

# Spatial Behavior and Cognitive Mapping: Implications for Traveler Information Systems

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## ABSTRACT

This paper reviews research on human spatial behavior and discusses implications of this work for the design and use of Advanced Traveler Information Systems (ATIS). Models of spatial information processing and structure are used as frameworks for the discussion. Particular attention is paid to the structure of cognitive maps and how these structures affect and are affected by spatial behavior and spatial knowledge. Additionally, a comprehensive effort is made to identify significant gaps in current knowledge and to suggest topics for future research. The primary findings are that individuals vary greatly in their spatial abilities and preferences, and that different spatial tasks are aided most by task-specific styles of information provision. Furthermore, an attempt is made to match specific travel information needs with particular types of information provision. In sum, the findings suggest an ATIS design that allows individuals to customize their systems based on their individual needs, abilities, and preferences.

## KEYWORDS

Spatial Behavior  
Advanced Traveler Information Systems (ATIS)  
Cognitive Map  
Mapping  
Intelligent Vehicle Highway Systems (IVHS)  
Information Processing

## **Spatial Behavior and Cognitive Mapping: Implications for Traveler Information Systems**

Where am I? How do I get **there** from **here**? Is the bank near the park? These are the types of spatial problems that we face routinely, and how we respond to them depends largely on our spatial knowledge and spatial behavior. Although we probably take spatial abilities for granted, without them we would be unable to answer these simple questions and would find it difficult to maintain our bearings. Indeed, spatial behavior occupies a central role in daily life.

From time to time nearly all of us become lost or disoriented. At other times, we may have some vague idea of where we are--some sights look familiar--but we would be hard pressed to locate specific landmarks or pinpoint our location on a map. In our own neighborhoods, on the other hand, we may have a detailed understanding of the location of almost every house, shop, and intersection. Thus, the sense of knowing where one is ranges from complete bewilderment to a complex understanding of relative positions, route names, the locations of particular landmarks, and how to travel from one place to another. Furthermore, meeting the demands of everyday life forces us to venture out from our homes and into the surrounding community, where we must use our spatial knowledge to move about in a reasonably sure fashion. This moving about constitutes one aspect of our spatial behavior--how we proceed through space, regardless of our mode of travel; maintaining our bearings and the acquisition and mental manipulation of spatial information are other important aspects.

Maps are the traditional supplement to our internal spatial knowledge and often serve to assist spatial behavior. Other conventional means of supplementing spatial knowledge include obtaining verbal or written directions, usually from a person who is more familiar with

the geographical area. Recent advances in electronics and telecommunications technologies, however, have made possible new approaches for the provision of spatial information to travelers. Many of these approaches are in the process of being realized within Advanced Traveler Information Systems (ATIS), which are designed to provide travelers with timely and accurate information about relevant travel conditions. For example, cars may be equipped with in-vehicle displays that respond to roadside transmitters placed at key points along the freeway for the purpose of providing motorists with up-to-the-minute traffic data. Upon receiving this information, some drivers may alter their planned route. In general, how travelers will use ATIS technologies will depend, in part, on users' spatial behavior and spatial knowledge, and, in turn, the use of ATIS will affect users' spatial knowledge and spatial behavior. Both of these outcomes have implications for those who are designing and deploying ATIS.

Before tackling the important and timely questions surrounding the interaction of spatial knowledge and spatial behavior with ATIS, a review of past work--and much has been done--in the areas of spatial knowledge and spatial behavior is essential. The topics to be discussed in this paper are (1) cognitive maps and the structure of spatial knowledge; (2) the acquisition of spatial knowledge, including map learning and a discussion of the processing of spatial information; (3) map reading; (4) the implications of past research on spatial behavior for ATIS; and (5) the potential influence of ATIS on spatial behavior and knowledge. A thorough understanding of human spatial information processing is crucial for the effective design of spatial decision-support systems. This paper reviews the theoretical and empirical literature regarding human spatial knowledge and spatial behavior with the intent of enlightening future efforts to design such systems.

## **The Information Processing Model of Spatial Cognition**

Of course, humans receive and process many types of information, and spatial information is only one of these types. As a result, it is important to discuss briefly a model of human information processing so that spatial behavior may be viewed within a larger context. Several such models exist, and these models share many characteristics. To discuss all of these models, however, is beyond the scope of this paper. Instead, this section will present a simplified version of the model postulated by Wickens (1984), who developed a composite model containing elements drawn from several other investigators. Those desiring a more comprehensive study of human information processing should consult the substantial literature of this field.

In the Wickens model, the sensory systems (e.g., sight and hearing) serve to briefly prolong a stimulus (e.g., the view through a car's windshield) through the use of short-term sensory store. Higher levels of the nervous system then begin to process the information. First, the stimulus is perceived and assigned to a perceptual category (e.g., an intersection). This perceptual decision requires the accessing of long-term memory to aid the decision-making process, by, for example, comparing the current stimulus with known perceptual categories. Once recognition has occurred, the perceiver must decide how to react to the stimulus (e.g., turn left or continue straight). Finally, the perceiver acts on the decision (e.g., by turning left), requiring the completion of a complex sequence of muscle commands. The action, in turn, leads to more stimuli (the sight along a different street), and the process begins anew. The whole process, therefore, can be viewed as a feedback loop. It is really more than that, however, because the flow of information is not as linear as has been explained here. Expectations, for example, may lead one to categorize a stimulus differently than it may have been categorized in the absence of these expectations. For example, if our destination is a business that we know displays a yellow, neon sign, then we may mistake another yellow, neon

sign near the business as our intended destination, even though the wording on the two signs is different.

