REPRESENTATION OF KNOWLEDGE:
NON-LINGUISTIC FORMS

DO WE NEED IMAGES AND ANALOGUES?

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. OLD HOMONCULI NEVER DIE

It is no accident that inside most psychological theories of representation we can, if we look closely enough, discern a small person with his eyes on a screen and his hands on the controls. The metaphor is so seductive that almost all theories of perception succumb to it (as Kaufman, 1974 as noted in his recent review of theories of perception). True, we try to deliver the homunculus a better and more stable picture than falls on the eye of the larger person whose eye is controlling -- in fact we usually go to the trouble of presenting him with a three-dimensional model (often holographic), hoping to lighten his load, but the little man seems so friendly and familiar that we can't imagine how we could do without him. The dilemma this places us in goes back several millennia. It runs something like this. We need to have some internal representation of the world in order to think about it (indeed, in order to apprehend it at all). But if this internal representation is too similar to the world itself it cannot help us to apprehend it; if it is merely moves the same problem inside. On the other hand if it is too dissimilar then how can it represent the world at all? Epistemologists have squirmed under the horns of this dilemma trying by various means to make the problem disappear. Psychologists on the other hand have by and large dismissed the problem as old-fashioned (which it is) and have proceeded to be rigorous in their experimental analysis of the "functional role of images", where images are not merely "pictures" but are actually becoming much more fleeting and sketchy. Sometimes they are referred to as perceptual schemas, sometimes as "the activation of perceptual processes", and more recently as analogues. The little man or his part has been put in a black box where he continues to live under such guises as "the visual system" or as something which responds to the analogues by moving limbs or uttering sentences as required. This account is admittedly unfair to the many investigators who understand the basic problem quite well and are struggling to develop representation systems adequate to the task. But I believe that the caricature adequately characterizes the vast majority of psychological approaches to the phenomenon of so-called "non-verbal representation".

I will confine my written remarks to a small subset of questions bearing on this dilemma. I would be glad to provide reprints of my other relevant papers on request. Primarily what I will try to do is

to point out that many of the ways of casting the problem of "alternative forms of representation" are misguided and that by blurring certain distinctions and emphasizing others we may be burying the significant problems in a mire of catchwords (e.g., procedural embedding, analogical, holistic and even propositional -- which I now regret using because of the sentential connotations which, despite all my efforts, it continues to have).

II. THE FUNCTION OF REPRESENTING:
"RESEMBLING" OR "DESCRIBING"?

Let us look at the representation dilemma again. It asked (in part) how an entity could represent some object if it was too dissimilar from that object. But this, like a great many other questions of this sort, already presupposes something crucial. We normally only speak about two things being similar if they are to be examined in the same way -- in particular if they are both to be viewed. Since we don't want to start off with this as the assumption (we might then ask "who does the viewing inside?") we should drop the idea that the representation literally resembles the thing it represents (see Goodman, 1968, for more on this point). Well then can the representation be any arbitrary symbol? Clearly it cannot in general be an unstructured atomic symbol since then there would be no way to show that the thing represented had a structure -- i.e., had subparts, relations and attributes. So what constraints are there on the structure of the representation? Here the going gets tougher. One is tempted to give the recursive reply that it must have substructures, relations, properties, etc. which represent the substructures, relations and properties of the object(s) being represented. But here we have to be careful for two reasons. One reason is that if the representation maps all the structures, etc. of the object we will have an isomorphism which has all the disadvantages of the picture-in-the-head alternative. The representation must not only be highly partial but it must be partial in the appropriate way (see below). The other reason is that it is meaningless to speak of the structure of the representation. Structure is relative to the processes which construct and use the representation. It is these processes which define the semantics of the representation: we may speak of the structure of a representation relative to a Semantic Interpretation Function (SIF). Thus the two distinct strings of symbols "not (p and q)" and "not-p or not-q" are identical structures from the point of view of a theorem prover and the distinct strings "x + y" and "(LEFT-OF STAR PLUS)" may be identical structures from the point of view of some other SIF. Neglect of the SIF represents one of the most ubiquitous sources of confusion in discussions about representation. It leads some people, for example, to assert that non-linguistic representations "preserve the structure of that which they represent". They do so of course only to the extent that the "same

structure" is extracted by some appropriate SIF. In that sense the sentence "the book is on the table" can be said to preserve part of the structure of a scene containing a book on a table. To be sure the latter has a lot more structure as well but so does the sentence (it has order, length, color, etc.). It is up to the SIF to pick out those aspects which are signifying from those that are not and to process the string (in the appropriate contexts) as it would the scene. Without knowing what the SIF did we could not speak of structural similarity. I don't mean to imply by this example that sentences provide an adequate representation of scenes (they don't for other reasons) but only that the differences are more subtle than captured in the simple claim that the scene and the sentence have different structures. At this level all we can say is that they don't "resemble" one another.

