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Cognitive Ontologies

Mapping structure and function of the brain from a systemic view

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July 30, 2008

Contents

Abstract

The accelerating pace of discovery in neuroscience demonstrates that we are far from any theoretical upper limit in our capacity for understanding the cognitive mechanisms operating in the mammalian brain.

The brain is a stupendously complex system, no action, thought or perception is possible without the nervous system and brain. It is also a finite machine undoubtedly with a finite capacity for understanding. Rather than claim for holistic emergent properties, or mysterious nature, we should encourage research that strives for a complete physical understanding of the brain and of its properties.

We propose a methodology consisting of building a cognitive ontology that integrates functional (cognitive processes) and structural (anatomical) aspects.

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. Thanks to the new brain imaging techniques, to describe the areas engaged in a cognitive function,it is now a technically possible.

The conceptual and theoretical challenge or the problem of predicting which functions are necessarily engaged with which structure, more of a complex issue; this is the *hard problem of brain mapping*. We present a methodology, exemplified by an algorithm, to build cognitive ontologies that integrate cognitive and anatomical models of the brain.

1 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. This has resulted in a new cognitive neuroscience to a state of art extremely rich in experiments and data.

Traditionally, cognitive psychology studied mental processes based on behavioral evidence; in other words, the subject or subjects, were exposed to stimuli and their actions measured. A number of functional architectures of the brain have been built following this paradigm which is based on quantitative observable phenomena like the keystroke time response or eye movements.

In the actual state of science is frivolous and *brainless* to prescind of brain imaging studies for cognitive modeling. It is seems plausible to support the thesis that, in order to make substantial progress in the sciences of mind, models of cognition based on impaired behavior or anatomical lesions are insufficient for the convergence between cognitive architectures and empirical data.

For example, Williams syndrome and autism are both mental disorders that involve dysfunctions noticeable from their cognitive manifestations. In (14) (15) it is shown that infants with Williams syndrome have a preference, as normal kids do, for face-like stimuli. On the contrary, kids with autism spend more time looking objects than people's faces and when they are solicited to look at faces, they avoid looking at the eyes.

William syndrome shows no behavioral disparity with normal subjects in face recognizing but presents lack of depth perception and an inability to visualize how parts assemble into larger objects(e.g. puzzles). This is caused by a significant reduction in the brain's volume (grey matter reduction). Indeed, fMRI studies for tasks about spatial relation, show a weak activity in the dorsal area and in the *fusi form area* FFA, which is located in the middle part of *fusi form gyrus*, the brain region mainly responsible of face recognizing stimuli (29) (28) (27).

Individuals with autism have hypo activation of FFA when they accomplish a face recognizing task, but when the individuals are instructed to attend the eye regions, FFA activation is normal. Hence, we may that infer abnormal cognitive capability based on abnormal brain area activation can be misleading.

Indeed, both Williams syndrome and autism have a strong genetic basis. Synaptic strength and growth of new synapses require the synthesis of new proteins which are initiated after the activation of a set of genes.

We can infer from this the next two conclusions: the former claims for the necessity of both top-down and bottom up approaches in brain studies and the later informs about the danger of the regional localization in the brain of cognitive processes, said schematically:

1. Similarities in behavioral competences can not be explained with cognitive modules like face processing. The underlying abnormalities at neural level and even at a genetic level are also necessary.

2. The same neural structure can perform multiple functions depending on whether other areas are interacting with each other.

2 A first approach to structure-function mapping in the brain

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

Facing the problem of building a theory of cognition, we easily identify two domains: the neural structures and the cognitive components. The reminiscences with the age-old brain vs. mind dichotomy is more than obvious.

Of course, the structure-function mapping can be described at multiple levels and whether that mapping is 1 to 1, 1 to N , N to 1 or N to N, depends ultimately on which level of abstraction we are discussing.