Different ATIS may affect a driver's spatial information processing in different ways. First, ATIS may prolong the amount of time that a piece of spatial information remains available for a driver to sense and store the information, thus making that information more salient. ATIS may provide a ready categorization and/or decision-choice set to which a driver may respond. Using the yellow, neon sign example, ATIS may be able to provide less ambiguous information from which a driver may make a decision.

By providing lasting, unambiguous, and prescreened (hopefully relevant) information, ATIS not only may improve reaction times to the information, but also may free attentional resources that then will be available for the performance of other tasks. On the other hand, if ATIS provide highly complex, ambiguous, or irrelevant information, then such systems may impair decision making and significantly tax the attentional resources necessary for route decision making and, perhaps, safe driving.

Though a spatial example has been provided, Wickens's model of human information processing is intended to cover all types of information, and the example easily could be altered to explain one's recognition of a popular song. The processing of spatial information is in many ways no different than the processing of other forms of information. Thus, though it is possible to examine the processing of spatial information separate from other forms of information processing--and this paper will do so--it is important to remember that the central nervous system processes many types of information simultaneously and that spatial information is just one of these.



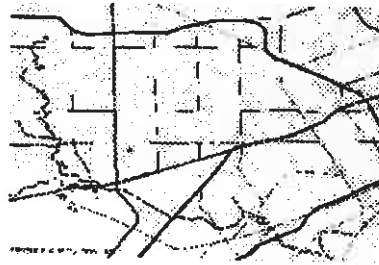
## Cognitive Maps

Prior to departing for vacation or a business meeting in some unfamiliar locale, many people consult a road map for help in choosing highways and roads on which to travel along the way. In our own neighborhoods, however, we seldom, if ever, consult a map; from our experience, we have learned the spatial layout of the area. It might be said that we have created a map of our own neighborhood in our heads. This common-sense, map-in-the-head description of spatial knowledge often is referred to as a **cognitive map**, which Kuipers (1978) has defined as "the physically unobservable structure of information that represents spatial knowledge." Stressing its pictorial qualities, another team of researchers defined a cognitive map as "a mental representation of our milieu" (Garling, Book, and Lindberg 1984).

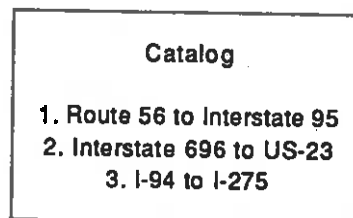
Tolman (1948), who coined the phrase "cognitive map," argued that learning consists of building cognitive maps in the nervous system. These maps, he observed through experiments with rats in a maze, vary in form from individual to individual, with some appearing to be strip-like (i.e., lacking detail and breadth) and others taking on a broader and more comprehensive form. Kuipers (1978) has extended Tolman's notion that not all cognitive maps are equal, by defining three possible components of a cognitive map: (1) a **map in the head**, actually many, inconsistent, loosely related maps; (2) a **network of streets and intersections**, though the exact shapes and lengths of links may be missing or distorted; and (3) a **catalog of routes**, each "a procedure for getting from one place to another" (see figure 1). These procedures tend to be independent (e.g., one may not be aware of overlap between routes) and may resemble an ordered sequence of actions (e.g., turn left on Main, then go two blocks and turn right, etc.) or they may be triggered by environmental cues. All three of these components are not present in all people for all locations, however, implying that there are individual differences in cognitive-map form.



**(1) A map in the head**



**(2) A network of streets and intersections**



**(3) A catalog of routes**

**Kuipers's conception of the  
form of a cognitive map**

**Figure 1**

Levine, Jankovic, and Palij (1982) have proposed two other notable characteristics of cognitive maps understood as maps in the head. The first of these is **equal availability** ("equiavailability," in their terms), meaning that all of the information contained in a cognitive map is, as with a physical map, equally accessible. The second is **specific orientation**, meaning that the map is in line with a particular visual perspective. These two characteristics are important to the study of cognitive maps because they allow for empirically testable hypotheses regarding the structure and nature of cognitive maps, including tests of the validity of the cognitive-mapping paradigm. These two characteristics, therefore, will figure prominently in the empirical research reviewed later in this paper.

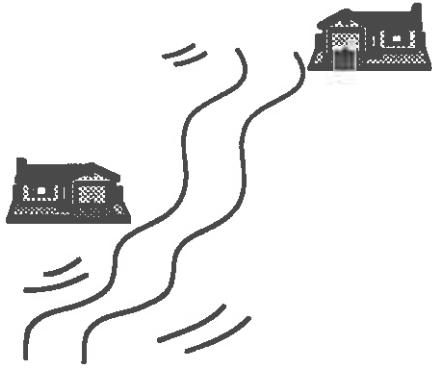
Just as Tolman described learning as the creation of cognitive maps, Kuipers (1978) describes problem solving as the process of consulting a cognitive map to extract answers to specific questions. In essence, the past is used in the present to solve the future (Downs and Stea 1977). A cognitive map, therefore, supports at least two functions: (1) mapping—building the cognitive map from observations—and (2) navigating—"creating and successfully executing a plan to travel from one place to another" (Kuipers and Levitt 1988). Therefore, like a cartographic map, "a cognitive map mediates a number of important spatial behaviors" (Hardwick, Woolridge, and Rinalducci 1983). In other words, a cognitive map serves as a personalized, internal atlas that aids in the performance of spatial tasks.