One can of course remove much of the arbitrariness in the above characterization of the structure of representations by requiring that the SIF be perceptual in nature -- i.e., by assuming that the SIF has much in common with visual perception. There is a good deal of psychological evidence suggesting that imaging and perceiving are similar in many ways. Although this seems like a reasonable proposal it creates many problems and must be approached with care. It is tempting to "explain" aspects of cognition (e.g., Moyer's (1973) account of magnitude judgments from memory) by pointing out that they are "like" their perceptual counterparts in respect to such measures as reaction time. But since we have no idea of how the latter is accomplished this is a case of "obscurum per obscurum". Furthermore to note that some cognitive operations bear a (not yet well understood) relation to perception is in no sense evidence that these cognitive operations involve pictorial or analogical or any other entities which resemble objects in the environment. Presumably perception involves the construction and processing of internal representations just as does imaging so some relations between the two should not be too surprising. Furthermore there are some major differences as well. These are related to the fact that objects in the environment have a stable existence so they can be re-examined and to the fact that transformations of internal objects (such as those studied by Shepard) depend on the person's tacit knowledge concerning permissible transformations. The way in which this knowledge must be brought to bear -- and not intrinsic properties of the representation (i.e., not the rigidity of patterns being mentally rotated) are what must account for experimental results on mental transformations (we shall return to this point in section III).

But perhaps the main argument against the view that the SIF is perceptual -- assuming that we can specify what we mean by perceptual in other than hand-waving terms -- is that it implies that the representation to which it is applied is something capable of being perceived.

Unfortunately no matter how hard we try to make it sound like we are avoiding pictures (or worse, objects) in the head there is no coherent intermediate ground: if the SIF has perceptual primitives (e.g., operations such as those studied in vision for feature detection, etc.) it must be applied to something which, however fleeting, sketchy, vague, dynamic, etc. is still pictorial or isomorphic in a sense which is incompatible with the facts of human memory and cognition. I want to make it clear that I don't object to the reification of pictures or some such analogues on ontological grounds, but simply on the grounds that such objects as a class have the wrong properties. Our representations of the visual world are not like any (degraded, topologically transformed, filtered, etc.) projection of proximal stimulation: they are constructed from aspects of the world which we notice (and such aspects can be global, abstract and highly cognitive -- i.e., knowledge-driven and assimilated into available conceptual categories) and they represent equivalence-classes of stimuli which are physically very different from each other and from any conceivable picture-like entity. For example I might notice shapes (or at least a class of shapes) but not colors, objects but not locations, and non-sensory relations such as causality, potential actions, intensions, etc. Such representations, derived from visual perception, cannot be sharply distinguished from knowledge derived by other means; that is why I prefer to refer to them as "structured descriptions". The vocabulary of such descriptions and the accessibility relations may be quite different from that of linearly ordered utterances. Such "visual images" are in some ways more like models than logical statements insofar as they may not contain quantifiers (at least the current computational models of imagery do not -- e.g., Baylor 1972, Moran 1973). Images in such an approach are data structures in which objects are individuated (i.e., there is no node for "seven blocks"), contain many "default" attributes and typically use spatial relations as access paths. Yet in my view it is more appropriate to refer to them as descriptions than images because the term is less misleading since they consist of conceptual structures very much like those constructed when the input is linguistic -- except perhaps using a modality-specific vocabulary of symbols. One cannot of course rule out the possibility that there are cognitively functional aspects of percepts which cannot be captured in such a discrete symbol system, but I have yet to hear a persuasive argument for that case. Furthermore, I have argued elsewhere (Pylyshyn, 1973) that there are many conceptual traps awaiting those who talk in terms of storing and using images.

