Using a brain model to develop an ontology for neuropsychology and cognitive psychology

Alan H. Bond

Center for Cognitive Phenomics, Neuropsychiatric Institute,
University of California at Los Angeles, Los Angeles, California 90095
email: alan.bond@exso.com

Abstract We give a brief discussion of the potential relevance of brain models to the goals of cognitive phenomics. We suggest that a hierarchy of concepts can be defined based on information processing in the brain. This would constitute an ontology for neuropsychology.

1 Introduction

Cognitive phenomics seeks to find new and more useful categorizations of psychiatric phenomena by using cognitive categorizations of human performance, human brain measurements and human genetic data. We are developing a system-level model of the human brain and we want to consider how this might contribute to the attainment of these goals.

Figure 1 shows the kind of model we are working on.

Our general approach is to represent information in the brain, what kinds exist in the brain, how it is represented, where it is stored, how new information is computed, and how information is transmitted around the brain. We call this a system level of analysis. At the neural net level of analysis, connectionist and neural net models represent neural systems directly in terms of neurons, their connectivity and dynamic properties. In our system level analysis however, we represent these same neural systems in terms of the information that they process, transmit and store. We use a logical modeling methodology in which we represent information by logical terms and we represent information processes, in which new data are computed, as logical inferencing of new logical terms.