For the purposes of this paper, then, cognitive mapping may refer to the acquisition of spatial information or to the use of this information to solve spatial problems. Attention shall not be focused here, however, on the application of the terms "cognitive map" and "cognitive mapping" to studies lying beyond the scope of spatial knowledge and spatial behavior, though this practice is relatively common (e.g., Axelrod 1976).

### *The Structure of Spatial Knowledge within Cognitive Maps*

Theories on the structure of spatial knowledge seek to explain how people categorize and interpret entities in the physical environment and how they interrelate these entities spatially. The concepts addressed in these theories include the relative and absolute positions of physical entities and the relative and absolute orientations (e.g., north) of entities. These theories have been developed within a number of disciplines (e.g., urban planning, geography, and cognitive psychology), and not all of the theories address the same concepts. Furthermore, these theories continue to be refined and adjusted as further empirical evidence becomes available.

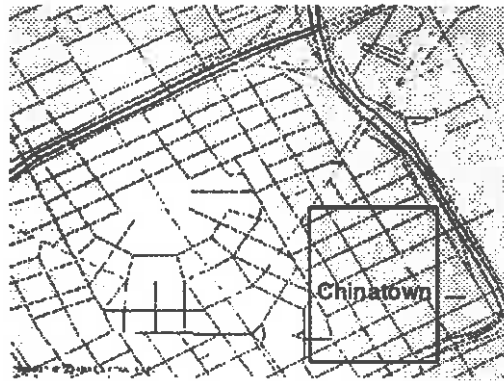
In an early effort to determine how spatial knowledge is structured, Lynch (1960) asked residents of Boston, Los Angeles, and Jersey City to sketch maps of their city and to complete a lengthy interview in which he asked respondents to describe and locate various places in their city. In addition, trained observers were sent into the field and instructed to create detailed maps of the cities' features. By analyzing the similarities and differences between the maps created by the trained observers and the sketch maps and other data provided by the respondents, Lynch postulated the existence of five basic building blocks of people's images of cities: paths, nodes, edges, districts, and landmarks. In Lynch's usage, **paths** are channels along which one may move (e.g., a street); **edges** are linear elements that are not paths (e.g., a row of buildings); **districts** are two-dimensional areas with a distinct character that one can envision entering (e.g., San Francisco's Chinatown); **nodes** are the focal points of a trip (e.g., a major intersection); and **landmarks** are physical objects (e.g., a building or a statue). (See figure 2.) While Lynch does not use the phrase "cognitive map" explicitly, clearly his typology represents an attempt to explain the organization of spatial knowledge, at least as it pertains to the urban environment.



