The Integrated Implementation of Imaginal and Propositional Data Structures in the Brain

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1. Introduction

I sketch a speculative model (to be presented in greater detail in [1]) of the human brain's implementation of the temporary data structures appearing in cognition. I assume the following working hypothesis:

> The Representation Hypothesis. Much of human cognition is to be explained as the manipulation of data structures, in as literal a sense as the sense in which computers manipulate data structures.

The model is not committed to any particular data structure 'language' in the brain, but it leads to interesting suggestions concerning such languages. The model unifies 'propositional representation', 'imagery' [2] and perception.

A background assumption I make is that the temporary data structures in the brain are physically implemented as short-lived patterns of 'neural enhancement'. These patterns can cause particular events (e.g. changes in the patterns) to occur in the brain. The vague term 'neural enhancement' is intended to encompass possibilities such as higher than normal pulse activity (cf Hebb [3]) and disturbed dendritic-potential microstructure (cf Pribram [4]). To avoid making unnecessary hardware commitments, however, I cast the model at a higher level of description which is intended still to allow relatively easy mappings down to the hardware level.

2. The Main Ideas of the Model

It will become clear that the model postulates sharing of the mechanisms used in perception and those used in the implementation of temporary data structures. For the purposes of this paper, let us simplify matters by taking monocular vision to be the only sense. (A fuller account will be given in [1].) The following hypothesis is a proposal about visual mechanism, bearing family resemblances to proposals such as Marr's primal sketches [11]. Again for simplicity, we assume the retina can be considered to be a 2D rectangular array of (possibly overlapping) receptive fields (finite in number).

> The Vision Hypothesis.
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> a) The brain contains a number of permanent abstract entities called 'perceptual pattern matrices' (PPMs). Each PPM is a 2-dimensional rectangular array isomorphic to the retinal array of receptive fields. There is a set of 'enhancement types', and at any moment each element of each PPM has a 'degree of enhancement' for each type. The 'state' of a PPM is the current pattern of degrees of enhancement over the PPM. Retinal stimulation is converted by low-level preprocessing into a state of some PPM. The enhancement degrees at an element in the PPM for some enhancement types encode the presence of features in the element's corresponding receptive field. Examples of such features are line segments, edges, corners, textures, colours, etc.
>
> b) The possession of more than one PPM allows the brain to maintain very short term iconic memory (cf [12]) of retinal input, and to integrate succesive views.

Now it has been suggested that (conscious or unconscious) visual imagery is based on states of retina-like data structures (e.g. Kosslyn [6]). It has also been mooted that the mechanisms used in visual imagery are shared with visual-perception mechanisms. Suppose we adopt these suggestions, in the sense of allowing the internal generation and manipulation of states of PPMs. If we closely followed the examples used by Kosslyn and others, the PPM states so manipulated would be spatial-analogue images, i.e. would picture physical objects, crude maps, etc. I now claim that, assuming the brain can internally generate such images, there is a priori no reason to think that the PPM states it can generate are restricted to be such images. For instance, there is no reason to think that the brain cannot generate ('pictures' of) written words, abstract diagrams (perhaps depicting abstract network structures), or other symbolic shapes of non-pictorial, non-lexical form. (Once generated, the presence of such PPM patterns is no more bizarre than if the patterns had resulted from seeing words, diagrams, etc.) These observations suggested to me the central postulate of the model:-

> The Main Hypothesis.
>
> a) Any temporary data structure considered to reside at some moment in the brain is implemented as (part of) a state of a single PPM or as a vector of (partial) states of several PPMs.
>
> b) There exist processes which examine PPM states and can, if they detect suitable subpatterns, cause PPM state changes. These processes together with the PPMs are regarded as a production system [5], with pos-

sible concurrent firing of productions. This production system constitutes the entire machinery the brain has for the internal manipulation of temporary data structures.

c) One enhancement type is called 'attention'. Elements with higher degrees of enhancement of attention receive preferential treatment by PPM manipulation processes. A locus of high attention values in a PPM can be slid around in a PPM to effect scanning.

d) The response by pattern-detection processes to PPM patterns is spatially continuous in the sense that the effect of 'spatial' deformations of patterns can be made arbitrarily small by making the deformations sufficiently small.

e) To a first approximation, the effect of the presence of a pattern in a PPM is independent of the identity of the PPM.

f) If approximately the same subpattern is simultaneously present within two different PPMs, and the attention enhancement of the elements used by the subpattern in at least one of the PPMs is sufficiently high, then the attention enhancement of both pattern instances can become boosted. Thus there may be implicit associations among PPM states. (No direct 'pointers' between PPMs are proposed.)

g) There may exist considerably more PPMs than are required by the Vision Hypothesis (for the purpose of receiving preprocessed retinal stimulation, maintaining iconic memory and integrating views).

h) The issue of consciousness is not addressed by the model. There is no assumption that the brain is conscious of any of the PPM states existing at a given time. There is no assumption that when the brain is conscious of a visual image it is conscious of a single PPM state.

