Cognitive Ontologies: Mapping structure and function of the brain from a systemic view

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Vindicating Gall

\[ R \]

\[ R' \]

mental functions

R Skull as a surface representation of the surface of the cortex
R' Neural system represents mental objects

Cognitive Ontologies: Mapping structure and function

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Infering cognition from brain studies

• Let us imagine that the scientific community has built a theory of the brain, of course empirically tested, successfully enough to be extensively used in the varied spectrum formed by the cognitive sciences.
  – [Direct inference] determine which areas are active given a cognitive process.
    (i.e. "language processing activate the Broca's area" or "Anterior Cingulate Cortex exhibits increasing activity during deception")
  – [Reverse inference] determine from the activation of a brain region, which particular cognitive process is engaged.
Infering cognition from brain studies

Schematically

[Hypothesis 1] When task T is presented, brain area A is active

[Hypothesis 2] When cognitive process X is engaged, brain area A is active

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[Inference] Brain activity in area A, demonstrates the engagement of the cognitive process X by the task T
In fMRI study with rats, for the tasks “pup suckling”(A) and “cocaine administration”(B), demonstrates that there is a higher increment in the ventral stratum for A task than for B. [Ferris05] [Poldrack06]

• The authors conclude that pup suckling(A) is more rewarding(X) than cocaine administration.

This is logical fallacy!
A cognitive process was inferred from activation in a particular area
The problem of selectivity

• How can we determine which areas are relevant for a cognitive process?
• Which areas are activated incidentally when a cognitive process is engaged?
The problem of incidentally

- Brain image studies detects activation that may be incidental to the task
- To claim that an area is involved in task is very different that the area is specific to that task. [Price, Friston05]
The problem of proliferation

• Since most psychologists focus on “their” cognitive task, different labels to the same brain area are assigned

  – Studies of reading refer LPLFr(left posterior lateral fusiform region) as VWFA (visual word form area)
Cardinality S-F

- Can a brain region have more than one function?
- ...yes...maybe no?
- BOTH!
- It depends at which level we are measuring the brain responses and to what do we call cognitive function.
- Structure-Function relationship can be describe at many different levels.
- 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.
More problems. . . contradictory results

• The obtention of contradictory conclusions in different experiments.
  – Ventral activities occur in the contrasts between coherent and incoherent motion [Cheng94] vs
  – The ventral area is activated only when the coherent motion represents a curved surface rotating in depth [Paradis00]

• It is a logical consequence of the lack of an ontology that maps the functions with their correlated brain structures and vice versa.
Cognitive ontologies

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.

"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”.

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?
The cognitive ontology building process
An algorithm for the cognitive ontology building process

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.
An algorithm for the cognitive ontology building process

• It is assumed 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.

$$F \rightarrow A \iff F \rightarrow \square A$$

• 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.

As a consequence of the iterative process implemented by the algorithm, the relationship between the functions and structures in the ontology converge. The mapping function structure at the end will be 1:1.

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

• It is essential to be in possession of a cognitive ontology that instantiates the structure-function mapping of the brain

• Reverse inference is powerful but dangerous, it awaits for the development of detailed scalable cognitive ontologies

• Explore Formal Tools against insistence in ordinary language
  – Isomorphism: when the categories are I. can be formalized as objects of a category and make statements with CATEGORICAL RIGOUR

• Knowledge advances not by copying reality but by schematising it

• Intuitive vs Formal is another fallacy
Thanks!

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