PARTIAL DRAFT

The psychiatric significance of spatial working memory

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1 Introduction

1.1 Overview

1. I have found most of the relevant papers on spatial working memory and frontal executive functions, in monkeys, normal humans and schizophrenics. I seem to have amassed over 200 papers and books on the subject.

2. I have concluded that all of this work can be captured by my system design.

3. I have also concluded that the various descriptions by psychologists of memory and frontal phenomena can be captured alright with the concepts of my own framework, I don't need to introduce any additional mechanisms or modified mechanisms for these. So I can "translate" everything into my own theoretical framework, which has a smaller number of concepts and also is precisely defined.

4. I have had to deal with two hard problems (a) how to deal with spatial memory in posterior areas and (b) how to deal with the mechanisms of memory access in general. My conclusions are that:

(a) spatial memory seems to be spread over several different posterior areas, including
(i) the parahippocampal area of Epstein and Kanwisher which is mainly just the spatial frame of a percept and is used for encoding episodic memories,
(ii) areas anterior to this which are partly hippocampal and which are implicated in route finding and spatial problem solving,
(iii) areas posterior to it which are in the cingulate and which are probably long term

memories of spatial layouts. So this is the confused current state of the art, however what is more depressing is that noone has done any experiments or has any thoughts on how the total percept is bound together, i.e., how the spatial frame is bound with the identities of objects in the scene, which are represented in temporal areas. I can model this situation, although it needs some decision of how the two areas would interact. So the spatial frame had better have some descriptors that can be sent to object areas to evoke descriptions of the various objects in the scene, as required. So this is a little bit hard but can be solved.

(b) the issue of how memories are to be accessed is something I have been working on for some time. Basically one has to decide what kinds of message are to be sent from the frontal planning areas to the posterior areas where the memories are stored, what activity this causes and what messages are then sent out by posterior areas as a result, possibly with a response sent back to the frontal planning area. This is a very fundamental problem and again I have at least a partial solution that can be used for this particular model. It involves slightly generalizing what a brain processing module does.

5. There are a few other issues such as how visual perception and imagination coexist in the same module but this should work alright with the existing mechanism.

1.2 Working memory

To briefly summarize current thinking on working memory:

Working memory has been investigated using psychological experiments, single electrode experiments in monkeys, and PET and fMRI experiments on humans. Most of the latest, clearest and most detailed information comes from imaging experiments. A useful review is by Curtis and D'Esposito [Curtis and D'Esposito, 2003].

1. There are phenomena of working memory for different types of data, including spatial, verbal, visual stimuli and objects.

2. Spatial working memory tends to involve the right hemisphere frontal lobes and verbal memory the left hemisphere frontal lobes.

3. The basic experiment has activations in both frontal and posterior areas, and this corresponds to the information being stored in a posterior area with the frontal area performing maintenance of its activation by rehearsal.

4. Maintenance does not use the dorsolateral areas but, instead, spatial uses an anterior part of area 8, and verbal uses a more ventral area which is part of 45.

5. Dorsolateral frontal cortex, areas 9 and 46, is used when something more than maintenance is needed, such as manipulating the items or selecting a response from two or more possible responses.

6. Posterior regions for spatial information are in medial parietal regions and inferior lateral regions. For purely visual information, V4, for objects, TE0, for verbal information, Wernicke's area.

7. Spatial stimuli probably have a distributed representation with the spatial layout represented in one area (e.g. the parahippocampal place area) and the identities of objects in the scene represented in other areas such as TE0. There are probably other areas involved also.

8. Spatial memory uses areas which are also used in visual perception, so these areas can process both perception and storage of previously perceived stimuli simultaneously, depending on the attention regime which is created by the execution of the current plan or plans.

9. Working memory of all types has also been investigated for schizophrenic patients and also for schizotypal subjects. In general, they show deficits of at least one standard deviation compared to normals. This has been done mainly for medicated schizophrenics but unmedicated patients and premorbid subjects have also been tested. There is some improvement with medication but not back to normal performance.

10. Working memory is just one of a set of basic cognitive functions which are impaired in schizophrenics, including executive control and episodic memory. Surveys have been published by Bilder et al [Bilder et al., 2000] and also James M. Gold [Gold and Green, 2005].

1.3 Our proposed model

Our proposed complete model is diagrammed in Figure 1. This is intended to deal with a wider class of phenomena, including oculomotor responses, and the plan recognition needed for WCST. It should be able to be used as a basis for modeling most of the published experiments on spatial and verbal working memory and frontal executive function. Dashes lines indicate areas on the medial surface.