It is sometimes suggested that a neural enhancement pattern might be some form of node/link structure representing propositional information. Lifting this idea to the abstract level of PPMs, it is quite conceivable that abstract, propositional information is represented in the form of diagrammed nets. That is, nodes are localized groups of contiguous enhanced PPM elements, and links are chains or ribbons of such elements. (It is not, however, suggested that net patterns are particularly close to the precise net diagrams to be found in the literature, e.g. [7].) Nodes and links in a net-like PPM state can be considered to be associated to long-term knowledge by virtue of labels they are adjacent to, in that the labels are subpatterns which can be detected by some productions (see Main Hypothesis, part (b)). For example, a node label might be a special pattern which has (for us as theorists) the meaning 'dog': by virtue of suitable productions detecting the subpattern, the brain would take actions consistent with the node's representing a dog. It is worth noting that the 'dog' label could be either a stylized picture of a dog or the word 'dog' itself! It could, however, be a subpattern of non-lexical non-pictorial form.

The basic actions in the productions of Main Hypothesis part (b) include: movement of subpatterns within and between PPMs, deletion and creation of subpatterns, changes of enhancement degrees (especially of attention), etc. The action part of a production is tentatively proposed to have a simple sequential form. The productions are thought of as constituting LTM. The model allows, as a detail of this LTM, the existence of a long-term store of encoded PPM states: these can be decoded and read into PPMs, and can be encoded from the contents of PPMs.

Some detection of subpatterns must be primitive in that it is achieved without the need to examine other data structures. I propose that, at least, some simple geometrical shapes, some stylized pictures, some words, and some specialized non-pictorial non-lexical graphic items (including nodes and links) can be primitively detected. (Much of this ability would arise form maturation and experience.) But non-primitive forms of detection can be proposed. For example, by sliding a locus of high attention enhancement around in a PPM, a detection process (perhaps itself made up of production firings) could check for the presence of a piece of network by tracing it out. Also, the associative mechanism of Main Hypothesis part (f) allows the matching of two (not necessarily primitively detectable) subpatterns in distinct PPMs, where one of the subpatterns might be taken to be a template (of pictorial, network, orthographic or any other form). Note that the PPM production system can construct transformed versions of patterns to facilitate further processing. For instance, in the course of visual perception an abstract net representation of a scene could be constructed from a picture of it in a PPM.

3. Selected Implications

The model unifies unconscious spatial imagery and propositional representation at the same time as providing an (intermediate level) implementation of propositional representation. A particular consequence of the Main Hypothesis is that abstract symbolic representations, spatial-analogue images constructed in visual imagery, and images resulting directly from retinal stimulation are just special cases of PPM states. (A more popular route to unification - annotating propositional structures with spatial information [8] - does not address the

issue of implementing propositional structures.) The model can incorporate, in a natural way, hybrid forms of symbolism such as are found in, for instance, maps, cartoons (especially those which include words), road signs, and many forms of semi-abstract sketch and diagram. Moreover, the internal presence of such hybrid symbolism may be closely related to the fact that we deal with it externally with such naturalness, ease and frequency.

The model may help to explain how the human capacity for abstract cognition evolved. That is, assuming that at some stage of primate evolution the Vision Hypothesis held and spatial-analogue PPM states could be internally generated and manipulated, it is plausible that the necessary pattern detection and manipulation operations could have evolved into a form which could deal with more abstract PPM states. (See Minsky [9], Section 6.5.4, for another proposal in which abstract symbolic manipulation evolves from perceptual operations.)

I am just embarking on a computer simulation of a simplified, precise version of the model. This paper has only sketched a 'model schema' in which many parameters (e.g. number and size of PPMs) remain unspecified. The first stage in the project is the exercise of developing a diagrammatic version of a simple production system derived from PSG [10].

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