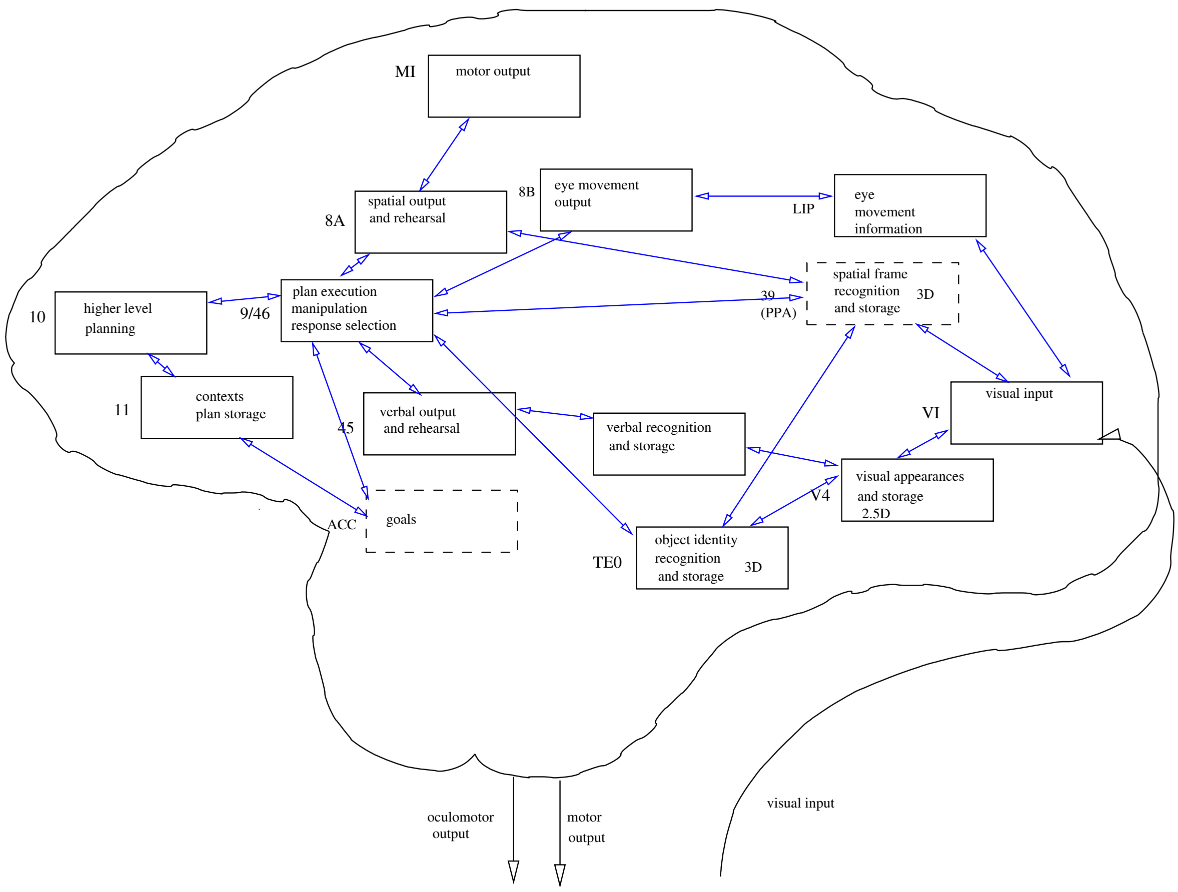

Figure 1: Outline diagram of the general model

This gives a more abstracted level of analysis, and it introduces a logical, rather than energy-based, dynamic approach. From such system-level models, it should be possible to develop neural net models which are at a more detailed level of analysis of the brain.

The notion of data type is basic to computer science, where a basic dictum is "first describe your data". Kosslyn introduced information processing concepts including structures and processing modules in developing his information processing model of mental imagery [Kosslyn, 1980] [Kosslyn, 1981] [Kosslyn et al., 1984].

Figure 2 shows Kosslyn's diagram, from [Kosslyn, 1980] p. 117, of what he calls "the components of a cognitive theory".

Boyer and Barrett [Boyer and Barrett, 2005] have argued for the evolution of an *intuitive ontology* consisting of a set of distinctive domains that the brain has evolved to compute

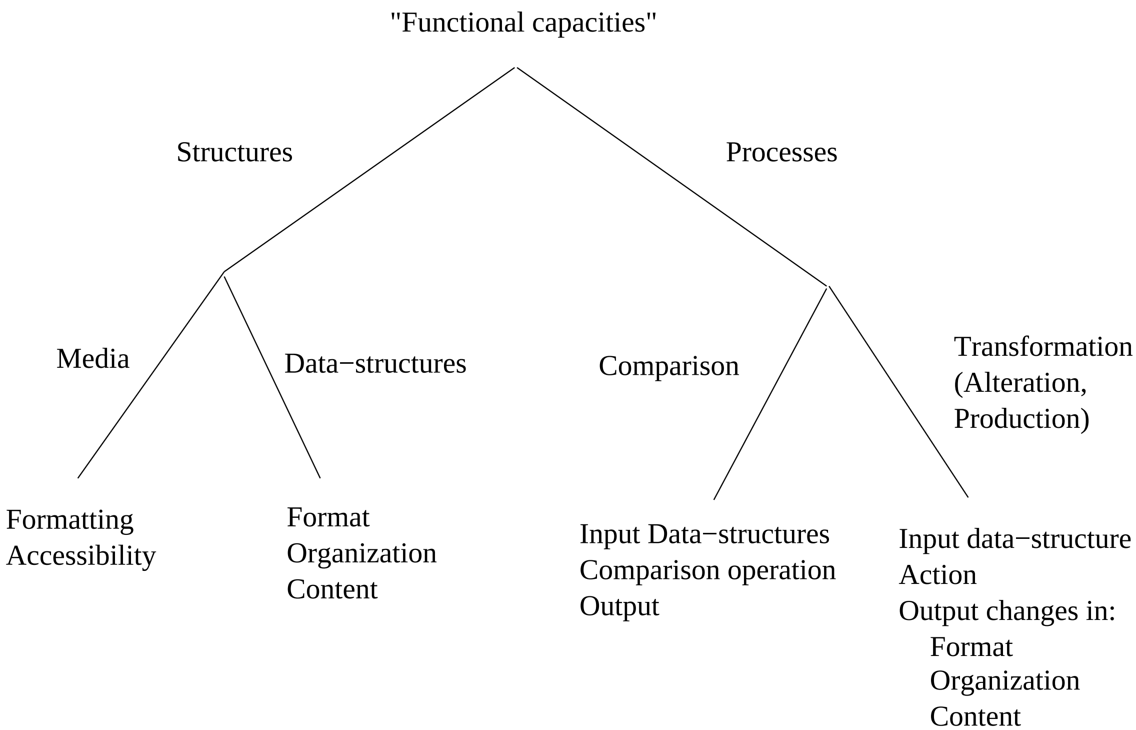

Figure 2: Kosslyn's components of a cognitive theory

with.

