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Brain networks, structural realism, and local approaches to the scientific realism debate

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ABSTRACT

We examine recent work in cognitive neuroscience that investigates brain networks. Brain networks are characterized by the ways in which brain regions are functionally and anatomically connected to one another. Cognitive neuroscientists use various noninvasive techniques (e.g., fMRI) to investigate these networks. They represent them formally as graphs. And they use various graph theoretic techniques to analyze them further. We distinguish between knowledge of the graph theoretic structure of such networks (structural knowledge) and knowledge of what instantiates that structure (nonstructural knowledge). And we argue that this work provides structural knowledge of brain networks. We explore the significance of this conclusion for the scientific realism debate. We argue that our conclusion should not be understood as an instance of a global structural realist claim regarding the structure of the unobservable part of the world, but instead, as a local structural realist attitude towards brain networks in particular. And we argue that various local approaches to the realism debate, i.e., approaches that restrict realist commitments to particular theories and/or entities, are problematic insofar as they don't allow for the possibility of such a local structural realist attitude.

1. Introduction

Brain networks are one of the primary objects of study in cognitive neuroscience. These networks are characterized by the ways in which brain regions are anatomically and functionally connected with one another. Cognitive neuroscientists use a variety of noninvasive techniques (e.g., fMRI) to study these connections. They use graph theory to represent these networks formally as graphs, where the nodes of the graph correspond to brain regions, and the edges correspond to connections between regions. And they use a variety of graph theoretical measures to analyze the ways in which brain networks are organized.

Our goal in this paper is to examine this work in cognitive neuroscience, determine the kind of epistemic commitment towards brain networks that this work licenses, and draw some conclusions about the scientific realism debate based on our analysis of this work.

In order to determine the appropriate kind of epistemic commitment, we examine the scientific practices involved in the study of brain networks and the attitudes that cognitive neuroscientists take towards brain networks as a result of engaging in those practices. We consider two possible kinds of epistemic commitment. Since cognitive neuroscientists represent brain networks as graphs, one possibility is that this work licenses an epistemic commitment to the graph theoretic structure of brain networks, without giving us knowledge of what instantiates that structure. We call this possibility *structural knowledge of brain networks*.[1] Alternatively, if this work gives us knowledge of what instantiates that structure, then we have what we call *nonstructural knowledge of brain networks*. We argue that this body of work in cognitive neuroscience gives us structural knowledge of brain networks.

In order to draw our conclusions regarding the realism debate, which concerns issues like the truth of our best theories and the existence of the entities that they posit, we focus on two positions within that debate. The first is structural realism, which is most often understood as a global position regarding our best theories in general, according to which those theories latch onto the structure of the unobservable part of the world. We argue that our claim regarding structural knowledge of brain networks should not be

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[1] If knowledge is too much of a loaded term, we can put the same point in terms of belief or epistemic commitment.

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understood as an instance of a global structural realist claim regarding our best theories in general. Instead, it ought to be understood locally, with no presumption that what goes for this work in cognitive neuroscience will generalize to other branches of science. The second position is what we call a local approach to the scientific realism debate. Unlike global structural realists, proponents of local approaches restrict their realist conclusions to particular theories and/or entities (Fitzpatrick, 2013; Magnus & Callender, 2004). We argue that these approaches can be problematic insofar as they involve a choice between realism and anti-realism regarding a particular theory or entity; adopting a kind of local structural realist attitude, as we do towards brain networks, is not an option. And we discuss how Saatsi's (2015) exemplar realism allows for this possibility, in which case our conclusions regarding brain networks fit most comfortably within that position.

The approach that we take in this paper involves a careful examination of the practices involved in the study of brain networks, and this approach has both strengths and limitations. One strength is that our conclusions are grounded in actual scientific practice. Another strength is that we bring a relatively novel case to bear on issues in the realism debate. While cognitive neuroscience, and work on brain networks in particular, features in the philosophy of science more generally (Bechtel, 2015; Colombo, 2013; Zednik, 2015), it has not played much of a role within the realism debate. And by bringing this case into the realism debate, we're able to explore a relatively unexplored possibility within that debate, namely, the possibility of adopting a kind of local structural realist attitude. However, the fact that our conclusions are so closely grounded in scientific practice is a double-edged sword, since it may turn out to be the case that cognitive neuroscientists are on the wrong track regarding the kind of epistemic commitment that this work licenses. That said, we still take it to be worth considering what kinds of philosophical conclusions can be drawn from this work on the assumption that cognitive neuroscientists are on the right track.