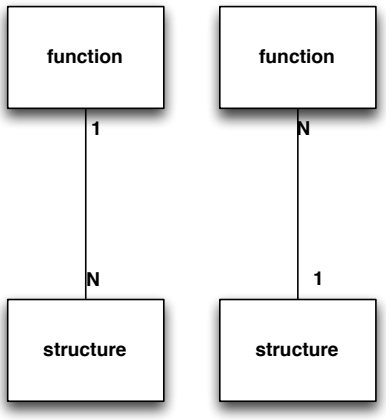

Figure 1: A function-structure mapping with valence 1 to N is a degenerate case, the same function activates N brain areas, while N to 1 valence is pluripotential, thus to predict the activation of the function we need that N areas are activated

Therefore the answer to the question is, Is it possible to have brain region with more than one function? The answer is yes and no, depending at which level we have described the otology. Thus in 1 a) the function is higher level function than the N areas that it activates. Contrary, in 1 b) the function has lower level of abstraction and is activated by different areas.

Decomposing that function conveniently, it should be possible to find a 1 to 1 assignation. The minimal description level is the neuron, which in our ontology represents the minimal operational structure. One single neuron can participate in diverse functions.

A lively debate has arisen from whether the neurons encode in a disperse/distributed way or they do sparsely. According to the distributed hypothesis, as individual neurons respond to similar features the structure-function mapping at neural level might be 1 to N.

Contrarily, for those that support the sparse thesis, encoding involves the activation of fewer and fewer neurons as neural activity represents more and more selective features. Accordingly, the mapping for some neurons might be 1 to 1.

3 Structure-function mapping in depth

We have sketched the cardinality of the structure-function relationship in the brain. But whether a structure can be one neuron, a spatially related group of them or a brain region where groups of neurons fire synchronously to some stimuli, has been obviated. It is time to define what kind of brain structures are we speaking about.

Assigning responses to neural populations is a neurophysilogist's fundamental mission, to that end brain scanners provide data about metabolic changes in the brain.

The usage of brain imaging techniques in cognitive psychology, is relevant only once has been accepted the hypothesis that exists a systemic mapping from cognitive functions like abstract thinking, face recognizing or sensory motor activities to anatomical structures of the brain.

3.1 Technical aspects

There are two main techniques in brain imaging studies, namely haemodynamical and electrophysiological. Examples of the former are PET (positron emission tomography) and fMRI (functional magnetic resonance imaging), while EEG (electroencephalography) and MEG (magnetoencephalography) are cases of the last. Both techniques can be used complementarily in the same experiment, recording spatial and temporal brain region activation.

We focus in haemodynamic techniques and in particular in fMRI.

It is worth noting that the fMRI scanners, do not measure the neural activity directly but the signal associated with changes in the local tissue. These local changes are noticeable by changes in the deoxyhemoglobin concentration. In turn, variations in deoxyhemoglobin arise as a consequence of changes in oxygen consumption in blood flow which are finally coupled with neural activity.

To be precise, fMRI does measure a signal named BOLD (Blood Oxygen Level Dependent).

In (13) the direct link between BOLD signal and neural activity is demonstrated. *BOLD, though a surrogate, does indeed measure changes in neural activity allowing to map regions of changing activity.* .(16)

Admitting that fMRI measures neural activity, the question that now arises is how spatially precise is this measurement. For PET the accuracy of locating the peak is $\simeq 2$ mm and in fMRI > 1mm and < 6 mm.

Different from spatial precision is the concept of spatial resolution which measures the spread of activation underlying the detected peak, the resolution in fMRI is much higher < 1mm than in PET scanner which is > 6mm.

A voxel, is the minimal surface measured by the fMRI scanner, therefore activations within the same voxel cannot be spatially resolved. This surface corresponds to a neural population. To be ideal, fMRI technique should measure simultaneously individual neurons rather than as it does, take samples of a number of voxels every few seconds.

3.2 Methodological aspects

Finding 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 (In (2), ventral activities occur in the contrasts between coherent and incoherent motion, whereas in (1), the ventral area is activated only when the coherent motion represents a curved surface rotating in depth), although good for scientific discussion, it is a logical consequence of the lack of an ontology that maps the functions with their correlated brain structures and vice versa.

We identify four causes to this problem, the core of this paper is to provide insights and possible solutions to all of them.

