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ADAPTATION, STRUCTURE AND KNOWLEDGE

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G. T. Moore and R. G. Golledge (Eds.)
<u>Environmental Knowing: Theories, Perspectives, and Methods</u>. Stroudsburg, Pa.: Dowden, Hutchinson and Ross. 1976, 32-45.

Supported by
Institute for Environmental Quality
University of Michigan

Department of Psychology
& Department of Computer and
Communication Sciences

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AN INTRODUCTION FOR READERS NOT PLANNING TO READ THIS PAPER

Some years ago there was a newspaper report of a student who decided to travel the several hundred miles between his college and home by bicycle. Upon reaching his destination he announced with some surprise that the country was covered with tiny crossroad towns consisting of one filling station and one grocery store. Clearly, a former expressway habitué had undergone a change in his cognitive map. But he also experienced a change in his beliefs. One might even say that he corrected a prejudice.

The point is that cognitive maps, beliefs, even prejudices are not clearly separable portions of the cognitive apparatus. Rather, they are all cases in which an individual possesses an internal model of a portion of his environment. This internal model presumably arose out of experience (either direct or vicarious). It serves as a basis for imagination and thought. It can be manipulated by the individual in whose head it resides and thus provides a basis for decision and action.

Given this very general description, one might rightly suspect that internal models are rather pervasive. A few examples might underscore both their diversity and their influence in determining behavior:

1. The imperialist who believes that natives must be treated like children.
2. The farmer who believes that natural hazards are God's will and not subject to human intervention.
3. The industrialist who believes that people dislike work and thus must be forced and coerced into doing it.
4. The traffic engineer who believes that people want to get from one point to another as rapidly as possible (and could care less what they see along the way).

Note that even the reaction of an individual to a behavior setting must be based on an internal model. People with no prior experience in the particular setting may not know how to act (since they lack an internal model); people with prior experience can describe appropriate behavior in that setting without even being there. Those who argue that the "environment is not in the head" should not be too hasty. Certainly they are correct on technical grounds; nonetheless, an internal model of the environment does reside in the head. It can play a central role in the interpretation of real environments and thus in the resulting behavior.

ON FUNCTIONAL REQUIREMENTS AND THE ROLE OF MECHANISM

The concept of cognitive maps is a fascinating one and shows signs of taking hold in a variety of fields: anthropology (Fischer,1971), planning (Greenbie, 1974), education (Reif,1974), and sociology (Suttles, 1972), as well as psychology and geography (Downs and Stea, 1973a; Gould and White, 1974). But at present the idea that people have a map in their heads remains essentially a metaphor. It is not yet entirely clear in what ways this knowledge of the environment is like a map or, indeed, whether it has enough in common with a map to merit the name. Yet the idea is sufficiently attractive that it is hard to resist the challenge to take the next step, to move from metaphor to mechanism. "Mechanism" is used here in the sense of the machinery that underlies the observed phenomena, in other words, the specification of how it is constructed and how it works. This paper is a continuation of a search for a mechanism that began in "Cognitive Maps in Perception and Thought" (Kaplan, 1973b). The approach I have taken focuses on information processing viewed in its broadest sense of comprehending the environment, evaluating it, planning about it, and deciding on appropriate actions to carry out in it.

A point of view that considers mechanisms in terms of the functions they perform is properly considered a functionalism. Indeed, functionalism in psychology has a long and noble history. It arose as a consequence of Darwin's theory of evolution and had among its early proponents such eminent psychologists as Angell, Carr, and Dewey. William James (1892), functionalism's most articulate spokesman, analyzed the processes and tendencies of the organism in terms of their usefulness (i.e., function) in aiding the organism in making its way through the environment. Such an approach follows from the functionalist assumption that the mechanisms underlying behavior arose not merely by accident, but because of their importance to the survival of the organism. In this context, the corresponding assumption would be that the capacity and propensity to build cognitive maps arose through evolution. The cognitive map would then be viewed as a response to selection pressures favoring those of our ancestors' generation who were more adroit at processing information.

Thus, the basic strategy followed here is to look for mechanisms that meet the requirements of adaptive functioning. From this perspective it is important to consider information-processing capacities that would have been necessary for survival of the human species. The discussion of these issues, undertaken in the next section, is based on the assumption that the evolutionary environment was uncertain and dangerous. Survival in such an environment requires the capacity of object recognition, the anticipation of future events, abstraction and generalization, and responsible innovation. In discussing why these capacities were essential, the next section outlines some requirements that must be met by an adequate theory of human information processing. In the subsequent section a set of interrelated mechanisms intended to fulfill these requirements is described. The paper concludes with an application of the proposed mechanisms to the problem of way-finding.

ON INFORMATION AND THE MANAGEMENT OF UNCERTAINTY

Why the emphasis on information in the relationship between people and the environment? In a functional perspective, this question can be viewed in terms of the role information plays in getting along in the environment and, more specifically, its role in survival during the time when humans evolved. At least a beginning of an answer to this question can be made in terms of the three interrelated issues of strategy, speed, and scarcity.