Our brain model provides an approach to describing cognitive phenomena in terms of basic cognitive operations. It should provide a set of parameters for cognitive performance.

These parameters could be used to define measures of maintenance, manipulation, attention and executive functions.

The general hope is that more mechanistic parameters such as these will be easier to determine, using imaging, and also easier to connect to neurotransmitter and genetic measures.

2 Levels of description of cognitive phenomena

We list here some examples of operations and abilities and their measures, and organize them into levels of complexity and aggregation:

Level 1 concerns memory and communication within the brain.

1. memory storage. intensity of memory response to incoming data items to a given module, speed of storage of a new item, strength of resulting stored item.
2. attenuation rate of stored memories, quiescence levels, and possibly intrinsic noise levels, in a module.
3. retrieval from memory modules, speed of response to cues and queries, strength and intensity, certainty, completeness of a set of responses
4. speed and reliability of transmission of information between modules.

Level 2 concerns basic computational processes and their control

1. ability to carry out a computation reliably and quickly.
2. ability to carry out basic sensing and perception of the environment.
3. ability to generate and to maintain motor output.
4. ability to focus attention and processing resources.
5. ability to carry out more than one computation in one module.
6. measures of coordination of processing among modules.
7. ability to store several activated items.
8. ability to visualize, to generate mental images.
9. ability to manipulate mental images to solve problems.

We also should include here some affective abilities, e.g. fear, pleasure, satisfaction, etc.
1. ability to generate and process affect in given mental situations.
2. ability to generate and process appropriate affect.
3. ability to associate affect with memories.
4. ability to remember affective experiences.

Level 3 concerns intelligent processes, higher level aggregations of processing, storage and communication.

1. ability to maintain goals over a period of time in the goal and planning modules.
2. ability to pursue several goals at once.
3. the existence in the system of various kinds of plan, their selection and execution.

4. the ability to elaborate plans.
5. ability to monitor progress and to keep track of plans and goals.
6. ability to change plans.
7. the ability to recognize success and failure of plans and goals.
8. ability to integrate affective information into cognitive processes.
9. ability to make reliable affective assessments of internal mental states.

Level 4 concerns aggregate mental abilities.

1. ability to perceive.
2. ability to remember events and to use information about events.
3. executive function of organizing thought and problem solving.
4. ability to maintain and integrate affective aspects of mental experience.

Level 5 concerns personality and overall behaviors.

1. current clinical syndromes.
2. personality types.
3. personality disorders.
4. brain damage types.
5. neurological disorders.

Viability. Psychiatric conditions often involve and even may be defined as, lack of viability, the inability of the subject to live a normal satisfying life.

3 The logical structure of our brain model

Figure 3 shows the logical structure of the brain model we are working on.