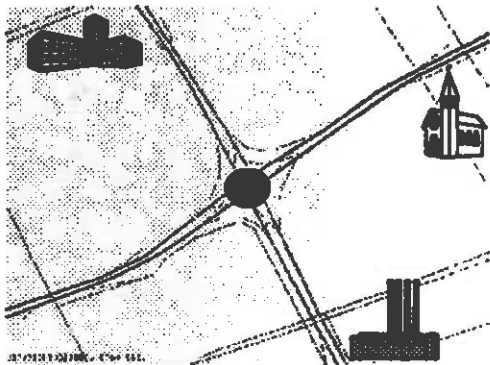
A path



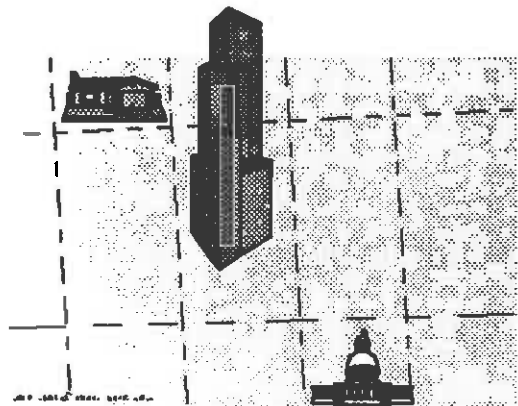
An edge



A district



A node



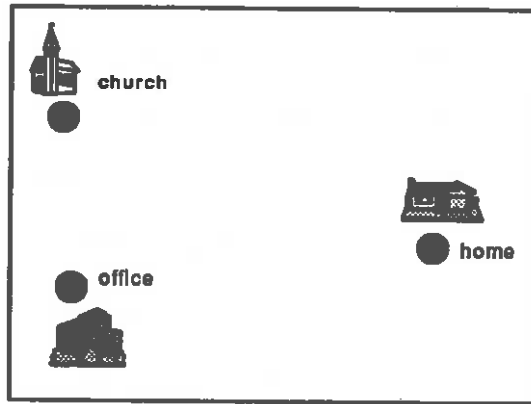
A landmark

Lynch's categorization of spatial knowledge

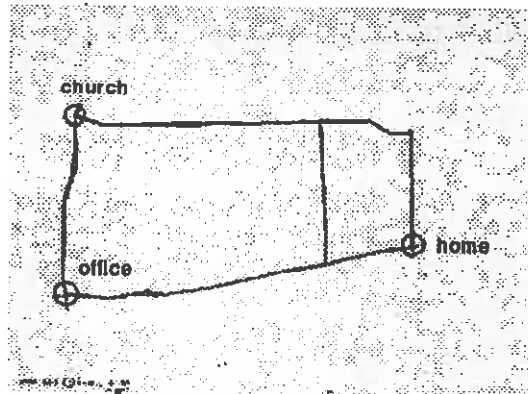
Figure 2

Since Lynch, other researchers have refined his categorization of distinct levels of spatial knowledge. Garling and his colleagues (1984), for example, found Lynch's taxonomy to be too narrow and instead discuss three broader components of cognitive maps: (1) places, the basic unit; (2) spatial relations between places; and (3) travel plans. By spatial relations between places, they refer to a degree of spatial knowledge characterized by spatial inclusion or nesting (e.g., knowing that a particular shop is located within a particular building, and the building within a particular district, and so on), metric relations (i.e., the distances between places), and proximal relations (e.g., knowing that Chicago's Union Station is near the Sears Tower). Clearly, this categorization overlaps with Kuipers's (1978) outline of the form of cognitive maps: maps, networks, and routes.

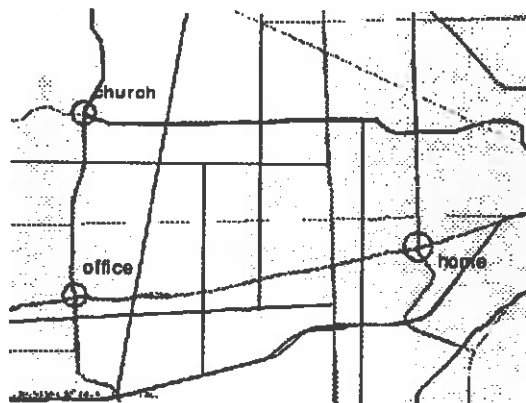
At the current time, many researchers appear to have settled on a three-level model of spatial knowledge (see figure 3). In the terminology of Stern and Leisser (1988), this model consists of landmark-, route-, and survey-level knowledge. **Landmark-level** knowledge refers to knowing the locations of particular places; **route-level** knowledge is marked by linking some landmarks; and **survey-level** knowledge consists of integrating route- and landmark-level knowledge beyond a simple itinerary. If, for example, one knows that the Art Institute of Chicago is located on Michigan Avenue near its intersection with Adams, then one has landmark-level knowledge; knowing how to get to the Art Institute from Water Tower Place constitutes route-level knowledge, and, finally, knowing how to travel from any point in Chicago to any other signifies that one has survey-level knowledge of the city.



(1) Landmark-level knowledge (or declarative)



(2) Route-level knowledge (or procedural)



(3) Survey-level knowledge (or configurational)

The three-level model of the structure of spatial knowledge

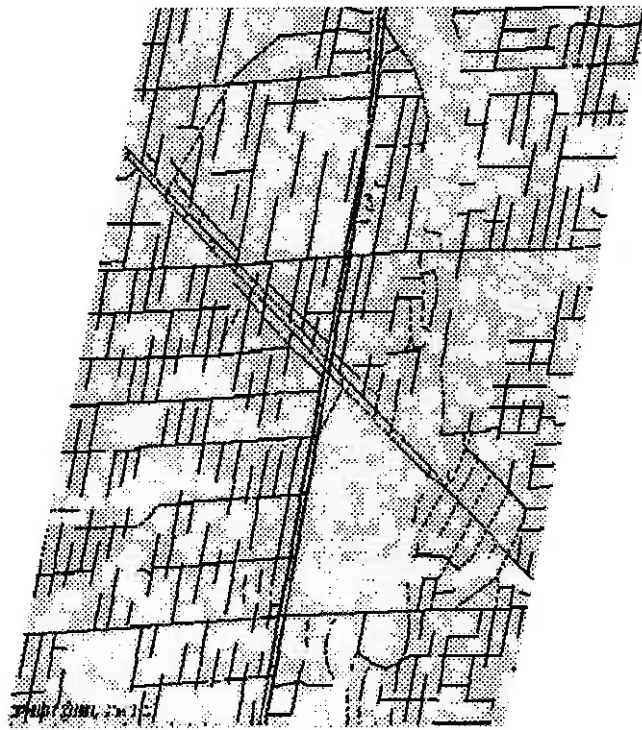
Figure 3

While proposing similar distinctions, other researchers have used different terminology for the three proposed levels. Golledge and Stimson (1987) refer to declarative, procedural, and configurational knowledge. Additionally, they have expanded the concept of declarative (or landmark) knowledge to include spatial attitudes. Indeed, they define declarative knowledge as knowledge about objects and places, including both attributes (such as shape) and attitudes (such as knowing a place's function). Together, these attributes and attitudes allow a place to be both recognized and characterized. Thus, one may recognize the local grocery store and know that it is a good place in which to buy food. Procedural knowledge they define as being able to find one's way in some environment, and configurational knowledge they define as integrated spatial knowledge; these last two are almost identical to Stern and Leisser's description of route-level and survey-level knowledge.

