Title
The Spatial Representation and Processing of Information in Cognition

Journal
Proceedings of the Annual Meeting of the Cognitive Science Society, 3(0)

Authors
Strong, Gary W.
Whitehead, Bruce A.

Publication Date
1981

Peer reviewed

THE SPATIAL REPRESENTATION AND PROCESSING OF INFORMATION IN COGNITION[1]

by
Gary W. Strong and Bruce A. Whitehead[2]

Objects spatial patterns within them, and spatial patterns among them form the concrete structure of our world, and intelligent action in it depends upon such spatially patterned information [1]. Therefore, it is important to define the role of spatial pattern in the internal representation of the environment and in the processing applied to this internal representation.

The premise of our model is that the spatial pattern of real-world information shows regularities independent of its information content. Extensive analysis of stimulus properties [2-5] have indeed demonstrated such regularities (invariances) and pointed out their value as the basis of an information processing strategy. We have investigated the feasibility of such a strategy by simulating a proposed cognitive operator mechanism.

Our model postulates an internal space image which represents the spatial pattern, but not content, of environmental stimulus information. (The properties of this internal space image correspond to those of the parietal cortex in the brain.) Cognitive operations upon this internal space correspond to transformations in real-world spatial pattern. As hypothesized in the information processing principles below, the cognitive operator serves a dual role: It represents a generic real-world action which transforms the spatial pattern of incoming information, and it carries out the corresponding cognitive operation on the spatial pattern of the internal space image. In this latter role, the cognitive operator tracks or predicts the spatial transformation of the environmental stimulus which will result from the real-world action.

Our model is highly simplified with respect to brain structure and limited to a specific problem domain: the movement of attention over the visual field. The enhancement effect in parietal cortex has been put forth as a substrate for this cognitive operation. While a cognitive model such as ours cannot show detailed neural mechanisms, it can be constrained to be neurally feasible and to be consistent with the neural data, as discussed under "Physiological Constraints" below.

Hypothesized Information Processing Principles

The simulation model implements hypothesized principles by which neural interconnection structure represents spatial pattern information about the environment. Content representations are modeled only as they participate in the control of the spatial processing system. More precisely, distributed processing of spatial information is influenced by associations between the spatial and the figural representation systems. The role of figural representations in the model is restricted to the effect of their associative connections to spatial patterns. This effect is hypothesized to serve as a control mechanism for distributed processing by spatial operators, according to the principles below:

(a). The cognitive operator must both represent a transformation of space and carry out such a transformation upon object information.

(b). Control of processing must be distributed among content-addressable representations of spatial operators. Content addressability is achieved through associative connections to figural representations.

(c). Content representations must preserve identity across change of spatial locus.

(d). The cognitive operator must be able to carry out spatial transformations independently of object content.

Principles (a) and (b) have been developed in previous work [6]. Efficient access to the information in a representation requires content-addressability. However, this content addressability can be achieved by competition among the representations themselves acting as independent, parallel processors. This avoids the need for centralized control of the distributed processing network.

Physiological Constraints

The enhancement effect in parietal cortex is a neurophysiological correlate of the spatial locus of psychological attention over the visual field [7-9]. No mechanism has previously been put forth which (i) carries out the spatial transformation (Principle a above), (ii) produces its neurophysiological correlate (the parietal enhancement effect), and thus (iii) moves the psychological locus of attention. A model based upon parietal cortex implements our hypothesized mechanism. The model is designed to be consistent with neurophysiological data without attempting to be anatomically complete.

Parietal cell recording studies [7-8] demonstrate internal representations where the spatial layout in the neural tissue represents that in the environment. The anatomical coordinate system is in this sense an image of the surrounding

---

[1]This research supported in part by National Science Foundation Grant No. IST-8011617.

[2]Systems Science Institute, University of Louisville, Louisville KY 40292

environmental space. In the present model, it is termed the INTERNAL SPACE IMAGE.[3] Enhancement in the response of parietal cells to a peripheral stimulus has been shown to

(e). Correspond to the environmental locus of the target stimulus [7-8].

(f). Correspond to a psychological locus of attention (Jonides' [10] "mind's eye") directed toward the stimulus [7-8].

(g). Precede not only a saccadic eye movement to the stimulus, but also a reaching hand movement to it [8], or even the directing of attention to the stimulus without making eye, hand, or other movements to it [8-9].

In sum, while neural enhancement encodes the spatial locus of an impending attentional shift, it does not depend upon the motor characteristics of the shift. Parietal enhancement is therefore associated with a more general spatial transformation than the enhancement effect in superior colliculus which is rigidly tied to eye movement shifts [9].