Strategy. When the anthropoid ancestors of humans descended from the trees quite some time ago, they did not find the ground uninhabited. Numerous other species got there first. For the most part the good niches were taken. Survival based on leftovers, on taking advantage of opportunities that happened to be overlooked, requires a strategy that is highly information dependent. There are at least two reasons for this. First, an opportunistic organism must be well informed, and well informed about a great many things, to compete with already well established competitors. Furthermore, since any single food source was necessarily uncertain, a large spatial area would have to be covered to increase the likelihood of obtaining something edible (Peters and Mech, 1975). Considerable spatial information was required to know what to look for, where to find it (e.g., Flannery, 1955), and how to get home again. Humans are home-based communal animals; the capacity to return home was a survival necessity.

Speed. The transition from the trees to the ground had another important influence as well. The ground is a dangerous place. Lacking dazzling speed or exceptional protection in the way of fang and claw or hard shell, the early human was dependent on anticipating events before they got out of hand. This adaptation was facilitated by the good vision developed in the arboreal environment. Likewise, upright posture allowed a better view of unfolding events. The intimate relationship between seeing something at a distance and anticipating it is expressed in the word "foresight." But vision and uprightness themselves are insufficient. To survive ill-equipped in a dangerous environment required that this information-handling capability be used with great speed. Speed, of course, is bought at the price of accuracy. The maintenance of reasonable behavior in the absence of high accuracy is one of the great accomplishments of the information-processing system under discussion. How this is achieved must await the more detailed discussion of cognitive maps and cognitive structure that follows.

Scarcity. Information plays a vital role in the organism's commerce with the environment; it is, in effect, the currency of this relationship. Economists argue that the value of something is a function of its scarcity; given the value placed on information in the human design, one must conclude that it was scarce. This may seem somewhat odd; after all, one central problem of the earth environment is that its inhabitants are inundated with information. But the pressure of speed makes a difference here, as does the kind of information. Anticipation of danger, or of opportunity for that matter, requires *salient* information. The remaining information is considered merely background if it is innocuous or noise if it is potentially distracting. And there is a scarcity of information if it must be salient and if it must be now.

Thus, pursuing a strategy based on information is made difficult both because of the importance of speed and the scarcity of salient information. Stated another way, the environment that confronted our ancestors was, in informational terms, highly complex and uncertain. They could not know how the weather would turn out. Plentiful deer this year could mean even more next year, or it could mean an oversupply leading to a marked decline next year. That dim figure approaching camp at dusk may be a member of the group or he may not. (It should be noted that the environment of modern man is not markedly different in such respects. Weather and even natural hazards still exist. Resources have been known to become suddenly scarce. And the dim figure approaching can still be friend or foe, even in our times.)

SOME REQUIRED INFORMATION-HANDLING CAPACITIES

The most basic of the required capacities is *object recognition*. Unfortunately, this is a relatively technical and involved issue, which would require a lengthy paper all to itself. Since most students of environmental cognition are more interested in the comprehension of space and of objects in space than in objects per se, for present purposes it will simply be assumed that recognizing objects requires dealing with a great deal of uncertainty. (Readers who find this counterintuitive might find it helpful to consult my previous paper; Kaplan, 1973a.)

Once the problem of object recognition has been identified, several additional mechanisms are immediately called for. The organism must be able to *anticipate* future events. Recognizing a given object (or a configuration of objects that might conveniently be referred to as a "situation"), the organism must be able to anticipate a likely next object (or situation). This capacity to anticipate or predict possible consequences is essential to making intelligent choices. Often, in fact, a single-step prediction is insufficient and a whole network of future possibilities must be explored in order to make a suitable choice. Samuel (1963) develops this argument effectively in discussing his famous checker-playing program. He emphasizes the necessity of "lookahead," the consideration of possible future board configurations necessary for evaluating the next move. The importance of lookahead is not, of course, restricted to games. As I have argued previously, it may be a vital issue in comprehending contemporary environmental trends (S. Kaplan, 1972).

A second requirement is the capacity to *abstract* and *generalize*. Experiences are particular and nonrecurring. Learning is futile if what one has learned can never be applied because that precise circumstance never occurs again. Anticipation, likewise, cannot be of a particular subsequent state but rather of a class of such states. Thus, the capacity to abstract and generalize from experiences is not merely desirable but essential for adaptive behavior.

A third requirement is closely related to the second. There are times when there is no "similar" precedent to go on, when abstraction and generalization provide an insufficient basis for behavior. This depends, of course, upon the novelty of the situation. A circumstance too unlike the past experience of the organism requires innovation. Such innovation must not, however, be random. It must be commensurate with whatever abilities and past experience the organism can bring to bear. Thus, this capacity might most appropriately be referred to as *responsible innovation*. In the traditional psychological literature, the process of generating responsible innovations is often referred to as "problem solving."

Thus, to the basic requirement of object recognition must be added three further requirements for which object recognition is a necessary but not a sufficient condition. Anticipation concerns the prediction of future objects and situations; abstraction and generalization involve going beyond the precise appearance of particular objects and situations in order to be able to treat certain other objects and situations as "similar" to what one already knows. And finally, responsible innovation is required when similarity fails but some reaction is called for nonetheless.

SOME PROPOSED MECHANISMS

In this section we attempt to provide mechanisms that meet the proposed set of requirements. Just as space limitations precluded spelling out the requirements for object recognition, the detailed development of the mechanism must also go unspecified. At the same time, an acquaintance with this mechanism is necessary, since it serves as a basic building block with respect to the other mechanisms. An abbreviated sketch of what an object-recognition mechanism might look like is provided as background.