- Level of Granularity: Depending on the level of description required, different areas of the brain can be assigned to different cognitive operations. Technical details of the scanner and parameters like the activation threshold are relevant

- Localism-Modularist optimism: The brain is a system so adaptative and complex that it offers many opportunities for getting what you are seeking. Are the cognitive modules isolatable entities? Is it licit to locate the brain areas engaged in their cognitive operations? Or we should follow the Uttal's suggestion: *mysteries of relation mind brain would remain because the level of psychoneural is to be found at a microscopic level* (3)

- Experiments and functional labels: As most psychological experiments are focused on *their* cognitive task, the areas are labeled *ad experiment*. For example, the *Left posterior Lateral Fusiform Area (LPFLA)* in a experiment of Reading (17) is named VWFA(Visual Word Form Area), while in (18) for visual and tactile shape processing experiments is named *LOTv (lateral occipital tactive visual region)*

- Necessity: Cognitive models specify cognitive components that are necessary for a particular task, but on the other hand, fMRI techniques detects regional activation in the brain that can be incidental and not necessary to the task

3.3 Direct and Reverse inference

Lets imagine that the scientific community has built a theory of the brain, of course empirically tested, succesfully enough to be extensively used in the varied spectrum formed by the cognitive sciences. Such a theory would have the next capabilities:

Direct inference It might determine which areas are active given a cognitive process.

Reverse inference It might determine from the activation of a brain region, which particular cognitive process is engaged.

Examples of direct inference of brain regions engaged in cognitive tasks are numerous: ”language processing activate the Broca’s area” or ”Anterior Cingulate Cortex exhibits increasing activity during deception”, just to cite two of them.

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

Unfortunately, to infer, from the activation of an area, that it is a necessary condition for a cognitive process, is an habitual praxis in brain imaging studies. *Nearly every neuro imaging paper uses reverse inference to explain the occurrence of unpredicted regions of activation* (5).

In actual fact, the activation of one area can be incidental to a cognitive process. This is the problem of reverse inference, in section 5 we propose a computational method to deal with it.

Put simply, as long as we do not yet have built a hierarchical classification of cognitive tasks, processes, subprocesses and their anatomical counterparts, lax structure-function relationships will keep on proliferating in journals.

Schematically, reverse inference in neuroscience studies used to have this form

Hypothesis 1 When task A is presented, brain area Z is active

Hypothesis 2 When cognitive process X is engaged, brain area Z is active

Inference Brain activity in area Z, demonstrates the engagement of the cognitive process X by the task A

We can find an example of this logical fallacy in (6). This fMRI study with rats, for the tasks “pup suckling” and “cocaine administration”, demonstrates that there is a higher increment in the ventral stratium for the former task than for the later. The authors conclude that pup suckling is more rewarding than cocaine.

The logical fallacy in the reverse inference is clear, a cognitive process, reward, is inferred from the activation of a brain area, the ventral stratum. We have to be

extremely cautious with this reverse inference, from the classic logic perspective is a logical fallacy.

Both direct and reverse inference encounter with the **problem of selectivity**. How can we determine which areas are relevant for a cognitive process?. This is a considerable problem, but unfortunately, the story does not finish here. There is another major matter, which areas are activated incidentally when a cognitive process is engaged?

3.4 Bayesian formulation in Reverse inference

That said, the reverse inference or abduction, is a primordial tool for scientific discovery and in particular, is a helpful instrument for a deeper understanding of the neural implementation that supports cognition. (31)

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, in 5 we argue that modal logic can shed new light in the *hard problem of brain mapping*[1](30).

In (5), Poldrack argues that neuroscientist community should be circumspect in the use of reverse inference for structure-function (the hard problem). The author places this problem in a probabilistic framework based on Bayes analysis.

$$P(X/Z) = \frac{P(Z/X)P(X)}{P(Z/X)P(X)+P(Z/\sim X)P(\sim X)}$$

Being,

P(X/Z) is the *a posteriori* probability that cognitive process X arises, once area Z is active. It represents the selectivity of activation in Z

P(X) is the *a priori* belief in the engagement of process X, given a task Y (for simplicity it has been assumed that P(X)= P(X/Y)

Although reverse inference, rewritten in Bayesian terms is a formidable tool, its strength depends upon the value of the a priori belief and the selectivity area, P(X) and P(X/Z) respectively. For example, if Z is activated by a lot of processes, P(X/Z) will have a low value. Consequently, the predictive capability of a cognitive theory using this framework will be flawed.

In conclusion, bayesian theorem leads to an enhanced epistemic asset but it still lacks the ontological component, necessary to build a predictive cognitive theory, which is able to map structure-function and function-structure.