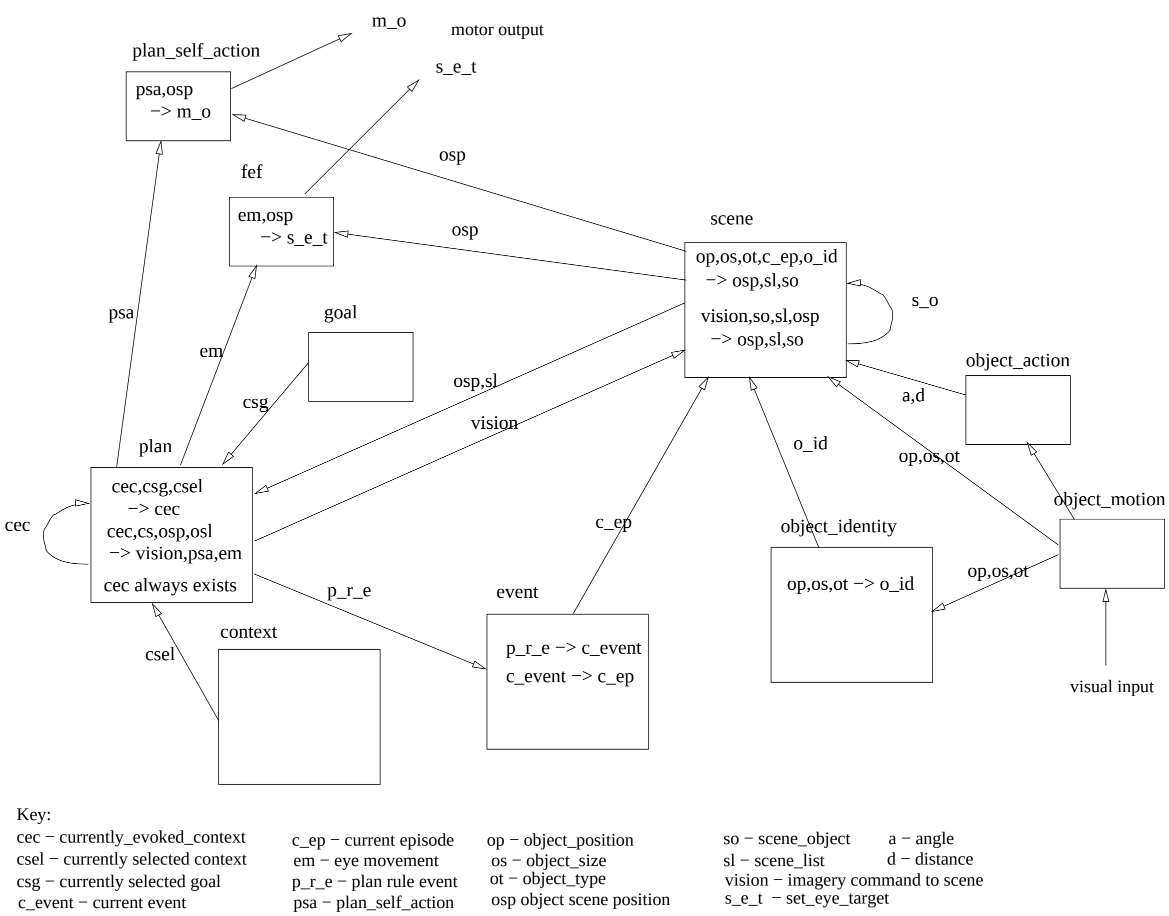

Figure 3: The logical structure of our brain model

If we initially ignore temporal development and dynamics, this consists of a set of data types which are distributed over the different brain modules.

A data item is a package of information corresponding to a chunk, and it is formally represented as a logical term, which is a bracketed expression. A datatype is the set of all data items of the same form. A chunk contains parameters, so for example object_position([[0.8],object1,[120.0,30.0,-45.0]) might represent the information on a perceived object held in an early perceptual module. Its current spatial position is given here by x,y,z coordinates [120,0,30,0,-45.0], its identification is given by a name object1, and the strength of the chunk is given by 0.8.

The diagram outlines how different data items are computed from other data items and how they are transmitted to other modules. Data items enter the system from senses, and exit through effectors such as muscles and glands.

Our work shows how such a system can carry out behaviors and can model the corresponding human behavior. We should also be able to show that various disturbances and deficits in the system will cause deficits in behavior corresponding to observed human symptoms.

The diagram gives a systematic way of determining the different kinds of component deficit that are capable of causing a given system deficit.

The set of data types, plus the rules for constructing data types from others, is fairly close to a datalog program, and so constitutes a deductive database. The rules we are using are executed bottom-up, and we do not use function letters.