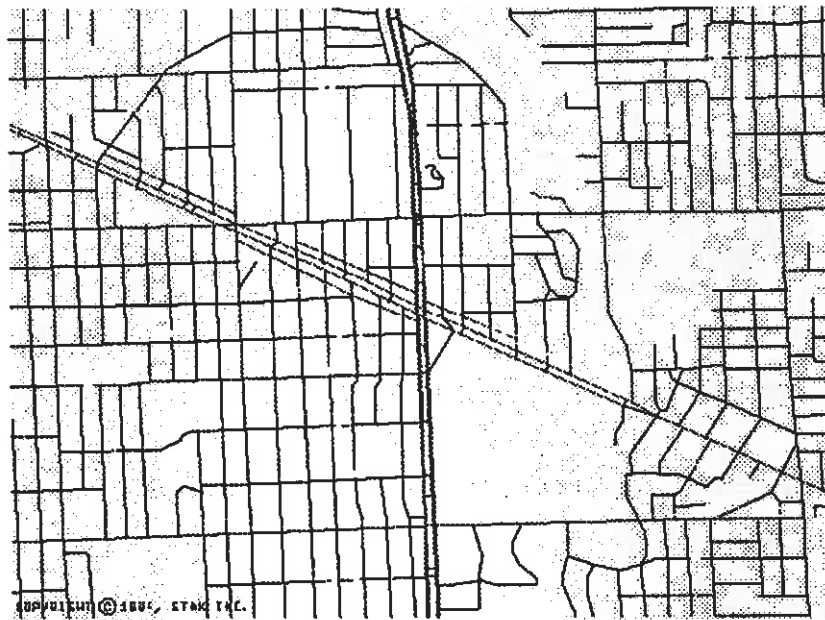
Not all researchers, however, agree upon the validity of a three-tiered categorization of the structure of spatial knowledge. In particular, some have observed that it is possible for a person to possess correct topological knowledge about an area, but to lack knowledge of the correct distances and angles between points. For this reason, some researchers have conceptualized the survey (or configurational) level of knowledge as consisting of two distinct entities. Freundschuh (1989) makes a theoretical distinction between network knowledge and map-like knowledge. **Network knowledge** he defines as a topologically correct, two-dimensional representation, but with highly distorted angles and distances—like a rubbery paper map that can be pulled and stretched in a multitude of ways. **Map-like knowledge**, on the other hand, is "a geometrically correct two-dimensional representation of space" (see figure 4). Kuipers and Levitt (1988) stressed a similar theme in differentiating between topological and metric descriptions of large-scale space. A topological description they define as being based on fixed entities (landmarks or routes) properly linked in terms of connectivity and order; in a metric description, however, fixed entities are linked by correct



knowledge of the relative distance and angle between points and the absolute distance and angle of places measured from a fixed point. This structure, by accounting for the differences between topological and metric knowledge, better matches actual knowledge than does the three-level approach and would appear to be the most valid base for future research efforts, though it should not be taken for a literal truth.



Network knowledge



Map-like knowledge

Figure 4

Experiments conducted by Gale, et al. (1990) support the distinction between declarative (landmark) and procedural knowledge. In this study of children's wayfinding in an unfamiliar environment, one group of children learned a route by following it for five practice runs, while another group learned the route by watching a videotape of the route for five runs. Statistically, the groups showed no difference in the recognition and recall of specific places (landmark-level knowledge), but the group that learned via actual experience proved superior in following the route on the sixth run, when all subjects were instructed to traverse the route in the field. Because similar magnitudes of landmark-level knowledge did *not* lead to equal route-following performance, the authors concluded that landmark- and procedural-level knowledge are separate entities. Another possible explanation is that the video failed to capture all important panoramic and three-dimensional navigational cues, even though the researchers attempted to make the video view match what would be seen by a pedestrian traversing the chosen routes.

Garling, Book, and Ergezen (1982) found evidence that the relative locations of places are learned *before* paths are learned by comparing subjects who had different lengths of residence (ranging from 2 to 14 months) in the experimental area. The experiment consisted of presenting subjects with local landmarks and paths on a television screen and then testing their spatial knowledge of the local area. The researchers found that length of residence was *not* an important determinant of subjects' ability to learn the relative locations of local landmarks. All subjects could identify the relative locations of landmarks, even those with only two months of local residence. On the other hand, length of residence was an important determinant of route-level knowledge, which increased and became more accurate with longer residence. In addition, none of the subjects completely remembered the tested system of paths. To explain this result, the authors noted the relatively short time that all subjects had been local residents (i.e., no more than 14 months).

Examining these issues from a slightly different perspective, Golledge (1975, 1978) has hypothesized that spatial knowledge is organized hierarchically about nodes of high relative importance to the individual; that is, people's cognitive maps are richer and more complex around points with which they are quite familiar, such as home and work. Between these points, the extent of spatial knowledge drops, leaving a skeleton upon which new knowledge can be added. According to this theory, all types of spatial knowledge (e.g., landmark and procedural) are organized in this manner. In a wayfinding study using one subject (a ten-year-old male), Golledge (1985) found some support for this hypothesis in that the subject possessed the most spatial knowledge about the origin and destination points, followed by key choice points along the way. While generalizations should not be made from such a limited study, the results do point to a research topic deserving further attention.

The possible structure of spatial knowledge within cognitive maps has important implications for ATIS development. Specifically, ATIS products should make optimal use of existing spatial knowledge structures. That is, ATIS products should provide information that people are less accurate at gathering and recalling (e.g., detailed paths, angles, and distances). In order to assist people's development of useful cognitive map structures, ATIS products also should provide information that people seem to encode quickly and accurately (e.g., landmark-level knowledge and possibly broad, but simplified, network-level information). By combining these information structures, ATIS can serve not only to guide drivers accurately using known cognitive structures, but also to facilitate learning and understanding of the spatial environment.