III. ANALOGICAL AGAIN

The most common proposal for an alternative form of representation for perceptually derived knowledge is that it is analogical. This term has become the new

uzzword in cognitive psychology and is used as a synonym for anything from "warm and oddly" through "holistic", "continuous", or imply "anything which is not language-like". Few psychologists have tried to be very specific in characterizing the meaning of this term. When people have tried to be explicit (as, for example, Loman 1971; Block and Fodor 1973; Lewis 1971, Goodman 1968) they have found it to be a very difficult concept to characterize and have had to distinguish several different senses in which the term is used. I have discussed some of these elsewhere (Pylyshyn, in press) so I will not repeat myself here.

want merely to add to what I have written some discussion of why people may be tempted to reach for analogues to account for certain psychological evidence, and to suggest why such entities whatever they may be, fall short of serving the function expected of them.

As a psychologist one of the main objections that I have to the whole notion of analogue representation is that it seems to me to be a convenient way of hiding a large part of the problem we are trying to explain -- i.e., how people represent and reason about objects and actions. You may recall being at least mildly surprised that there is such a thing as a "frame problem" in reasoning about actions (McCarthy and Hayes, 1969; Simon, 1972). The reason that it never occurred to many of us that there was a problem is that when we interact with the environment (as opposed to thinking about it) the laws of physics take care of all the relevant interactions among events -- we don't have to worry about overlooking what will happen to everything else in the world when we carry out some action on a part of it. Such relations are given to us free by the environment. In the case of reasoning, however, the relations are not free. We must in some way explicitly build in the knowledge regarding what effects do and don't follow from any action. Now it seems to me that the notion of an analogue representation is in part an attempt to get this information for free gain. Thus the claim that data on the time-course of mental rotation (c.f., Cooper and Shepard, 1973) argues that the process is analogue (since, as the proponents innocently ask "how can you rotate a data structure through its intermediate positions?"). This carries the implication that once we start a rotation the medium will take care of maintaining the rigidity of the total pattern and carry along all the parts for us -- just as the laws of physics take care of this for us in the real environment. But, as in the frame problem, we are overlooking the fact that the person (or the robot) must know what will and will not happen to the bottom part when the top part starts to rotate. In a descriptive structure this is precisely what makes "mental rotation" appear awkward and computationally unduly costly. But this is unavoidable unless we have an analogical modelling medium which intrinsically follows the laws of physics. Unless we are willing to ascribe such laws to brain tissue (which, by the way, is what Gestalt psychologists

attempted to do) we are stuck with locating it in what I have called the SIF (which does not, incidentally, preclude it from being a distributed computation attached to the data structure itself). If we admit this, however, there appears little reason to call the resulting representational system analogical (though Shepard's use of the term is, by his own admission, broad enough to cover this case).

Another example where analogues are invoked in a similar role is for the representation of magnitudes. When we "mentally compare" two objects -- say a dog and a horse -- to judge which is larger, the answer seems immediate and intuitively appears to depend on a comparison of two images or some sort of "analogues". Now we have some idea of what sort of operation is involved when two physical objects are compared by placing them side-by-side. Again the laws of physics and optics assure us that, as in the frame problem, the right things will happen (e.g., the object sizes will remain fixed as they are moved, the smaller object will partially occlude the larger, etc.). But in the mental comparison case we somehow feel that the analogues will "do the right thing" because of intrinsic properties of the analogue medium, just as in the mental rotation example we feel that analogues will intrinsically maintain their form in a rigid manner during rotation. In the mental comparison case the assumption is that if the process is analogue, the SIF does not need to "know" the rules of transformation nor does it need to "know" about order relations -- e.g., that such relations are asymmetric and transitive -- since it has merely to "read off" the answer from the analogue. The representation again seems to have the answer "written on its sleeve". Thus by attributing such properties to the intrinsic nature of the representation we beg the very question of how magnitudes are encoded and compared.

The phenomenon of attributing to the intrinsic nature of a representation some of the crucial aspects that need to be taken into account (because these are so intuitively obvious to the theorist) is not confined to analogical representations. Woods (1975) has recently shown that we frequently commit the same oversight in the case of semantic networks. This is why it is important to attempt to simulate a significant portion of cognition by machine (although even here the existence of such built-in functions as an arithmetic processor may create the illusion that we get magnitudes for free -- i.e., we need not model them in detail).

In conclusion let me reiterate that I don't claim to have made an argument against analogical modes of representation -- and still less that I am satisfied that semantic networks, procedures, etc. are adequate to handle all forms of knowledge. I have simply tried to argue that many of the reasons people have for jumping on the "non-linguistic" (whatever that may be) bandwagon are insufficient. Furthermore we

are so far from understanding the semantics of discrete data structures (as Woods has cogently argued) that any mass movement to abandon them (or even augment them with something radically different) is at the very least premature.

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