Recognizing Objects

The solution proposed for the object-recognition problem is, in simplest terms, an internal model of the object. This permits recognition despite uncertainty and incomplete information. It gradually arises in a person's head through repeated experience with the object.

For those inclined to take their rules of learning and perception seriously, it is perhaps more accurate to say that this mental entity gradually arises through the association of various cues or features[2] which the organism extracts from the object. The rule of association here is *contiguity*; contiguity in turn is assured by the fact that examination of any object leads to the experiencing of a contiguous sequence of cues from that object. Admittedly, the order of cues will be highly variable. But this will tend to promote many cross associations, creating the very order free network required for an entity, rather than a string or list or tree of cues. (For a more complete discussion of the genesis and possibilities of the network structure, the reader is referred to the groundbreaking and deeply insightful work of Hebb, 1949, 1963.)

This discussion of cues and association may cause some to suspect a hidden neoassociationist at work. Although the proposed model *is* elementaristic and associationistic, this is not in contrast to a gestalt or wholistic or organismic ap-

> proach. Indeed, what we are considering is a *whole* (i.e., entity) that gradually emerges out of a vague, global, relatively undifferentiated state. In other words, what is assumed to occur here is differentiation (à la Gibson and Gibson, 1955) through association (à la Postman, 1955).
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> To understand how this occurs, it is necessary to descend into the murky depths of the molecular level and look at the basic properties of the system. A system is characteristically made up of elements and relations. The operation of the system is based on the initial condition and the rules of change. Here the elements are neurons and relations are associations or connections among them (which can vary in strength between +1, through zero, to −1. The initial condition is a state of widespread, weak, positive connections among the elements. The rule of change, here the learning rule, is in fact rather complicated Two key properties are as follows: (1) any neuron that helps fire some other neuron will tend to become more strongly associated with it, and (2) the total strength of association of any given neuron with all other neurons shall remain constant. One implication of the second assumption is that, as a neuron comes to be more strongly associated with a particular neuron, it will tend to become less strongly associated with other neurons. Thus, at the same time that the strength of connections among salient elements is gradually becoming stronger, the association with other (i.e., irrelevant) elements is correspondingly weakening. In this way the internal model of an object gradually emerges out of an undifferentiated background of random connections.

This internal model is conceptualized as a network of elements corresponding to cues characterizing the object. It incorporates cues in proportion to their importance, it has the capacity to search for cues that are missing, and it can fill in any remaining incompleteness once substantial evidence concerning the presence of the object has been gathered. The capacity to fill in means that the network of elements will tend to act as a whole, as an entity rather than as a mere collection of elements.

The entity or thing-like property of the network allows it to serve as an element in thought as well as in perception. By the rules of learning that gave rise to it, it *corresponds* to an object in the environment. It is the particular internal model whose activity signals the presence of that object in the environment. When the object is not present but only thought about, this same network, by a lower level of activity, is capable of standing for or representing the object in the thought process. It thus is often referred to as the internal *representation* of the object. Clearly, a representation is an abstraction; it is incomplete, schematic, and partial, which allows it to "fit" a wide range of differing circumstances while being experienced as a "thing" and not as an idea.

Information-Processing Mechanisms and the Importance of Space

The object is a physical entity. The cognitive map implies space. These physical-spatial emphases are by no means accidental; nor are they intended to be restrictive. I have assumed throughout this discussion that the problem of dealing with the physical-spatial environment was a central and challenging feature of human evolution (see Peters and Mech, 1975). Accordingly, human information-processing patterns might be expected to reflect this influence in a profound way. Mechanisms that evolved under pressures of dealing with the physical-spatial environment may now be handling other kinds of information as well. There does indeed appear to be a pervasive use of physical-spatial referents and analogies in the human comprehension of the nonphysical world. Concepts of proximity, order, and distance, for instance, play an important role in a wide variety of nonspatial matters. The domain of human relationships provides numerous examples. People are said to be "close" or "distant," some are thought to be "higher" than others (on the pecking "order"), and so on. The future is often thought of in spatial terms. Thus, one speaks of "distant" goals or of the difficulty in "seeing where one is going." Comparably, issues of value may revolve around the true "path" from which one might be tempted to stray. Indeed, one of the best known deviations is referred to as the "primrose path."

The mechanism concerned with anticipation, that of *sequence*, is at the same time clearly spatial and not spatial at all. In the context of the cognition of space, sequences refer to routes. Yet the paradigm of sequences may actually be temporal; spatial sequences may be coded because they are experienced temporally. (This would be consistent with the rule of learning assumed throughout this paper, that is, contiguity, which states that events which happen close together in time will come to be associated with each other.) Even the comprehension of the ordering (i.e., sequences) of digits in a number and of letters in a word has been shown to depend on a spatial ability (Kinsbourne, 1971).

Abstraction, the next process to be discussed, is obviously pertinent to nonspatial domains; indeed the vast majority of abstractions we deal with are not obviously spatial. But "region" is a spatial abstraction, and "state" (as in "the United States") also fits this description (see Shepard and Chipman, 1970).

Responsible innovation, the final of the processes requiring a suitable mechanism, is usually thought of as essentially nonspatial since most problems requiring an innovative solution are not obviously spatial. But the literature on problem solving frequently characterizes the process as finding a path between start and goal. Thus, way finding can be viewed not only as an interesting problem in the cognition of space but also as a paradigm for problem solving in general.