Resulting Model Specifications

It would seem that the parietal enhancement mentioned above should help in some way to produce a more functional percept by emphasizing retinal information which is to become the target of a movement or attentional shift. However, in the usual case where the peripheral stimulus is quickly brought to the fovea, the function of enhancement at the original peripheral neural locus is unclear. The simulation model seeks to clarify the function of this peripheral enhancement as follows:

FIGURE 1: THE REPRESENTATION OF A TRANSFORMATION

In a system which represents transformations, representation of the magnitude and direction of the shift is essential. This information is defined by the enhanced peripheral locus (point p in Figure 1) in combination with the fovea (point q in Figure 1). Therefore, the function of such peripheral enhancement may be to encode such a vector in the parietal representation of space. The peripheral enhancement would then indicate the activation of the encoded vector.

The Hypothesized Information Processing Principles (a-d) and Physiological Constraints (e-g) above imply these model specifications:

(1). A fundamental transformation mechanism exists as shown in Figure 1 (discussed above).

(2). Figural content of input is separated from its spatial locus information (Constraints c and d). Only the spatial locus of input is passed to the internal space image (Constraint e). Therefore, figural content of input can affect the internal space image only in the selection of spatial transformations.

(3). Information representing spatial locus in the environment is coded by activity at corresponding loci in the internal space image (Constraint e).

(4). The figural identity of active loci in the internal space image must be represented elsewhere in the system (Constraints c and d).

(5). Since control of processing must be distributed among content-addressable representations (Constraint b), control must originate outside the internal space image.

(6). Therefore, the spatial transformations which act upon the internal space image must be selected by their associations to content representations (Constraint a).

By decomposing stimulus information into its spatial and figural components (Principle d leading to Model Specification 2), each component is independently generalizable. A new stimulus can therefore be separately matched with (i) spatial representations learned in a different figural context and (ii) figural representations learned in a different spatial context.

The remaining point to be addressed in the model is the control of distributed processing (Principle b). More specifically, only one of the operators in the spatial transformation set will be appropriate for a given stimulus. Selection of this operator must depend upon both spatial and figural properties of the stimulus. This selection process therefore requires reconvergence of the spatial and figural components of stimulus information. Appropriate spatial operators are addressed via convergent association with active figural representations. This associative content-addressing serves as the control mechanism for the distributed processing network (Model Specifications 5 and 6).

[3] "Image" is used here in the sense of a mathematical function from external to internal coordinate systems.

The Model Structure

As described above, the model operates by initial decomposition of incoming stimulus information into generic spatial and figural components and subsequent association of these components. A model structure which illustrates this and which also satisfies Model Specifications 1-6 is shown in Figure 2.

Perceptual input arrives at the circle labelled LOCUS-DEPENDENT FEATURES. Its feature content information is picked up by LOCUS-INDEPENDENT FEATURES, while the spatial locus of each input feature is simply mapped one-to-one onto a corresponding "hotspot" within the INTERNAL SPACE IMAGE. The locus of the "hotspot" in the INTERNAL SPACE IMAGE therefore represents the spatial position of the feature, but does not carry any content information. However, each "hotspot" activates a set of affordances (movement possibilities) by virtue of the fact that one or more LOCUS-DEPENDENT OPERATORS in the spatial transformation set may originate at the locus occupied by the "hotspot". Each of these LOCUS-DEPENDENT OPERATORS represents a specific, local transformation in the INTERNAL SPACE IMAGE. At any one time, numerous, conflicting possible transformations may be suggested by the current set of "hotspots" in the INTERNAL SPACE IMAGE.

The selection of an appropriate, consistent set of transformations for the model to carry out requires the convergence of activation from two different pathways: (1) from active LOCUS-INDEPENDENT FEATURES, through the (learned) ASSOCIATION NETWORK, into LOCUS-INDEPENDENT OPERATORS; and (2) from the set of possible transformations (affordances as defined above) given by the current analysis of the INTERNAL SPACE IMAGE, into LOCUS-INDEPENDENT OPERATORS. Thus activation from two pathways converges into the set of LOCUS-INDEPENDENT OPERATORS. Any such operator receiving simultaneous activation from both pathways represents a transformation that is suitable to perform, given both the spatial and content limitations of the environment. At this point, the operator selected by convergent activation may in turn activate its associated LOCUS-DEPENDENT OPERATORS, leading to actual behavior as well as to a prediction of the next internal space layout.

This model structure has been implemented and tested in a computer program. The model exhibits not only recognition of spatially-patterned objects but also fill-in of missing features in appropriate places, suggesting the successful encoding of pattern information within objects. Further testing is underway to examine its ability to form generalizations from perceptual input. We plan to adapt the model to a game, such as chess, which might simulate (in a serial program) the ability of neural circuitry to efficiently process spatially-encoded information in parallel.