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

3.5 The ACT-R case

John Anderson's ACT-R theory of cognition is a cognitive architecture which reflects assumptions about human cognition. These assumptions are based on facts derived from psychology experiments.

In the recent article *"A central circuit of mind"*, (7) 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"*.

The necessity of accounting for brain localization pushed for a major revision of ACT-R theory. By the year 2002, ACT-R 5.0 was released and it introduced the concept of modules, specialized sets of procedural and declarative representations that could be mapped to known brain systems. (21)(8)

But in order to test which modules were active during the performance of a task, ACT-R continued to use only behavioral data. Indeed, before ACT-R incursion in magnetic resonance imaging studies, it was only able to accurately log events such as mouse clicks, keystrokes or patterns of eye movements. These data failed to provide an accurate explanation, let alone prediction, of the modules engaged in a task due to the lack of empirical commitment.

The figure 2 ilustrates the mapping between ACT-R modules and brain areas.

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.(7)

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. As a module engagement involves a metabolic demand in its brain region, the neural correlation of the cognitive module, is modeled in Table 3.5

But it has to be remarked that despite of the worthy effort realized by Anderson's and his co-workers towards a converge of theoretical cognitive modules with brain responses, ACT-R is still flawed. In fact, it still rests upon extreme localism, see 3.5 and it does not put its modules to test, rather it tries to find their neural correlates.

The ACT-R agenda of integration with fMRI data rather seems to be more a confirmation of its own modules. By finding out which area activates than a real

$B(t) = \int_0^t D(x)H(t-x)dx$
B(t): BOLD response in the region associated with a demand response D(t) D(t): demand function, given the probability that the region is engaged at t $H(t) = m(\frac{t}{s})e^{-(t/s)}$ models the hemodynamic function H(t). (19)(20)(23)

Table 1: Model for predicting the BOLD response in the region associated with that demand function, givien the probability that the region is engaged at time t.(7)

Module	Region Location (x,y,z)
retrieval from declarative memory	40,21,21
constructing imaging reprsentations	23,-64,34
setting controlling goals	5,10,38
procedural execution	15,9,2

Table 2: Talairach coordinates for the ACT-R modules

evaluation of the validity of the whole architecture. The question whether cognitive psychology can support a detailed formal otology of cognitive processes is missing here.

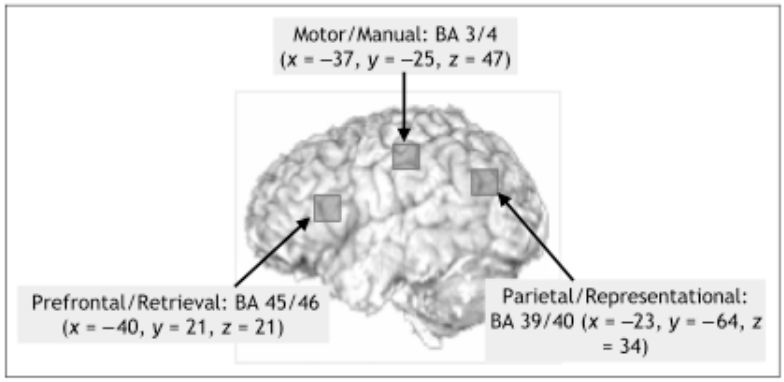

Figure 2: In this picture, three regions of interest are related to modules in ACT-R architecture. Left Prefrontal:BA 45/46, Left Motor: BA 3/4 and Left Parietal: BA 39/40

4 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.

In the cognitive ontology drawn in 4, we discern three relationships, two are structure-function type (RN,CA) and one is structure-structure (EC).

- *Relation necessary for* comes from functional imaging experiments measured by neurophysiologists.
- *Relation causes activation* are inferred from structural lesions in the brain and studied by psychologists.
- *Relation effective connectivity* Is functional interactions of anatomical areas. They are inferred from coactivation in these different brain areas.

The function of one area of the brain (from one single neuron to a whole region, like the frontal cortex) depends on its interactions with other areas.