Anticipation: The Coding of Sequences

Although objects are of undeniable importance in comprehending and reacting to the environment, their recognition per se provides little help in knowing what to do. Selecting an appropriate action requires prediction, that is, an assessment of what might happen next. Knowledge of "what follows what" is essentially a problem of storing sequential information. There are, of course, innumerable reasonably realiable sequences that are frequently encountered in the environment. There are in fact so many that an economical means of coding them is essential. Although the problem of storing sequences has long been recognized in psychology, the solutions proposed characteristically fall short of the necessary economy. Thus, associative chains have been a popular candidate, but the necessity of having a new chain for every new circumstance readily becomes a burden. More recently, tree structures have become popular (e.g., Hunt, 1962). There is a gain of economy here, but even though the flexibility of handling any given problem is enhanced, a new tree is still required for each new problem.

From the point of view of functional requirements—ignoring for a moment the issue of structure—the problem is straightforward. A representation should be associated with representations of events likely to follow it. Thus, a sequence is coded as a series of paths connecting representations. Economy in this arrangement is gained through overlap. All sequences having a particular representation in common pass through that representation. Such a highly overlapping structure constitutes a network. But note that, since the nodes of this network are representations and thus themselves lower-order networks, this network is necessarily on a larger scale. It is, in effect, a network of networks. Such a condensation of various spatial experiences into a simplified node and path structure is called a *cognitive map.*[3] In other words, a cognitive map in this framework is a network of representations coding both places and the sequential relations among them.

The proposed mechanism for the cognitive map achieves the economy of storage that eludes the chain and tree structures. The network coding of overlapping and intersecting sequences requires far less structure for the same quantity of information than would more independent forms of organization. Overlap is an advantage not only in terms of storage. It is also responsible for a parallel economy of experience. Since experience with a given object calls up the representation of that object, information about that object will tend to be stored together, despite considerable variance in circumstances, motives, and so on. Likewise, many different experiences that have in common a particular sequence will contribute to the development of the mental representation of that sequence. Thus, one may traverse a given neighborhood from various starting points, for various purposes, and at various times of day. All such information will contribute to the development of the same section of the cognitive map; it will be available for unanticipated as well as familiar purposes and circumstances.

Another kind of economy derives from the fact that the proposed cognitive map structure is not continuous. Rather, it is a discrete approximation to a continuous environment. But such incompleteness, although highly desirable, could also constitute a serious handicap. To be workable, any discrete, incomplete approximation must meet two requirements. It must be connected and it must be susceptible to an increase in completeness if circumstances warrant. Meeting the first requirement is rather straightforward, since a network is by definition a connected structure. Meeting the second requirement can also be achieved readily by making the assumption that the processes which generated the network in the first place continue to operate in its refinement.

Abstraction and the Concept of Layers

The discussion so far has concerned the way consistencies in sensory information can be utilized to build a model of the environment. A useful model must be one that can be applied to many circumstances, not merely to the particular circumstances that gave rise to it. To be more generalizable, experience must be coded in a fashion that introduces abstraction, that somehow ignores or rises above the many particulars which differentiate otherwise similar situations. Of the many ways that organisms achieve this, two are of particular interest here. One involves a simple restatement of assumptions already made; the other, concerning the matter of scale, requires an additional mechanism.

The first mechanism of abstraction is built into the way the recognition of objects is assumed to take place. Only features that are frequently detected when the object is present become part of the object representation. This guarantees substantial information loss; the particulars of any one instance will not become part of the network. (This schematic character of the representation in turn imposes itself on perception. When one identifies an object, one often fails to see or, more precisely, to represent internally aspects of the object that were not contained in the representation.)

A related facet of this "built-in" abstractive tendency is the capacity of the representation to be activated despite missing information. In this way, further generalization occurs; that is, a wider range of circumstances becomes capable of evoking the same internal reaction.

The second mechanism for reducing detail, or increasing abstraction, involves the capacity to shift scale, in other words, to view something as if from a longer perspective.

Certainly, cognitive maps range widely, from that of a neighborhood or even a room at one end to the entire globe at the other. And the capacity to shift scale, to treat a differentiated area as a single region or point on the "map" or to zoom in on a small section of a city, is an essential flexibility in the thought process. A similar problem exists for individual objects. We have concepts for classes of objects and even for classes of classes of objects. The issue in the case of both cognitive maps and representations of objects appears to be a matter of how many levels the concept is removed from sensory experience. A concept of a "street corner" is closer to sensory experience than a concept of a "city." The concept of "dog" is closer to sensory experience than is the concept of "animal."

A possible mechanism to deal with this distinction takes the "distance from sensory experience" metaphor quite literally. Imagine the brain as a series of layers. The first layer would receive feature information from the sensory analyzers. This layer would presumably come to contain a model of the environment closely tied to sensory experience. Since a major source of sensory regularities in the environment is the result of those packages of stimulation known as objects, I have argued that objects should dominate this layer. Sequential information relating objects to each other would also be present in this layer.

The next layer presumably would receive inputs from the prior layer. It thus will come to contain a model of a model of the environment. In this way, it should be possible to develop internal representations of classes of objects and of regions of maps. Higher and higher layers would be less and less closely bound to sensory events. They would also tend to develop later and to be less strongly organized than lower layers. Thus, a philosophy of life, while at the highest and most integrative level, may also tend to be somewhat vague and even to border on the nonexistent on bad days.

