity theory and the associated theory of constitutive inference is the fact that it provides an empirical criterion for the identity and/or reduction of mechanistic types. Section 5 discusses the kind of empirical result that, according to the regularity theory, implies an identity hypothesis. Section 6 summarizes the results and points to some puzzles in the context of the regularity of mechanistic constitution that will have to be left for future research.

2. Explanation in neuroscience

The test case for philosophical theories of mechanistic constitution and constitutive inference is their successful application to certain widely accepted research results in neuroscience. One such result that has become a standard case in the debate is the mechanistic explanation of spatial memory acquisition in rats (cf. Bickle, 2003, chaps. 3–5; Churchland & Sejnowski, 1992, chap. 5; Craver & Darden, 2001, 115–119; Craver, 2002, sec. 2; Craver, 2007, 165–170).

According to this theory, the phenomenon of long-term potentiation (LTP) at neural synapses within the rat's hippocampus is a central mechanism underlying spatial memory and learning in rats (cf. Bliss & Lømo, 1973; Lømo, 2003, 618; Morris, Garrud, Rawlins, & O'Keefe, 1982). Hippocampal LTP in turn has been demonstrated to involve the activation of *N*-methyl- D-aspartat (NMDA) receptors on CA1 pyramidal cells (cf. also Davis, Butcher, & Morris, 1992; Harris, Ganong, & Cotman, 1984; Morris, 1984; Morris, Anderson, Lynch, & Baudry, 1986).

The mechanism underlying NMDA-receptor activation is extremely complex. It is now believed that the NMDA-receptor channels of pyramidal cells are blocked by Mg^{+} ions during the rest potential phase (cf. Churchland & Sejnowski, 1992, 255–270). If the postsynaptic membrane is strongly depolarized through a train of high-frequency stimuli and through an activation of other receptors, the Mg^{+} ions are repelled whereby the blockade of NMDA-receptors is lifted. As a result, an increased influx of Na^{+}, K^{+}, and Ca^{2+} ions occurs. The resulting Ca^{2+} rise within the dendrite then activates calcium-dependent kinases (Ca^{2+}/Calmodulin-kinase and proteinkinase C). These processes add new channels to the postsynaptic dendrite, which requires in turn a modification of the cell genes expression (cf. Bourtchouladze et al., 1998), they alter the channels' sensitivity to glutamate, or they increase the channels' transmission capacity of Ca^{2+} ions (cf. Toni, Buchs, Nikonenko, Bron, & Muller, 1999). Through all these paths an increase in sensitivity of the postsynaptic receptors is attained which can last for a period of up to several hours.

With these results in the background, the neurobiological explanation of spatial memory has been described as involving at least the following central phenomena and mechanisms (cf. Craver & Darden, 2001, 118; Craver, 2007, 166):

1. The development of spatial memory in the rat
2. The generating of a spatial map within the rat's hippocampus
3. The long-term potentiation of synapses of CA1 pyramidal cells
4. The activation of NMDA-receptors at the synapses of CA1 pyramidal cells

The overall explanation then consists in a conjunction of claims about the *constitutive relationships* holding between these phenomena and mechanisms. Arguably, it is this relation of constitution that scientists generally have in mind when they say that a mechanism "is responsible for" (Bliss & Lømo, 1973, 331), "gives rise to" (Morris et al., 1986, 776), "plays a crucial role in" (Davis et al., 1992, 32), "contributes to", "forms the basis of" (both Bliss et al., 1993, 38), "underlies" (Frey, Frey, Schollmeier, & Krug, 1996, 703; Lømo, 2003, 619), or "is constitutively active in" (Malenka et al., 1989, 556) a phenomenon. To offer a transparent analysis of these natural language terms, and to provide an adequate analysis of the relation referred to, is the aim of the regularity theory of mechanistic constitution.

Along with this conjunctive claim stating various constitutive relationships comes a more or less explicit distinction of levels. If this reconstruction of the explanation is adequate, and if the example summarized above is paradigmatic for theories in neurobiology, it is evident that the notion of constitution plays a central role in standard neurobiological explanations.

3. Regularity constitution

Since, according to the received view mentioned in Section 1, the *relata* of mechanistic constitution do not have distinct instances, constitution is not a causal relation. Not having distinct instances does not imply that the instances are identical, it merely says that the space-time regions instantiating the relata of mechanistic constitution overlap.[2] But if constitution is not causation, it becomes significant to ask what relation precisely working scientists have in mind when they describe a mechanism as "responsible

[2] Note that two space-time regions can overlap without being identical in the case that they do not perfectly overlap (that is, if they are not both a mereological part of the respective other).