#### *The Structure of Spatial Knowledge: Alternative Theories*

The cognitive-mapping paradigm has not been immune to challenges, and alternatives have been proposed. In the 1940s and 1950s, Tolman's cognitive-mapping paradigm

competed with the theories of behavioral psychology (Sera and Blaut 1973). Hull (1952), for example, argued that learning was best described as the result of a sequence of discrete stimulus-response events, rather than as a building of cognitive maps in the nervous system. For Hull, spatial knowledge is developed through a complex series of stimulus-response events causing compound trial-and-error learning; linkage between these events occurs with the aid of either terminal (i.e., occurring once, at the end of the sequence) or serial (i.e., occurring throughout the trip) reinforcement. The reward of reaching the final destination (e.g., food, if one is traveling to the grocery store) serves as terminal reinforcement, while the assurance that results from recognizing intermediate nodes can be viewed as one example of serial reinforcement.

While few would argue that the behavioral paradigm provides a fully satisfactory theoretical foundation for ATIS development or prediction of ATIS's utility, it does provide a valuable (albeit limited) set of predictions. Perhaps the most valuable component of behavioral theory is its insights into the effects of punishment and reinforcement on both learning and subsequent behavior. This is of interest because ATIS products have the potential for providing drivers with both valuable stimuli and reinforcers.

To date, most attention has focused on terminal reinforcers. That is, the ATIS gets the driver to the desired destination, and arriving at the correct destination is the terminal reinforcer. If the ATIS product accomplishes its role, then the continued use of the product is reinforced, and the driver will come to value and place confidence in the product. The importance of serial reinforcers, however, often has been overlooked. Many ATIS products function to divert drivers from known, but heavily congested or otherwise troubled, routes to less troublesome, but less well-known, routes. In this situation, drivers may not recognize that the ATIS product provided a significant benefit, even though they reached their destination.

The ATIS-suggested route, for example, may have had numerous turns or secondary roads with low speed limits. Each of these may be perceived by the driver as a serial punishment for taking the ATIS route, thus diminishing the perceived value of the product and decreasing the likelihood of using it in the future.

If, however, the product provides counterbalancing serial reinforcers along the way, then the value of the ATIS product may not be diminished and may be enhanced. For example, the ATIS may provide information on the relative time savings for the alternative compared to the original route, or regular time-distance updates so that drivers can perceive for themselves that they are approaching their desired destination. The central point is that those designing and evaluating ATIS products should be aware that people respond to both terminal and serial reinforcements and punishments, and both can have a powerful influence on behavior and affective perceptions of the system.

Neither the cognitive mappers nor the behavioral theorists has been able to provide definitive evidence for the overall superiority of their paradigm. At the present time, the cognitive-mapping paradigm receives the majority of attention in studies of spatial behavior and thus will serve as the basis of the current review. This should not, however, lead one to believe that other paradigms do not exist, and these other approaches can be useful in understanding and predicting the utility of ATIS.

In another alternative approach, Neisser (1976) has raised an important issue in the cognitive-mapping field by arguing for the use of the phrase "orienting schema" in place of "cognitive map." Neisser's intention is to emphasize the "active, information-seeking structure" of cognitive maps. In making his argument, Neisser stresses that spatial imagery is just one part of the function of orienting schemata, with actual wayfinding another part. In cognitive maps

viewed as orienting schemata, two-dimensional survey knowledge is lost, and all spatial knowledge is structured similarly to procedural knowledge. This implies that the characteristic of equal availability should not hold (because of the lack of a map in the head), and objects positioned in front of a person should be easier to locate than objects to the rear (Sholl 1987).

Gell (1985) has argued that even if some spatial knowledge is structured much like an artefactual map, this structure cannot be responsible for most wayfinding behavior in a familiar environment, because familiarity with an area is judged by the lack of a need for navigational aids when traveling within that area. In other words, Gell argues that if an artefactual map is not consulted to find a familiar place (e.g., the local grocery store), then neither is a mental map. As an alternative paradigm, Gell presents the concept of "mapless practical mastery," which "consists of possessing complete knowledge of what the environment looks like from all practically-available points of view...." Within this conceptualization, wayfinding consists of matching views with stored images: one moves such as to encounter a series of views that match the stored sequence of images leading from A to B. In many ways, Gell's theory appears to be a refinement of Neisser's notion of an orienting schema. In the absence of supportive research, however, it is difficult to judge the usefulness and validity of this theory. Particularly troublesome to Gell's theory is the possibility that no artefactual map of a familiar area is needed, precisely because an accurate and complete mental map is available.

#### *The Utility of the Map-in-the-Head Metaphor*

Given ongoing disagreement concerning the validity and proper formulation of the cognitive-mapping paradigm, it is imperative to examine the general utility of the map-in-the-head metaphor. Taken to its fullest extent, this metaphor implies that "spatial knowledge, as stored in the cognitive map, is isomorphic to the information stored in a geographical map" (Kuipers 1982); that is, a cognitive map is a mental duplicate of a geographic map. This strong

version of the cognitive-mapping paradigm, Kuipers argues, is inadequate. To illustrate his point, Kuipers invites one to imagine a pair of points for which the imaginer has no conception of their relative position. If the cognitive map were isomorphic to a geographic map, this exercise should not be possible, as the relative locations of any two points on the map should be readily available, as has been suggested by Levine, et al.'s theory of equal availability.