Before leaving the concept of layers, one other matter should be mentioned. A system that builds models of models readily evokes the image of something that gets more and more compact as it gets higher, ultimately ending, one must assume, in a point! But the hidden assumption here is that there is a single higher-level organization of the lower-level material. Consider the concept "tree." Although it is recognizable on the basis of many different stimulus patterns and thus can be seen as a point of convergence of many inputs, a "tree" also participates in a variety of higher-level concepts and can thus be seen as spreading out the connection pattern once again. A "tree" participates in such concepts as "living thing," "source of fuel," "landscape amenity," and perhaps "abstract mathematical concept."

Note that these more abstract concepts are also representations. Although the emphasis in the discussion has been on representations of objects, that is, essentially the first-layer representations, the rules for the formation of representations apply at higher layers as well. Higher-layer representations will tend to develop somewhat later, since their input is largely from lower-layer representations rather than from feature analyzers. There is considerable power in this orderly means of generating different levels of abstraction from the same information base.

The existence of layers coupled with the failure of the cognitive system to become increasingly compact as it gets higher yields a structure that is somewhat difficult to classify mathematically. Although at one time the possibility that it might be a semilattice (Kaplan, 1973a, following Alexander, 1965) seemed attractive, this is ruled out by the absence of "least upper bound." A semilattice requires that any two elements have a least upper bound and "that there is a unique *maximal* element which is the upper bound of all elements" (Friedell, 1967, p. 47). In other words, there is again the demand that the system come to a point! On the other hand, the system as a whole is not simply a random network, since this would fail to incorporate the layering concept and the possibility for hierarchies that goes with it. Thus, the structure is tentatively characterized as a "partially ordered network" in the fond hope that the mathematics of such structures will one day be worked out.

The "partially ordered network" designation applies not only to cognitive structure as a whole. At a smaller scale, it is the structure underlying the cognitive map; at a still smaller scale, it is the basis for the representation. The "partial order" at the scale of the cognitive map is the correspondence between spatial properties of the environment and the structure of the network. In other words, at each layer of the system, distance is a meaningful concept. The "partial order" at the scale of the representation has not yet been explored; it presumably relates to the spatial groupings of features in a typical object.

One way to view these various interrelated scales of cognitive structure is to consider the makeup and relationships of the typical representation (see Figure 1):

1. The representation is made up of elements.
2. It receives input from feature analyzers. (This is less the case the higher the layer to which the particular representation belongs.)
3. It is connected with representations in prior layers of cognitive structure. (This is more and more the case the higher the layer to which the particular representation belongs.) It serves as a more inclusive, higher-order concept relative to these lower representations.
4. It is connected with representations at the same layer that it has preceded or followed in frequent sequences. It is these lateral relationships that form the structure of the cognitive map.
5. It is connected with representations in higher layers, with respect to which it may be an instance or example.

Responsible Innovation and the Search Mechanism

The purpose of the final of the three representation-based mechanisms is to deal with the problem of novel circumstances. It is sometimes necessary to act when there is no clear precedent, no prior experience that provides a solution. It must be remembered that choosing any act at random could be perilous indeed. The "responsible" modifier points to the importance of choosing an act that is as appropriate to the setting and to the capacities of the organism as is possible, given the limitations created by the novelty. There is, in fact, a clear parallel to object recognition, where environmental uncertainty requires some astute "filling in." In both cases a tie to the past experience of the organism can serve as a partial compensation for the lack of guidance provided by the environment.

The parallel to recognizing objects is, in fact, far from superficial. To identify an object it is necessary to "find" a suitable representation of that object. To innovate responsibly it is also necessary to "find" something, in this case something that will