We proceed as follows. In section 2, we discuss the background and significance of this work in cognitive neuroscience. In section 3, we distinguish between two kinds of brain networks that cognitive neuroscientists investigate, namely, anatomical networks and functional networks. In section 4, we provide more detail regarding the noninvasive and graph theoretic techniques that they use to investigate these networks. In section 5, we argue that the application of these techniques provides structural knowledge of brain networks. In section 6, we discuss structural realism. And in section 7, we discuss various local approaches to the realism debate.

2. Modeling brain networks

For some time, neuroscientists have worked towards constructing models of neural connections, and recent technological advances in data acquisition, analysis, and visualization methods have allowed cognitive neuroscientists to construct models of neural connections in the human brain (Hagmann et al., 2008; Sporns, 2013; Sporns, Tononi, & Kötter, 2005; Wedeen et al., 2008). These technological advances led to the formation of the so-called Human Connectome Project (HCP) in 2010. As Van Essen et al. (2013, p. 62) put it, "to systematically explore the human connectome [is] to generate maps of brain connectivity that are 'comprehensive' down to the spatial resolution of the imaging methods available." They characterize one of the primary goals of HCP as "a systematic effort to map macroscopic human brain circuits and their relationship to behavior in a large population of healthy adults" (2013, p. 62). It's worth noting that other connectomic projects proceed at scales below the macroscale of brain regions, i.e., the meso- and microscales. For example, Bock et al. (2011) report a microscale connectome of a group of neurons in the mouse primary visual cortex using two-photon calcium imaging and large-scale electron microscopy. And Varshney, Chen, Paniagua, Hall, and Chklovskii (2011) build on previous work by White, Southgate, Thomson, and Brenner (1986) in order to produce a model, at the microscale of individual synapses, of the neuronal network of *Caenorhabditis elegans*. However, in this paper, our focus will be on the set of techniques that cognitive neuroscientists use to study human brain networks at the macroscale. Given the importance of techniques to HCP and other related research, any adequate understanding of this work, along with the models that this work produces, will have to pay particularly close attention to those techniques.

3. Structural/anatomical and functional brain networks

Our next task is to distinguish between two kinds of brain networks, namely, structural/anatomical networks and functional networks. In order to do so, we'll begin by distinguishing between two kinds of neural connections, namely, structural/anatomical connections and functional connections.

Structural connections are anatomical connections that link neural elements. These connections are often referred to as neural pathways or neural tracts. They consist of white matter, i.e., of bundles of mylenated axons that connect regions of gray matter in the brain. While the brain's structural/anatomical connectivity is relatively stable over the course of minutes, it can change over the course of hours or days (Sporns, 2013, p. 248). In what follows, we'll use the term 'anatomical' when referring to the kinds of connections and networks that cognitive neuroscientists label as 'structural.' Since we'll devote a fair amount of discussion to the implications of our case study for structural realism in section 6, we'll reserve the term 'structural' to refer to the more abstract, relational structure of interest to structural realists.

Anatomical connections contrast with another kind of neural connection that cognitive neuroscientists investigate, namely, functional connections. Functional connections are "patterns of statistical dependence among neural elements" (Sporns, 2013, p. 248; see also Smith, 2012). For example, if activity in one brain region occurs when some other brain region is active, and vice versa, there is a functional connection between those two regions, in which case they exhibit functional coupling. Functional connectivity is not nearly as stable as anatomical connectivity, and can change in the course of tens of milliseconds.

There is a corresponding distinction between two kinds of brain networks, namely, anatomical networks and functional networks (Bullmore & Sporns, 2009; Sporns, 2013; Wig, Schlaggar, & Petersen, 2011). Anatomical networks constitute the brain's anatomical connectivity, while functional networks constitute its functional connectivity. Cognitive neuroscientists use graph theory in order to represent these networks formally as undirected graphs. In general, a graph is made up of a set of nodes and edges, as shown in Fig. 1. The nodes are brain regions. In an anatomical network, the edges are anatomical connections, while in a functional network, the edges are functional connections. Hence, when cognitive

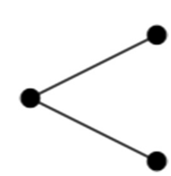

Fig. 1. A graph with three nodes and two edges.