In the ontology, these interactions are represented by the *effective connectivity* links.(10)

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 3, the stimuli and the tasks are the conditions under which the areas are activated. The left post lateral fusiform area (LPLF) is involved in ”visual word form processing” when are satisfied the following points:

- condition: the task is reading
- pattern of activation: there is coactivation in occipital, temporal and frontal areas

On the other hand, the same area is involved in ”action retrieval” when the task is manipulation of novel objects and there is coactivation in occipital parietal (OP) and motor regions(MR). (10)

Accordingly, based in the ontology depicted in the function 3, ”visual word processing” predicts the activation of the areas left post lateral fusiform area (LPLF) with occipital (OC), temporal (TP)and motor region (MR).

Thus, LPLF, OC, TP and MR areas configure the pattern of activation for ”visual word processing”. Likewise ”action retrieval” predicts the activation of OP and MR.

What is needed is an integrated ontology where the functional labels are constrained by the anatomical response. Figure 4 illustates spatial patterns of brain

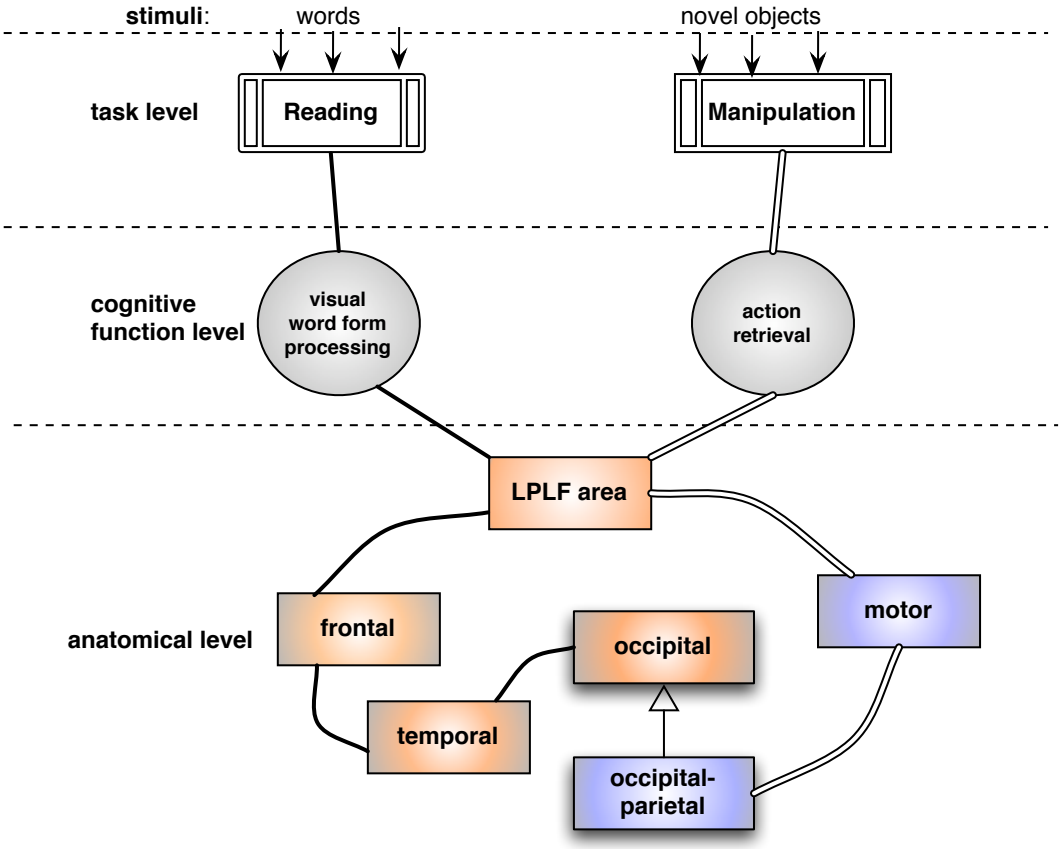

Figure 3: Cognitive ontology at functional and anatomical levels. In single line the causal link for visual word form processing and in double line for action retrieval

activity, which can vary form a single neuron to a brain region, linked by *effective connectivity* relations. This cognitive ontology would be able to predict the process that is engaged when an area is activated.

function-structure mapping 1 to N
Attending to motion in a visual stimulus (AM) increases the *effective connectivity* of areas V2 and V5. When, as is usual in cognitive models built in top-down fashion, we assign labels to cognitive functions to a posteriori find out their neural correlate, we are most of the times mapping functions with a higher level of abstraction than their neural structure. Whether V2 and V5 are specific for that function is a question to be answered through experimental study.

function-structure mapping N to 1
The V2 area is involved in either processing the contour of objects from the background (PCOB) and in attending to motion in a visual stimulus (AM). As the same area V2 is necessary for two functions, PCOB and AM, we can conclude that these function has lower level of abstraction than the correlated area V2. Thus the function-structure is N to 1.

