A CONTINUUM OF DIAGRAMMATIC DATA STRUCTURES IN HUMAN COGNITION

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ABSTRACT

It is proposed that human cognition consists of the manipulation of data structures which are "diagrammatic images". Images are not assumed to be the objects of conscious experience. They are patterns in media which are abstractly in the form of two-dimensional arrays. These patterns can be pictorial, propositional or of a hybrid nature, and lie on a continuum analogous to that of ordinary diagrams. The patterns are interpreted and manipulated by a production system. By virtue of a gross characterization of the physiological implementation of the image-holding media, the model provides in outline a simultaneous answer to three important questions: (1) how are the brain's data structures implemented? (2) where do the lower-level data structures (feature maps) which arise in vision fit in the whole range of data structures in the brain? and (3) how can both pictorial imagery and propositional computation be elegantly included in a cognitive model?

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SECTION 1: INTRODUCTION

"The brain computes by manipulating diagrammatic images." This is the core of an imagery-based cognitive model described in this report. There has been much debate* about whether human cognition makes use of "pictorial images", under various interpretations of that term. Let us take pictorial images to be patterns, in some "graphic medium" in the brain, which resemble the world in much the way ordinary pictures do. The cognitive model postulates that the brain makes use not just of pictorial patterns in such media, but also of patterns from a much wider class. This class of patterns is analogous to the full range of ordinary diagrams (patterns of marks on external graphic media). At one extreme, a pattern can be pictorial. At another extreme, a pattern can be purely ***"propositional"*** – that is, serve the purposes that network structures, logical formulae and other abstract data structures serve in cognitive theories. In particular, the propositional patterns in the brain are typically similar, in a ***gross*** way, to semantic network diagrams to be found in the literature (see e.g. Findler (1979)).

The purpose of this paper is to present in clearer and fuller form the claims just sketched. Detailed discussion and comparison with other work is, for the sake of brevity, postponed to later papers. The model is very briefly outlined in Barnden (1982). Two points should be clearly understood at the outset. First, the issue of conscious imagery is not addressed by the model – the images conjectured to exist are data structures which are not assumed to correspond to or generate conscious experiences. Second, what will be proposed is really a model schema rather than a model – many parameters will have to be specified for a model to appear which is testable by psychological experiment or computer simulation. For convenience, however, we shall continue to use the term "model".

The model provides a rough but unified answer to three important open questions about the nature of human cognition:-

(Q1) How is the brain's data structure manipulation implemented in terms of physiological mechanisms?

(Q2) How does the manipulation of data structures derived from perceptual input fit in with the brain's data structure manipulation generally?

(Q3) What is the relationship between the brain's spatial information about physical domains and its non-spatial information (about physical or non-physical domains)?

Underlying each of these questions there is a certain strong assumption. The assumption for the first question is the following.

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* See, for example: Anderson (1978, 1979), Baylor (1971), Block (1981), Bower (1972), Chase and Clark (1972), Cooper and Shepard (1973), Fodor (1975, pp.174ff), Hayes (1973), Hayes-Roth (1979), Hebb (1977), Hinton (1979), Kieras (1978), Kolers and Smythe (1979), Kosslyn (1981), Kosslyn and Schwartz (1977), Kosslyn et al. (1979), Neisser (1976), Paivio (1971, 1977, 1980), Palmer (1975, 1978), Peterson, Peterson and Ward-Hull (1977), Peterson, Thomas and Johnson (1977), Posner (1973), Pylyshyn (1973, 1978a, 1978b, 1979, 1981), Richardson (1969), Schwartz (1972), Simon (1972, 1978), Sloman (1971, 1975).

The Data-Structure Hypothesis

The brain's short-term cognition (natural-language understanding, perception, problem solving, general thought processes) can be explained largely as the manipulation of data structures in approximately as straightforward a sense as the sense in which the operations of a digital computer (running a program) can be explained as the manipulation of data structures.

This hypothesis is our version of the prevalent "symbol-manipulation" view of cognition, espoused by many researchers in cognitive science (notably Newell (1973) and Newell and Simon (1972)). We shall not argue for its validity here (even though it is not universally believed, and Dennett (1978) has argued that there is no cogent reason for accepting it). We content ourselves with taking Fodor's stance (Fodor (1975, p.27), Fodor (1981, p.29) that it is the most fruitful working hypothesis which is currently available. The word "largely" in the hypothesis allows some cognitive activity, such as low-level components of perceptual and motor activity, to escape the necessity to be straightforwardly explained in terms of data structure manipulation. Note that the hypothesis does not say that the data structures in the brain bear any resemblance to those in a computer. Nor does it say that the sense in which the brain manipulates data structures resembles the sense in which computers do.

The assumption underlying the second question is the following, and concerns a special form of data structure in the brain.

The Feature Map Hypothesis for Vision

Low-level preprocessing converts retinal stimulation into a "feature map" physiologically implemented in the brain. A feature map is a temporary association of values with the elements of a finite 2D array. Each element corresponds to a small region on the retina; neighborhood in the array corresponds to neighborhood of regions; and the values associated with an element constitute information about the presence of certain features (such as small line segments, intensity changes, color, etc.) of the retinal stimulation in the corresponding region.

(Thus the array is a medium analogous to an external graphic medium, and a feature map is a pattern in that medium. Feature maps are special cases of the images postulated by the model.)

Feature maps are similar to the lower-level representations commonly used in artificial-intelligence vision systems (Hanson and Riseman (1978)) and to Marr's raw primal sketches (Marr (1976)). It is sufficient for the purposes of this paper to adopt the simplifying pretence that we are monocular and that our feature maps are rectangular arrays (in an abstract sense, not necessarily a physical one).

It seems probable that some sort of feature map mechanism is physiologically implemented in the brain, because of the nature of the "columns" in primary visual cortex (Hubel and Wiesel (1979)). It is important to note, however, that the feature map supported by these columns need not be the only one in the brain, and that the idea that the main function of the columns is to support a feature map has been challenged