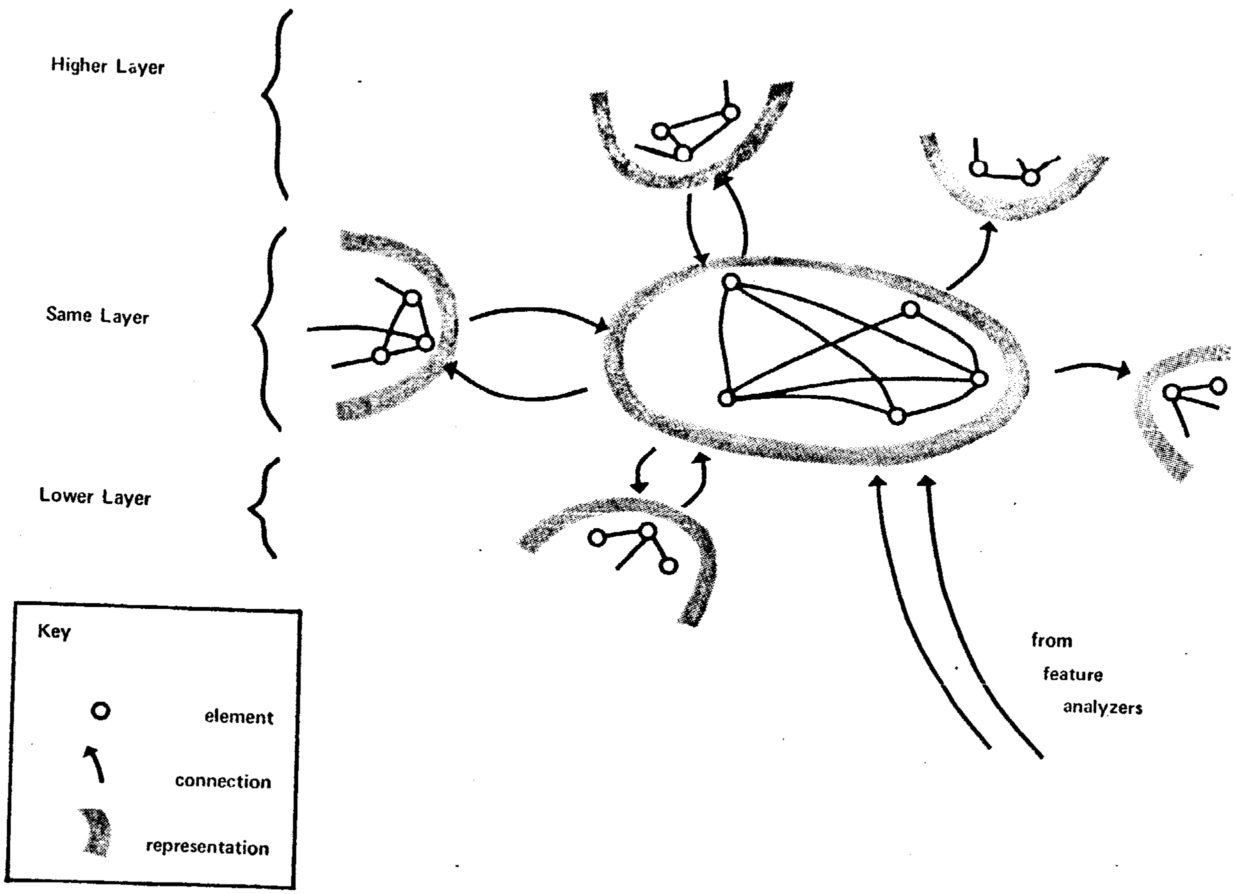

FIGURE 1
Possible connection pattern of a typical representation.

guide subsequent behavior. Before pursuing this parallel further, it is necessary to examine what it is that must be "found" and how this is achieved.

Responsible innovation is usually referred to in the psychological literature as "problem solving." Problem solving can be thought of as figuring out what to do when that is far from obvious. It can also be thought of as a circumstance in which one desires to move from the current state of affairs to a different, preferred state. This, in turn, readily translates into finding a path that takes one from "Start" (the present state) to "Goal" (the desired state). If one can represent both Start and Goal in one's cognitive system, problem solving becomes a process of searching the cognitive map for a path connecting these two representations.

The existence of a problem requires that the link between where one is and where one wants to be is not direct or obvious; if one had gone from this Start to this Goal many times in the past, there would be a clear path and, accordingly, no problem. Given the lack of any direct connection, one must locate a path indirectly, that is, through existing *subgoals*. Consider the problem of getting from Here to There. A solution requires that one think of a subgoal, Elsewhere, such that one knows how to get from Here to

Elsewhere, and from Elsewhere to There. Sometimes a considerable elaboration of subgoals is required to solve a problem. One may start by identifying a major subgoal, and then still have to identify intervening subgoals between the initial subgoal and Start or between the initial subgoal and Goal.

Thus, it becomes clear that responsible innovation involves facilitating one or more representations, just as was the case for object recognition. The innovation is "responsible" because it is not random but based on the past experience of the organism as represented by its cognitive map. The process is nonetheless innovative, because it involves tracing a new path that was never (or rarely) traced before.

An important difference between object recognition and responsible innovation is the extent of reliance on internal influences and the multiplicity of influences involved. In recognizing an object, the major source of influence is the external object from which certain features are extracted. In problem solving, the goal is not generally present in the environment. Thus, the influence of the goal in the search for a path must be generated by an internal representation. Although Start is in principle the stimulating environment itself, as James (1892) has pointed out, it can be seen in many different ways; how it is seen is often crucial in whether a path can be found or not. Finally, there are the circumstances or constraints that so often influence the process. One is Here and wants to get to There and spend very little money doing it. Or the bridge is out and one is fearful of alligators. The examples need not be spatial. When a poet tries to think of a suitable word to finish a line of verse, semantics, rhythm, rhyme scheme, and numerous other factors constrain his choice.[4]

The approach taken here centers on the consequence of a multiplicity of influences in the search for a solution. This approach was stimulated by and is a greatly simplified version of the "broadcast language" developed by Holland (1974) for dealing with a broad class of problems of this kind. For an intuitive feeling for the operation of the broadcast concept, imagine a system made up of a large number of interconnected points. If any point is active, it will send (or broadcast) a message along all its output lines. If we assume that elements are relatively difficult to activate (i.e., have high thresholds), a *convergence* of inputs from many broadcasting points is necessary for any next point to become active. In this way the system carries out a sophisticated search, that is, one in which the chosen representation is influenced by a wide variety of criteria.

The sort of structure we have been considering is ideally suited to a broadcast approach. Each element (i.e., representation) has many connections to other elements; furthermore, these connections vary in strength. Thus, the possibility but not the necessity of convergence is built into the pattern of connections. The search process makes possible subtle and varied problem solution; at the same time, there is no guarantee that a solution will in fact be found for any given problem.