Importantly, the question of whether there is a mapping 1 to N or N to 1 is a fictitious problem considering that depends on which level the ontology is being formulated. Only when the mapping is restricted to an appropiate level of correspondence we will have a 1 to 1 structure-funtion mapping.

In conclusion, the ontology has to be capable to predict correctly the activation patterns over all levels of tasks analysis. This can not be done ”at the first try”, but as an iterative process that manages the soundness of the entities and their relationships in the ontology.

5 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.

Modal logic is the study of modal propositions and the logical relation that they bear to one another. Of course, modal propositions are characterized by the use of modal operators. (22)

In the alethic modal logic, the modal operator $\Box$ expresses necessity: if the proposition A is read as ”it is true that A holds”, the proposition $\Box$A means ”it is necessarily true that A holds”.

For the modal operator for possibility is $\Diamond$. If ”it is true that A holds”, then $\Diamond$A represents ”it is possibly true that A holds”.

These two operators are connected with the following rules:

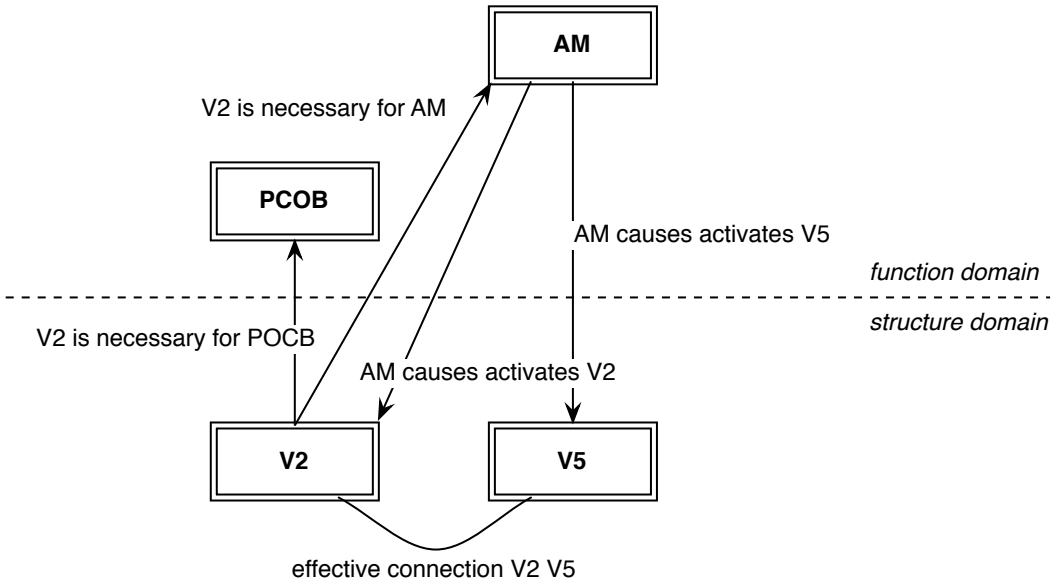

Figure 4: V2 area is necessary for both processing the contour of objects from the background (PCOB) and attending to motion in a visual stimulus (AM). Attending to motion AM, causes activation of areas V2 and V5, thus it increases the effective connectivity of areas V2 and V5

$\Diamond\, A \Longleftrightarrow \neg\Box\neg A$

$\Box\, A \Longleftrightarrow \neg\Diamond\neg A$

The algorithm we are presenting, deal with fMRI measurements for one brain region, for example the anterior cingular cortex (ACC) or the lateral inferior prefrontal cortex (LIPFC), and one single individual.

It is assumed as well that direct inferences are necessary. This means that for a normal healthy person's brain , if the cognitive function F activates the area A, it always does it, formally: $F \longrightarrow A \Longleftrightarrow F \longrightarrow \Box A$

We do not start from scratch, we know which areas are activated given a set of cognitive processes. So, we have initially ontology from fMRI studies of brain regions.