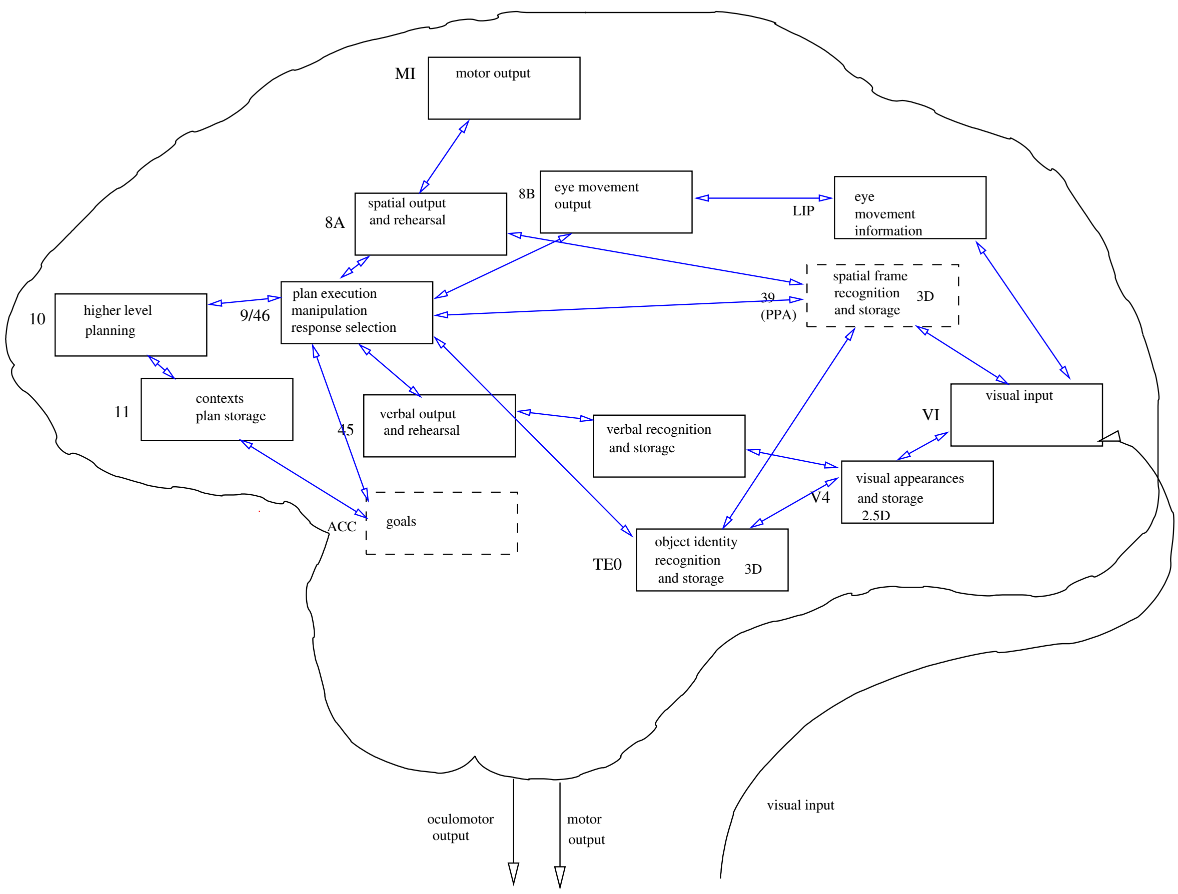

Figure 1: Outline diagram of the general model

The components of our proposed model are:

1. We equate the dorsolateral cortex with a planning module which selects and executes plans. In our concept, sets of plans and constraints, called contexts. are stored in a separate module, corresponding to a ventral prefrontal area, and these are evoked and selected and passed to the planning module for possible execution. This module would handle manipulation of spatial information, response selection, and other executive functions. It follows that some parts of the data would be processed in this module but very limited parts, the main stored spatial information would be in the parietal spatial memory area.

2. The maintenance of working memory is conceived as rehearsal which means that rules would be active in frontal areas and these would send messages, possibly as queries, to the posterior areas where they would evoke and maintain the activation level of the stored

items.

3. The overall plan for taking the experiment would be executed in the planning module, but it does not require a lot of processing.

