Cognitive Ontologies: Mapping Structure and Function of the Brain from a Systemic View

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Abstract

Rapidly developing research in neurophysiology has challenged classical cognitive models based on behavioral evidence.

Studies looking more closely at the relationship between cognitive function and the brain structure have shed new light on how the mental processes are physically implemented in the brain.

Regardless of whether the neural correlate of cognition is dispersed (the activity of a particular neuron is not representative) or distributed (the level of individual neurons is selective of a concrete feature), it is essential to establish a cognitive ontology that instantiates the structure-function mapping of the brain. The core of the present work relies on the next systemic assumption: at some level, different parts of the normal, healthy brain subserve functions. Consequently, functions should predict the structure and the structure should predict the function.

Direct inference or *What are the neural correlates of a cognitive operation?* and reverse inference or *What is the function associated with a brain area activation?* are dealt with this systemic and computational light.

Needless to say, the task ahead is arduous. Anyhow, important steps are being taken towards true brain inspired architectures in cognitive systems. *http://brainmap.org*, a database for querying and retrieving data about brain structure and function over the internet, is available to be utilized for testing empirically architectural assumptions.

We present a methodology, exemplified by an algorithm, to build cognitive ontologies that integrate cognitive and anatomical models of the brain.

Introduction

As a consequence of the recent and impressive advances in brain imaging techniques, there is myriad of work concerning how the mental functions are mapped in regions of the brain. Undeniably this has lead cognitive neuroscience to a state of art extremely rich in experiments and data.

Brain structure-function relationships

In this work is argued that cognitive and anatomical models are not valuable in their own but in terms of their mutual convergence. Both models must be integrated within a sound theoretical framework.

Methodological aspects

To find the neural correlates of a cognitive operation is the endeavor of a plethora of papers in journals like *Trends in Cognitive Sciences* or *Cognitive Sciences Research*, just to cite two.

The obtention of contradictory conclusions in different experiments, although good for scientific discussion, is a logical consequence of the lack of an ontology that maps the functions with their correlated brain structures and vice versa.

Direct and Reverse inference

Direct inference can be defective in terms of precision, while reverse inference can in addition be a logical fallacy.

Bayesian formulation in Reverse inference

We must be cautious with reverse inference especially when it is used within a deterministic framework, such inferences are not deductively valid in the bi valuated logic. To try to get over this difficulty, we argue that modal logic can shed new light in the *hard problem of brain mapping*[1].

The ACT-R case

In the recent article "*A central circuit of mind*", [Anderson] points out the *"rather unexpected convergence of an empirical and theoretical methodology. The empirical methodology involves fMRI, which has become a major research tool in cognitive science. The theoretical methodology involves cognitive architectures, which are formalisms for modeling mental interactions that occur in the performance of certain tasks"*. Empirical validation of the cognitive architecture and predictive power about the neural response after a module activation are the two major assets are claimed to be accomplished in ACT-R improved with fMRI experimental data.

[1] By analogy with Chalmers' hard problem of consciousness

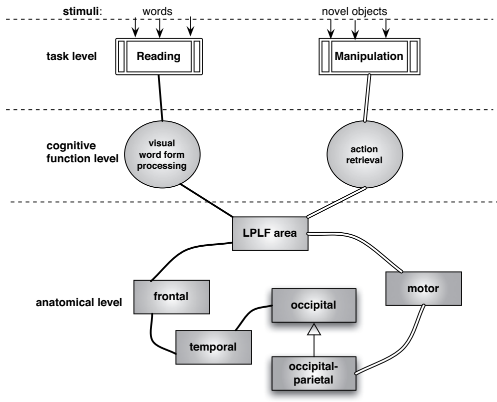

Figure 1: Cognitive ontology at functional and anatomical levels. In single line the causal link for visual word form processing and in double line for action retrieval

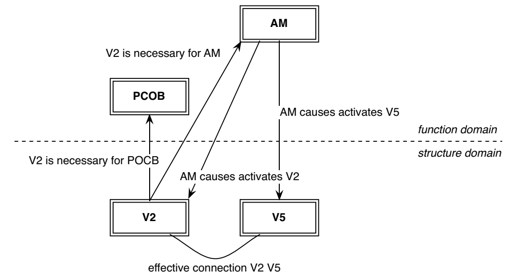

Figure 2: V2 area is necessary for both processing the contour of objects from the background (PCOB) and attending to motion in a visual stimulus (AM). Attending to motion AM, causes activation of areas V2 and V5, thus it increases the effective connectivity of areas V2 and V5

Empirical validation Brain imaging studies like fMRI, can provide empirical evidence for the theoretical architectural assumption. Accordingly, the model proposed is falsifiable and prone to be updated and modified based on the divergencies with the empirical results.

Explicability and Prediction BOLD response in a brain region can be predicted from time coarse of modules in ACT-R.

The cognitive ontology building process

Typically, brain imaging studies aim to find the spatial and (ideally) temporal pattern of brain activity that underlie the unique condition of function activation at any particular level. In short, a cognitive ontology must be able to predict the engaged function from anatomical activation and conversely, the anatomical activation necessary for the function triggering. This methodology of ontology building, assumes that both approaches top-down and bottom up are complementary. The top-down is the function-structure link *causes activation* and the the bottom is the structure-function link *necessary for*.

As illustrated in Figure 1, the stimuli and the tasks are the conditions under which the areas are activated.

In the cognitive ontology drawn in Figure 2, we discern three relationships, two are structure-function type (RN,CA) and one is structure-structure (EC).

Relation necessary for It comes up from functional imaging experiments measured by neurophysiologists

Relation causes activation It is inferred from structural lesions in the brain and is studied by psychologists

Relation effective connectivity Functional interactions of anatomical areas. They are inferred from coactivation in these different brain areas.

An algorithm for the cognitive ontology building process

We propose an algorithm for the ontology building process. We sketch briefly, for limitations of space, some main concepts of modal logic that are going to be used in the algorithm.

The aim of the algorithm is to obtain an ontology at the simplest possible level. As a consequence of the iterative process implemented by the algorithm, the relationship between the functions and structures in the ontology converge. In short, the mapping function structure at the end will be 1:1.