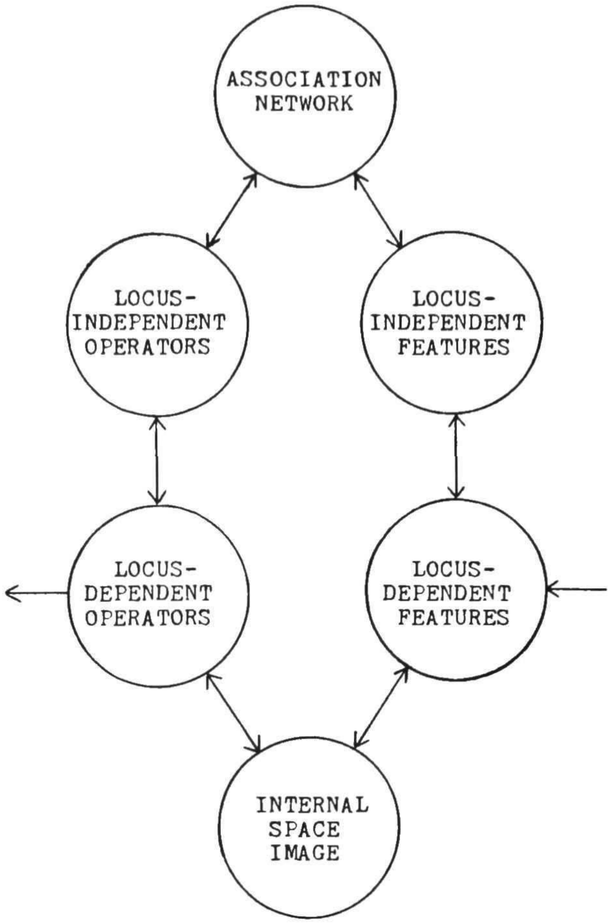

FIGURE 2: THE MODEL STRUCTURE

The important features of the model are that it encodes spatial pattern within a non-spatial association network, thereby eliminating the necessity of storing a "picture". Instead a network of stored feature-movement relations is sufficient to reconstruct the picture whenever necessary. Thus the model deals with the relational aspect of information as well as the bit-content aspect. Each feature-movement relation can be used not only to reconstruct the image of the perceived object but also to evoke behavior appropriate to the object. Finally, the model structure described can be translated into other domains requiring goal-directed information processing, such as in cultural systems [11].

REFERENCES

1. Posner, M.I., Nissen, M.J., and Ogden, W.C. Attended and unattended processing modes: The role of set for spatial location. In H.L. Pick and E. Saltzman (Eds.), Modes of Perceiving and Processing Information, Hillsdale, N.J.: Earlbaum, 1978.

2. Gibson, J.J. *The Perception of the Visual World*. Boston: Houghton Mifflin, 1950.

3. Gibson, J.J. *An Ecological Approach to Visual Perception*. Boston: Houghton Mifflin, 1979.

4. Lee, D.N. Visual information during locomotion. In R.B. MacLeod & H.L. Pick (Eds.), *Perception: Essays in Honor of James J. Gibson*. Ithaca: Cornell University Press, 1974.

5. Shaw, R. & Pittenger, J. Perceiving change. In H.L. Pick, Jr. & E. Saltzman (Eds.), *Modes of Perceiving and Processing Information*. Hillsdale, N.J.: Lawrence Earlbaum, 1978.

6. Whitehead, B.A. *A Neural Model of Human Pattern Recognition*. New York: Garland, in press.

7. Yin, T.C. and Mountcastle, V.B. Visual input to the visuomotor mechanisms of the monkey's parietal lobe. *Science*, 1977, *197*, 1381-1383.

8. Robinson, D.L., Goldberg, M.E., and Stanton, G.B. Parietal association area in the primate: sensory mechanisms and behavioral modulations. *Journal of Neurophysiology*, 1978, *41*, 910-932.

9. Robinson, D.L., & Goldberg, M.E. The visual substrate of eye movements. In J.W. Senders, D.F. Fisher, & R.A. Monty (Eds.), *Eye Movements and the Higher Psychological Functions*. Hillsdale, N.J.: Earlbaum, 1978.

10. Jonides, J. *Voluntary Versus Reflexive Control of the Mind's Eye's Movement*. Paper presented to the Psychonomic Society, November 1976.

11. Strong, G.W. *Information, Pattern, and Behavior: The Cognitive Biases of Four Japanese Groups*. Ph.D. Dissertation, University of Michigan, Ann Arbor, 1981.