There are however a number of substantial differences between our brain model and such a datalog program. We allow some complex computations in the bodies of rules. We have a strength parameter on each data item, and also strengths on components of rules which are compounded to determine the strength of the products of computation. In addition, we have time stamping and some time-dependent refractive and other mechanisms within each data item. There is also filtering and competition within the various streams of computation and transmission.

This deductive database specifies how one type of data is derived from others. Thus in the case of deficit it might be able to indicate types of component malfunction that might cause the problem.

The logical terms and rules in each given module of our model constitutes a theory of the action of that module, which corresponds to a particular region of the brain.

The dynamics of the model give a way of connecting overall cognitive performances and abilities with basic processing abilities of the brain. Thus, perhaps it will be possible to characterize various aspects of executive behavior in terms of simpler concepts such as goals, plans, memory and communication.

Our current work on a model of spatial working memory is exploring how this complex ability is composed from a set of more basic cognitive abilities.

4 Behaviors and experiments

Data in databases is often organized around particular behaviors, or particular experiments. Examples include the Tower of Hanoi problem, the Wisconsin Card Sort Test, and spatial working memory experiments. A given experiment will produce a certain sequence of mental states and processes.

Each cognitive property of interest will have certain measures, we need to decide how to quantify it, what are normal values what are maximum and minimum values or limits, and so on.

A given temporal interval in the experiment or observed behavior will have an associated set of cognitive properties with values of their measures.

Hence, one research activity might be the analysis and characterization of behaviors and experiments.

From these and a given experimental report, we may perhaps be able to derive information on capacities, speeds, intact abilities, and below normal abilities, of cognitive measures that the subject has.

In the case of spatial working memory, a basic experiment consists of a sequence of four phases, namely, fixation of the center point, perception and noting of the target object, maintaining of this mental image during a delay period when the target is not shown, perceiving the cue to respond, and responding by moving the hand to the position of the previously displayed target object. In each of these phases, a certain set of abilities and modules is used, and in a certain way as specified by a plan step that the subject uses.

Thus:

Phase 1 uses the fixation plan step, which uses information from scene and sends a message to fef.
Phase 2 uses the note image plan step, which uses information from scene and sends a message to scene which creates a mental image in a certain state for maintenance.
Phase 3 uses the maintain noted image plan step, which continuously send messages to scene to maintain the stored mental image.
Phase 4 uses the move hand to object plan step, which sends a message to scene to instate the mental image, so scene automatically sends the position to the plan self action module, and plan also sends, to plan self action, the command to make the move.

Each of these phases uses certain modules, certain data and certain communication operations. The overall effect of all four phases is to produce the spatial working memory ability and measure.

Failure to perform the behavior may be traceable to a deficit in one or more of these component abilities. The diagram gives us a systematic checklist of possible deficits. In phase 1, plan, scene and fef and their connections need to be working normally. In phase 2, scene must be able to form the noted mental image. In phase 3, scene must be able to maintain the noted mental image. In phase 4, scene must be able to instate the mental image so that the correct position information is sent to plan self action. In addition, plan must send the appropriate message to plan self action.

In addition, in all of these phases, the appropriate plan step needs to have been learned and be usable, and it needs to have been evoked in context, and communicated to plan successfully.

The goal module needs to generate the currently selected goal and to send it to plan and context. It is also necessary for these activations of goal and context to return to quiesence at a reasonable rate otherwise they could interfere with correct functioning of plan.

In addition, the plan module needs to be able to sequence from one plan step to the next, in the appropriate circumstances, and it needs to be able to remember which plan step it is executing.

The system is also coordinated by the event memory which assigns the current episode key, for this it must receive rule event information from plan, must form the appropriate current event and current episode information, and send it to scene, which must use the information correctly to develop data items that are sent to plan, plan self action and fef.

This example illustrates how a brain model could provide a systematic methodology for characterizing cognitive deficits in the context of given experimental behaviors or clinical tests.

Figure 4 is an attempt to relate the above discussion to a hierarchy of abilities and measures.