4. It is not clear whether we need worry about distractor tasks. Some experimenters use them during the delay period to prevent rehearsal, but others do not use them at all. Also some use verbal distractor tasks for spatial working memory tasks. These would also be effective is the rehearsal process was common to both spatial and verbal memories, and there is some evidence that this is not the case, so a verbal task would probably not prevent rehearsal of spatial memories.

5. For the verbal case, if we stick to words, letters, etc. then it should be possible to model experiments by providing two modules, an acoustic input module corresponding to Wernicke's area and a verbal output are corresponding to part of area 45.

6. For the oculomotor case, it seems that oculomotor information from the parietal area LIP should be used, otherwise it seems similar to the normal motor case where the subject points using their hand.

7. It is problematic that the cognitive deficits of schizophrenic patients are insensitive to reduction of symptoms by medication, and insensitive to the temporal variation in the intensity of symptoms. This means that the dopamine overproduction, and its possible influence on glutamate and GABA neurotransmitters, cannot be the complete explanation. There must be at least a chronic temporal adaptation and degradation effect which is slow or impossible to reverse.

8. There is some research on the activity of the basal ganglia during working memory tasks and also the variation due to schizophrenia. For the moment I am ignoring this work. It is intriguing that Kandel and Schwartz in their neuroscience textbook have a chapter on schizophrenia and they state that one of the first signs of schizophrenia is reduced blood flow in the left globus pallidus. I am in general interested in modeling the basal ganglia and I have a paper in the CNS05 conference on this.

Figure 2 shows a reduced model suitable for the basic spatial working memory experiments.