ON MAKING ONE'S WAY: AN APPLICATION AND A PERSPECTIVE

Making one's way, that is, traversing a path in space from Start to Goal, requires first that one can recognize critical loci where choices must be made. Given one is at such a point of choice, there must then be some basis for making decisions. One way is to have a specific rule that applies only to that locus. "Turn right at the stoplight" may be part of a recently received set of instructions or a long-practiced ritual. It matters not; if this is all the information one can bring to bear at that point, one is safe only if one is error free and lives in an unchanging environment. Otherwise, having a network of information, a larger picture, is far more adaptive than a rote solution. Such a solution is, after all, a single sequence and not a cognitive map in any sense that distinguishes it from alternative conceptions of cognitive structure. In the ensuing discussion, the focus will be on the components of a network of information, on the points of choice and direction,[5] as the most general and most useful means of making one's way in a spatial environment.

On Landmarks and Regions

Landmarks play a central role in the identification of both points of choice and direction. The more distinctive a place, the more readily it serves as a locus for decision making and a change of direction. Whereas proximal landmarks are thus vital in identifying points of choice, distant ones, in aiding lookahead, are a great help in maintaining direction. When the only available landmarks are close, decisions tend to be forced back onto rote operations ("a left turn just beyond the church").[6]

Regions, like landmarks, are important to both points of choice and direction. Regions can, in fact, be viewed as "oversized landmarks." They are distinctive places, but of considerably greater extent than is the case for landmarks. In identifying points of choice, a region can function as a low-precision landmark. One might take a turn "where the single-family houses start" or "in the general area of the pine woods." A region can also serve in conjunction with a landmark. One might look for the "clearing in the woods" or the "red-roofed house in the wealthy residential area." A region can play an important role in direction as well. One can proceed "through" or "along" or "away from" a given region. As with landmarks, the more readily a region can be seen from a distance, the more useful it can be in guiding direction.

It appears then that making one's way in a spatial environment depends importantly on landmarks and regions. In the discussion so far, landmarks and regions have been considered quite concrete and specific. They are representations for particular places or particular areas. But, fortunately for the flexibility and efficiency of the organism, not all knowledge is of the particular. Rather, knowledge can be viewed on a continuum ranging from the specific on one end to the completely generic on the other. Most practical cases will fall somewhere in between, but the distinction is a useful one. Generic knowledge provides a basis for comprehending new environments based on prior experience with reasonably similar environments. The existence of this kind of knowledge is helpful for understanding the different behavior of the novice and the experienced individual. Even though two individuals have never been in a particular environment before, the one who is thoroughly familiar with that *class* of environments will be more comfortable and acquire helpful information more rapidly than the novice. In the discussion that follows, an attempt will be made to demonstrate that the advantage held by the experienced individual is based on the facilitation provided by generic knowledge in the crucial task of identifying regions and landmarks.

Representations and Kinds of Landmarks

To analyze landmarks and regions in theoretical terms, it is necessary to return to the concept of representation, the central element of the cognitive map within the proposed theory. The representation is distinctly perceptual in origin; it not only provides a basis for perception, it is itself constructed out of perceptual experience. The representation is, at the same time, the basic cognitive element, since in the thought process it can stand for an object or place even in its absence.

A landmark is a known place, a place for which the individual has a well-formed representation. To understand what places are likely to become landmarks, it is necessary to consider those factors that enhance perceptual experience and perceptual learning. Certainly, the frequency with which one has commerce with a particular portion of the environment should play a role in learning. The distinctiveness of the place should also be an important factor, since the more numerous and the stronger the available features, the more readily the representation can be learned. Where blunt sensory contrast is not present, it may be necessary to fall back on a more refined sensitivity to the character of the surrounding area. These factors all play a role in the categorization of landmarks offered here. Although they can be used in a rough-and-ready sense to sort landmarks into different "kinds" of categories, it should be remembered that these are matters of degree; the typical landmark is not exclusively dependent on any single factor.

The first type of distinctiveness is *visual distinctiveness*, as emphasized by Lynch (1960). Visual forms that tower above the landscape are a good example of this property. Visual distinctiveness is sensory in nature; it depends upon factors that can immediately be discriminated from the surrounding environment.

Many landmarks that appear to be visually distinctive can be seen upon more careful examination to reflect instead a second factor, that of *inferred* *distinctiveness*. This factor depends upon background or regional information; it is thus more cognitive and more experience dependent. An oak tree, for example, can serve as a landmark to the individual who knows that all the other trees in the area are maples. Comparably, a building might stand out for an individual who knows that brown brick is the exception in that part of town. Such inferred distinctiveness can occur at all levels of knowledge. The newcomer to the city may only require half an hour of hapless wandering to discover that the lunch counter that seemed so ordinary is in fact the only one in a 10-block radius. On the other hand, the unusual handling of trim on an elderly building among other elderly buildings may serve as a landmark only for the architect.

Note here the importance of the region as an equivalence class. The inference of distinctiveness is based on being able to treat a spatially unified set of entities as essentially equivalent. Generic knowledge can play a vital role here. When one knows what a pine woods in general contains, it is easier to form a concept about a particular pine woods. Comparably, a concept of the "well kept, small house, older working-class neighborhood" in general allows one to grasp the flavor of a particular such neighborhood with little difficulty. Knowing what stands out is necessarily the complement of knowing what is ordinary or usual.