Kuipers is not, however, among those who advocate the abandonment of the cognitive map as an area of research. Instead, he argues that the map-in-the-head metaphor is useful for explaining some observed spatial behavior. Gell (1985), too, leaves open the possibility that some spatial knowledge may closely resemble an artefactual map, and that this structure is called upon when one wishes to compare route options or explore a new path within a known area. If cognitive maps are viewed as a useful metaphor or research tool, then the issue of their exact structure becomes less relevant. The important issue then becomes how cognitive maps, as a theoretical construct, can further our understanding of the processing of spatial information. Throughout the remainder of this paper, the phrase cognitive map will be used not in the literal, map-in-the-head form, but in terms of a metaphor or research tool, unless otherwise noted.

Interestingly, neurological research investigating the cognitive maps of rats has found some evidence of a memory-processing structure in the brain (located within the hippocampus) that stores spatial information (e.g., Madhavan, et al. 1991) in a manner so as to recover a two-dimensional form, like that of a paper map. While the exact form of this structure remains unclear, it appears possible that medical science may uncover the existence of an actual map in the head, at least in rats. Clearly, the last word on the map-in-the-head paradigm has yet to be written, and much more research will be needed to resolve definitively outstanding questions in this area.



## **The Acquisition of Spatial Knowledge**

Having examined several theories for explaining how spatial knowledge is structured and stored, the next order of business is to examine how spatial knowledge is learned. The key questions in this line of inquiry are: how is the cognitive map formed, and how, if at all, does the process of cognitive-map formation affect the structure and form of the spatial knowledge learned? The answers to these questions should provide useful insights into people's spatial behavior and another perspective on how spatial knowledge is structured and stored.

To a large extent, the literature on map learning and the development of cognitive maps parallels the literature concerned with the structure of cognitive maps, and the two certainly are interrelated. For example, Piaget and Inhelder (1967) found that children successively passed through three developmental stages of spatial understanding, and these stages closely resemble the levels of cognitive knowledge later developed by other researchers. The youngest children located objects in a model based on the location of one feature only and, hence, were confused by rotations of the model. The next oldest group employed an egocentric orientation scheme, but also used more than one feature at a time, which improved their performance. In an egocentric orientation scheme, external objects are located in relation to one's body, ignoring rotation effects; thus, an object originally located in front of the child to the left would be placed there again, even if the model had rotated 90 degrees in the interim. Unlike the younger children, the oldest group was able to account fully for rotation of the model and, therefore, was able to place objects in the model accurately under all conditions.

Moore (1976) also found three developmental levels of spatial reference systems in children. The first of these he labeled the "undifferentiated egocentric reference system," which consists only of elements having great personal significance to the subject. The second

level he termed the "differentiated and partially coordinated reference system," in which the environment is organized into clusters, but the clusters are not related to one another. The third level, "operationally coordinated and hierarchically integrated," is an overall coordinated reference system and includes knowledge of left-right and before-behind relationships, different viewpoints, and relative distances.

Acredolo (1976) observed similar results in her research, finding that three-year olds oriented themselves in large-scale models based on an egocentric criterion, disregarding changes in the positioning of the model, but that ten-year olds used a coordinated reference system based on the room in which the study was conducted to orient themselves correctly, regardless of changes in the model's position. Further work (Acredolo 1977) showed that providing more obvious landmarks in the room itself aided younger children in developing a coordinated reference system. This result supports Tolman's (1948) theory that an inadequate array of environmental cues is one cause of the creation of poor cognitive maps. Young children, it would appear, require more environmental cues than do adults or older children to build rich cognitive maps.

This brief review of the development of spatial abilities in children is not intended to suggest a one-to-one correspondence to adult functions. Indeed, there are many differences between ages, as pointed out in the developmental literature. Nonetheless, it is instructive to review some of this literature to provide a broader context for understanding some of the complex issues involved in the acquisition of spatial knowledge. Having done so, the focus can shift to the acquisition of spatial knowledge in adults, who, obviously enough, will be the primary users of ATIS.

When one is required to build a new cognitive map (due to a job relocation, for example), or when one's cognitive map expands to include newly discovered territory, Griffin (1973) has argued, elements of the previous cognitive map or orienting schema remain intact to "haunt" the new, as if one were attempting to draw a new picture on a blackboard before the old picture was erased fully. Depending on the circumstances, this residual information may prove to be either beneficial or harmful. If, for example, one moved from Chicago to Milwaukee and continued to orient oneself thinking that Lake Michigan always lies to the east, then one should have an easy time adjusting to the new environment. On the other hand, if one moves from Chicago to Muskegon, Michigan (where Lake Michigan lies to the west) and continues to orient oneself based on the lake to the east, then one will be lost a great deal of the time. Empirical research is needed to measure the extent and consequences of this residual cognitive mapping, but Griffin nonetheless suggests a plausible and testable theory concerning how a new cognitive map develops to replace or update an obsolete version.

Clearly, the act of wayfinding informs and influences the formation of cognitive maps, even if for no other reason than that the environment often is experienced primarily through travel. Maps, too, are a source of spatial knowledge, and still other means of acquiring spatial knowledge exist. Given this situation, an interesting area of ATIS, as well as general, research is to study how different means of spatial-knowledge acquisition lead to differences in resulting cognitive maps. This line of research may be posed as a question of determining what actions lead to the production of relatively better cognitive maps and more effective and efficient ATIS products.