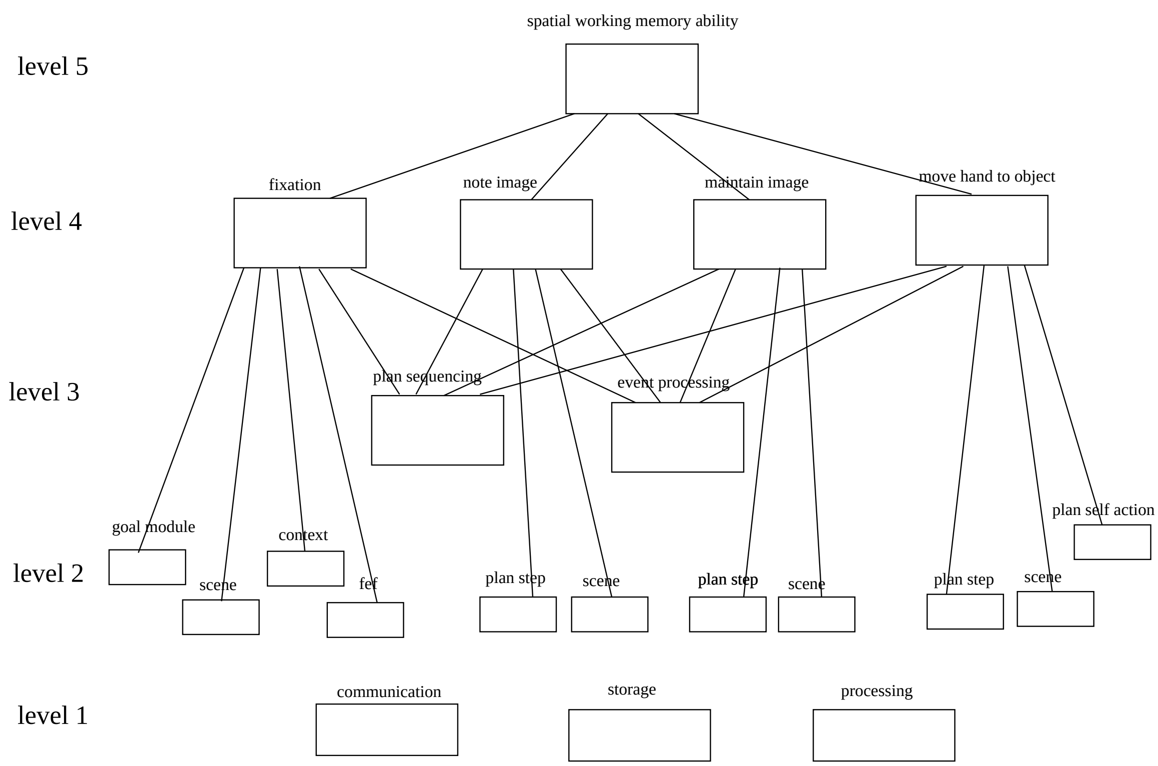

Figure 4: A hierarchy of cognitive abilities and measures

References

[Boyer and Barrett, 2005] Boyer, P. and Barrett, H. C. (2005). Domain specificity and intuitive ontology. In M.Buss, D., editor, *The handbook of evolutionary psychology*, pages 96–118. John Wiley, New York.

[Kosslyn, 1980] Kosslyn, S. (1980). *Image and Mind*. Harvard University Press, Cambridge.

[Kosslyn, 1981] Kosslyn, S. M. (1981). The medium and the message in mental imagery: A theory. In Block, N., editor, *Imagery*, pages 207–258. M.I.T. Press, Cambridge, Massachusetts.

[Kosslyn et al., 1984] Kosslyn, S. M., Brunn, J., Cave, K. R., and Wallach, R. W. (1984). Individual differences in mental imagery ability: A Computational analysis. In Pinker, S., editor, *Visual cognition*, pages 195–271. M.I.T. Press, Cambridge, Massachusetts.