The third factor in landmark formation has a compensatory relation to the other two. Even if there is nothing particularly distinctive to characterize a point of choice, eventually a concept of that place will develop out of frequency or repetition. Note, however, that the frequency factor does not refer merely to an uncomplicated "number of times experienced." The frequency that matters is the frequency of activation of central processes, or representations, or of "representations-to-be." For the representation of the place in question to achieve this sort of frequency, it is necessary that it serve some function for the individual. Landmarks that are learned primarily on the basis of *functional distinctiveness* will be referred to as *functional landmarks*.

For a place not merely to be passed by with some frequency, but to be frequently thought about, it must have the status of a goal or subgoal. Consider, for example, an individual new to a community and interested in buying groceries. To get to the nearest grocery store, one goes down the road a way and turns right at an intersection (that looks like all the others in the area). Here the intersection is technically a subgoal rather than a goal, but the distinction is of little consequence. Until one finds it, the subgoal can take on all the importance of a goal. Conversely, a goal can serve as an intermediate point of a longer trip, thus becoming a subgoal in that context. In any event, the goal or subgoal status is what converts a behavioral frequency into a cognitive frequency. In route selection, as in other kinds of problem solving, it is necessary to activate the representation of a goal to determine how to reach it. Thus, the more an individual utilizes a particular place, the more commerce, both behavioral and cognitive, he is likely to have with it.

The learning of regions follows essentially the same rules as for landmarks. Here, too, visual distinctiveness has the priority, inferred distinctiveness is next, and the functional basis by itself is slowest and hardest to learn. Identification of a region allows one to call on both specific knowledge (e.g., of the path structure of that area) and generic knowledge (e.g., characteristics of areas of that general type). Regions also, as indicated previously, have a role in the identification of landmarks by providing a background against which one can infer distinctiveness.

Regions, Generic Knowledge, and the Role of Experience: An Introduction to Some Empirical Studies

Regions have a special relationship to generic knowledge. Regional information is necessarily abstractive; it summarizes a range of specific information. Since other regions in other places could have the same properties, regional information is well on its way to being generic. At the same time, both regional and generic information take time to acquire. The "double novice" (both to a particular area and to the class of areas to which it belongs) necessarily labors under a substantial handicap. An environment with visually distinctive landmarks at key points of choice and with a readily comprehensible structure should be manageable even by the double novice. The sort of environment one is more likely to encounter, by contrast, could be formidable indeed.

The illustrative studies in this section deal with very different facets of these basic issues. Rachel Kaplan explores the experience of the double novice in a natural area. Given the redundancy characteristic of nature, visually distinctive landmarks are often lacking and certainly were in the area under study. This throws the individual back on information ordinarily acquired through extended experience. The research program described in Chapter 3 constitutes an effort to explore ways to foreshorten the experience required through the use of simulation.

In Chapter 4, Ann Devlin looks at individuals unfamiliar with the town in question but unusually experienced at adapting to new urban environments. Thus, one would expect generic knowledge to play a substantial role. The town in question was, as is not infrequently the case, deficient in visually distinctive landmarks, thus increasing the likelihood of being able to observe the other types of landmarks in use.

A Perspective

As with the cognitive-map concept itself, the issues raised here are spatial but need not be. The ideas of regional information, generic knowledge, and functional landmarks apply with equal force to an individual attempting to understand the bureaucratic structure that surrounds him and to his efforts to comprehend his spatial world. Indeed, certain issues are perhaps particularly pressing in the nonspatial domain. For example, it has been proposed that a network of points of choice and directions constitutes the necessary information for traversing an environment. The individual with points of choice and some rote operation to be carried out at each has what is in general a poor substitute for a cognitive map. The individual with such information is robbed of confidence, of flexibility, of competence in any larger sense. Yet this is precisely the sort of information that our increasingly expert oriented society makes available.

Ironically, the knowledge explosion has, for many people, led not to an expansion of alternatives but to a decline in the sense of direction. In part, this has been the result of overload (e.g., Milgram, 1970). It is also fostered by increasing specialization, and especially by the territorial tendencies of the experts who man the specialties. Experts make it clear that ordinary humans are incapable of grappling with, and perhaps of even comprehending, their vital areas of knowledge. Thus, people are not to make decisions they were presumably capable of making when life was simpler. When experts, further, disagree with each other, the ultimate in organized paralysis is achieved. The undermining of common sense and intuition has made a great many things harder to do than they were when we knew less.

People remain examples of the most powerful information-processing system the world has ever known. They can, however, be reduced to frustrated incompetence, as our factories, cities, and institutions have effectively demonstrated. But, if permitted, people can also be a vital source of ability. A sense of respect for this organism that was evolved in the context of information handling might be a good start. A feeling of horror for what this adroit organism can do when thwarted, frustrated, or manipulated also would not hurt. The opportunity to share problems, to comprehend difficulties, to face challenges (which are, after all, out there anyway) would tap much of what is best and strongest in human nature. It is hopefully not too late to undertake this modest revolution. At this late date, it constitutes less an opportunity than a necessity.

NOTES

1. Rachel Kaplan's insight, feedback, and guidance contributed importantly to the development of this paper. I would also like to thank Gary T. Moore and Bruce A. Whitehead for their thoughtful comments. Work on this paper was sponsored, in part, by the Institute for Environmental Quality, University of Michigan.
2. "Feature" and "cue" are convenient terms to describe the results of sensory analysis, but they may be slightly misleading. As Gibson (1966) has long emphasized, much sensory information is

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