The list of pairs L_0 formalizes this initial ontology. $L_0 = \{(F_1, A_1)...(F_m, A_n)\}$, where the tupla (F_1, A_1) represents that function F_1 predicts area A_1. As we are assuming that F$\longrightarrow$A $\Longleftrightarrow$ F$\longrightarrow$ $\Box$A and is for the same individual, the algorithm will modify this initial list L_0 only if new areas or functions are created.

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.

1. $L_0 = \{(F_1, A_1)...(F_m, A_n)\}$ // initial list of *causes activation* relations
2. while (($\exists$ in L some F$\longrightarrow$A tupla $\neq$ 1:1) or (added new functional label in L))
{
3. for (index=1; i++; index $<$ n) {
4. If ($A_i \longrightarrow F_i, F_j$) { Revise the label for F_i, F_j. A new lable F_k is needed }
5. If ($A_{1..i} \longrightarrow F_i$ and $A_k \longrightarrow F_i$ for k<i) {
6. $A_{1..i,k} \longrightarrow F_i$. Thus, A_k has a *necessary for* link with $A_{1..i}$ }
}
}

Example

For an extremely simple ontology focused in the visual cortex region, the execution of the algorithm would be as follows.

line 1 The fMRI study gives the list of the *causes activate* relations relationships between functions and areas. L_0 ={ (word-forms, LPF), (animal-contour, LPF), (face-recognizing, V5), (color-processing, V2), (color-processing, IT) }

line 2 As (word-forms $\longrightarrow$ LPF) and (animal-contour $\longrightarrow$LPF) LPF $\longrightarrow$F valence

is 1:N then

line 4 LPF is activated by either word-forms and animal-contour. Thus, it would be complicated to predict which function is engaged in knowing only that LPF was activated. The tupla (sensori-motor integration, LPF) is added to L, and the two occurrences of LPF, deleted from L. (10)

line 5 As V2⟶color-processing and IT⟶color-processing, V2 and IT forms an effective connection link, the pair (color-processing, V2-IT) is added to L.

At the end of the iteration 1, we have,
L_1={(sensori-motor integration, LPF), (face-recognizing, V5), (color-processing, V2-IT)}.

***iteration 2* line 1** The valence is 1:1, but the functional label "sensori-motor integration" is added. As we are assuming that F⟶ □A, "face-recognizing" will predict the activation of V5, likewise "color-processing" for the V2-IT area.

Contrarily, for the new label "sensori-motor integration", the algorithm has to test whether it predicts correctly the activation of LPF.

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6 Conclusions and future works

Traditionally, cognitive psychology studies mental process based on behavioral evidence. The subject or subjects, are exposed to stimuli and their actions measured.

Rapidly developing research in neurophysiology has challenged these classical cognitive models. There is a considerable body of knowledge about the mapping between cognitive processes and anatomical regions.

Studies looking more closely at the relationship between cognitive function and brain area has shed new light on how the mental process are physically implemented in the brain.

Regardless of whether the neural correlates of cognition is dispersed (the activity of a particular neuron is not representative) or sparse (the level of individual neurons is selective of a concrete feature), it is essential to be in possession of a cognitive ontology that instantiates the structure-function mapping of the brain.

In this paper, 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 under this systemic and computational light. We describe an algorithm that modifies ontologies with valence 1:N in its structure-function relationship to 1:1 relationship. We propose a systemic approach consisting on specify the conditions under which brain areas are activated and the pattern of activation evoked by cognitive functions.

Needless to say, the task ahead is arduous. Anyhow important steps are being given towards true brain inspired architectures in cognitive systems. Tools like *http://brainmap.org*, a database for querying and retrieving data about brain structure and function over the internet, are now 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

7 Acknowledgement

This work has been supported by the European Network for the Advancement of Artificial Cognitive Systems (euCognition funded network action NA 018-1).

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Title: Cognitive Ontologies
Subtitle: Mapping structure and function of the brain from a systemic view
Author: Jaime Gómez
Date: July 30, 2008
Reference: R-2008-006 v 1.0 Final
URL:

Autonomous Systems Laboratory

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