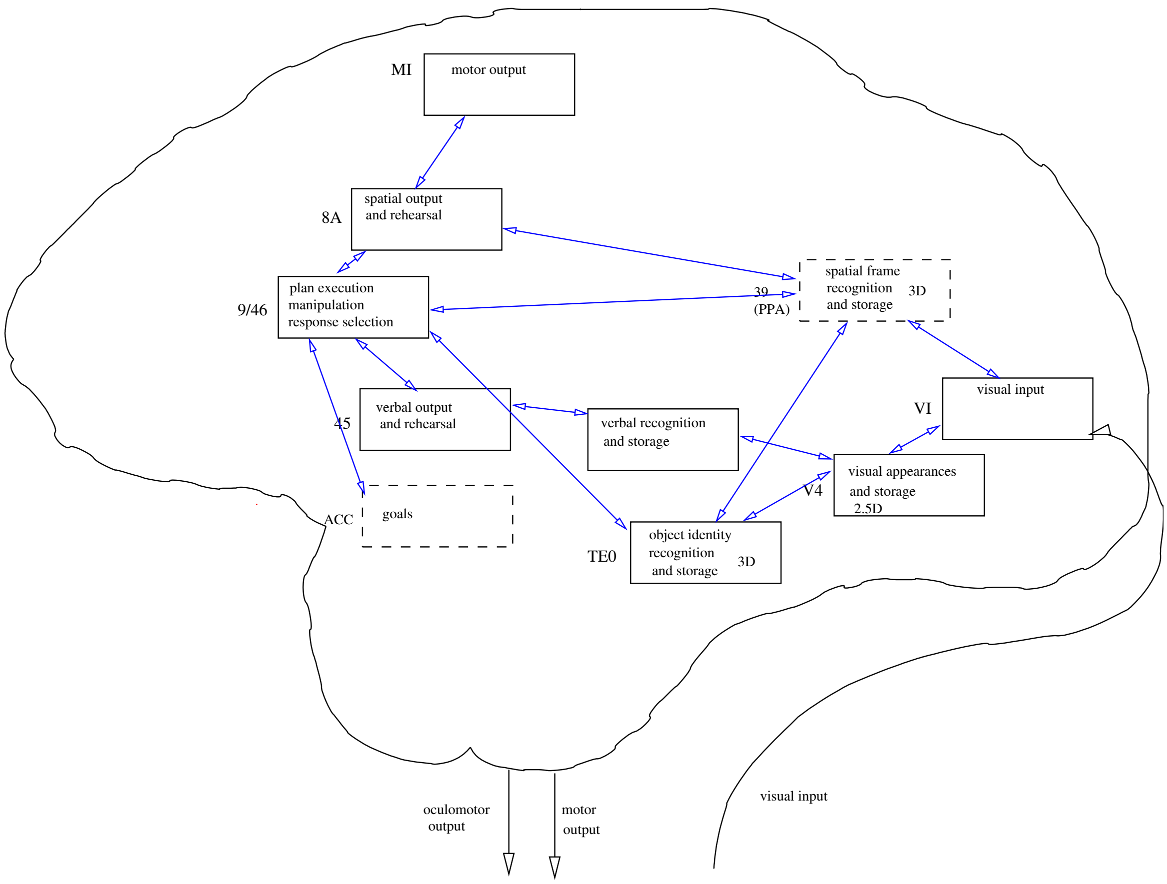

Figure 2: Outline diagram of an initial model

1.4 Brain modeling and cognitive phenomics

Our model should provide a set of parameters for cognitive performance. These parameters would be measures such as:

1. intensity of memory response to incoming stimuli to a given module, speed of storage of a new item, strength of resulting stored item.
2. attenuation rate of stored memories, also possibly intrinsic noise level in a module.
3. speed and reliability of transmission of information between modules.
4. speed of response of memory modules to queries received, evoking stored items.
5. ability to maintain goals over a period of time in the goal and planning modules.
6. ability to hold several activated items.
7. ability to perform more than one computation simultaneously in a given module.
8. ability to pursue several goals at once.

9. the existence of various kinds of plan, their selection and execution.

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 would be easier to determine using imaging and also easier to connect to neurotransmitter and genetic measures.

2 Review of the literature

2.1 The nature of the spatial information that is to be stored

1. There are two different imagery stores, visual and spatial. Visual means properties of the seen object such as texture, color, but also geometric shape; basically those properties leading to the object's identity. Spatial means layout of objects in space. Farah et al. described a patient with impaired visual store and normal spatial store [Farah et al., 1988] and Hanley et al. described a complementary case with normal visual store and impaired spatial store [Hanley et al., 1991].

2. Descriptions in the imagery literature indicate that the spatial component is more 3D or spatial-relational, i.e. has information about spatial relationships among objects in the scene or percept.

3. A mental image must therefore be a distributed representation of at least two component representations.

4. In a review of the psychology of vision by Kanwisher et al. [Kanwisher et al., 2001], four dissociable visual processes [Humphreys and Bruce, 1989] [Farah, 2004] are described:
(i) early vision, meaning computing two dimensional features, edges and contours,
(ii) computing object shape and higher level information, I think this may mean 2.5D, i.e. some relations are out of the plane. Patients with this impaired are said to suffer from apperceptive agnosia [DeRenzi and Lucchelli, 1993][Warrington, 1985]. Further dissociations within this process have also been described [Humphrey et al., 1996] [Davidoff and Warrington, 1993] [Warrington and Taylor, 1978],
(iii) matching shapes to long term memory of objects and scenes, presum-

ably this is mainly 3D, patient HJA, described by Humphreys and Riddoch [Humphreys and Riddock, 1987] had a selective impairment here, and
(iv) semantic/conceptual representations of the scene, patient JB of Riddock and Humphreys [Riddoch and Humphreys, 1987] showed selective impairment here, see also [Hillis and Camarazza, 1995].

5. Milner and Goodale [Milner and Goodale, 1995] describe two co-existing visual representations, visuo-motor, for planning movement, and spatial, for complex images and representations. They describe a patient where the visuo-motor part is normal but the spatial part is impaired.

6. There are of course many fundamental visuo-spatial abilities. Here is a table from Cornoldi et al.'s review [C.Cornoldi and Vecchi, 2003] abilities for which there are standardised psychological tests (their table has also the names of corresponding tests, together with references):

1. Visual organization, the ability to organise street completion test incomplete, not perfectly visible or fragmented patterns.

2. Planned visual scanning, the ability to scan a visual configuration rapidly and efficiently to reach a particular goal.

3. Spatial orientation, the ability to perceive and recall a particular spatial orientation or be able to orient oneself generally in space.

4. Visual reconstructive ability, the ability to reconstruct a pattern (by drawing or using elements provided) on the basis of a given model.

5. Imagery generation ability, the ability to generate vivid visuo-spatial images quickly.

6. Imagery manipulation ability, the ability to manipulate a visuo-spatial mental image in order to transform or evaluate it.

7. Spatial sequential short-term memory, the ability to remember a sequence of locations.

8. Visuo-spatial simultaneous short-term memory, the ability to remember visual information.

9. Long-term spatial memory, the ability to maintain spatial information over long periods of time.

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