In one attempt to measure how different means of spatial-knowledge acquisition lead to the creation of qualitatively different cognitive maps, Beck and Wood (1976) studied sketch maps produced by foreign visitors to Montreal and Europe and found that how subjects chose

to travel around their unfamiliar setting had a significant effect on the accuracy of their sketch maps. In general, those who drove cars produced better maps than those who rode public transit, who, in turn, produced better maps than those who traveled on foot. These results suggest that travel mode has an effect on the spatial information that one learns. Basically, those who traveled by different modes had different experiences of the city. The explanation for this relationship would seem to rest on two points: (a) the larger geographic area that can be explored via faster modes of travel (Hagerstrand 1974) and (b) the need for drivers, because of the interactive nature of their chosen mode of travel, to better understand their environment and to pay it closer attention. This latter point is particularly salient in comparing drivers to transit riders, who are engaged in a relatively passive mode of travel.

Another factor that appears to have an influence on cognitive-mapping performance is how spatial information is encountered. In this area, much research has been conducted, particularly with regards to differences between learning from a map and learning from navigational experience. Thorndyke and Hayes-Roth (1982), for example, found that subjects who learned an office floor plan by navigating through it were more accurate at judging the orientation of particular locations than were subjects who learned the floor plan by studying a map. Beyond differences of quality between different types of spatial learning, this study also indicates that different types of spatial learning lead to different types of spatial knowledge. Specifically, navigation subjects proved better at estimating route distances than at estimating Euclidean distances, and map-learning subjects achieved the opposite result: they were better at estimating Euclidean distances than at estimating route distances. Both types of subjects, however, performed better on actual, as opposed to simulated, orientation tasks.

In an effort to better understand differences in cognitive-mapping outcomes based on type of learning experience, Presson and Hazelrigg (1984) hypothesized a distinction between

primary and secondary spatial activity. According to their categorization, primary spatial activity consists of direct interaction with the physical environment (e.g., navigational experience). Secondary spatial activity consists of indirect experience of the environment (e.g., viewing a map). As can be inferred from these definitions, primary spatial activity provides information that can be acted upon immediately, whereas secondary spatial activity provides information, usually in the form of abstract symbols, that can be acted upon only after some time has passed and the symbology has been translated.

In order to test their hypothesis, Presson and Hazelrigg exposed subjects to paths by three different means: viewing maps of the paths, walking the paths while blindfolded, and viewing the paths from a single point without traveling them. They found that subjects who learned paths from a map suffered significant alignment effects when attempting to judge the relative orientations of points along the route; that is, when oriented opposite to the alignment of the observed map, these subjects performed worse at orientation tasks (e.g., pointing toward a target along the path). Subjects in the walking and looking groups, however, experienced no significant alignment effects. Levine (1982), in his study of you-are-here maps, also found alignment effects, and one-third of his subjects walked away from the target when the map was contralined.

These findings not only provide evidence in support of the hypothesized distinction between primary and secondary spatial learning, but they also suggest that primary spatial learning may entail both visual and kinesthetic interaction with the learned environment. As one potential explanation of why map-learning produces an alignment effect, whereas navigational learning does not, Presson and Hazelrigg note that many perspectives are available during navigation, but a map provides only one perspective. This explanation does not, however, explain why visual examination of a route from a single point of view—a view

aligned with that experienced by the map learners—also fails to produce an alignment effect. Further research is needed to develop an adequate explanation of this latter effect.

In another attempt to measure the differences between primary and secondary spatial learning, Sholl (1987) tested the ability of college students in the Boston area to point toward both local and distant places. Some targets, those located nearby, were learned from navigational experience (a form of primary spatial activity), while others, those located more distantly, were learned from a map. Sholl found that subjects' ability to point toward places learned from a map suffered from significant alignment effects, but that there were no significant time differences in pointing toward places lying in different directions, indicating that all information within that orientation was equally available. Furthermore, when pointing to places known by navigational experience, subjects pointed more quickly to targets in front of them, even if front targets were unseen. In total, by showing that secondary spatial knowledge follows the theory of equal availability and that primary secondary knowledge is recalled in an orienting-schema fashion, Sholl's results support the theory that primary and secondary spatial knowledge are encoded differently.

Returning to the map-in-the-head metaphor, Sholl's findings suggest that secondary spatial knowledge indeed may be structured in picture-like form. Conversely, her findings also suggest that primary spatial knowledge is *not* encoded as a map-in-the-head, but is much more like an orienting schema. This theory is supported by the finding that forward targets were easier to locate, as if one were traveling in that direction. Therefore, though further research is needed to make a definitive conclusion, both the map-in-the-head and the orienting-schema conceptions of cognitive mapping may be necessary and important for a comprehensive understanding of spatial behavior.

There are many ATIS implications of the effects that different spatial experiences have on spatial-knowledge acquisition. ATIS have the potential to expose drivers to more spatial information than they would have experienced otherwise, perhaps enhancing the development of more complex and useful cognitive maps. On the other hand, some ATIS provide specific and highly limited information, perhaps impeding the development of internal cognitive maps and increasing the driver's reliance on the system. The key question, then, is: does the use of ATIS products enhance or impede the development of spatial knowledge and spatial abilities? Furthermore, are there specific product features that can be identified as contributing to either process?

### **The Processing of Spatial Information**

Another important issue in the creation of cognitive maps concerns whether locational information is acquired through automatic or effortful processes. Automatic processes require little central processing capacity (Kahneman 1973) and automatically become active in the presence of certain input configurations (Schneider and Shiffrin 1977). In simpler terms, some stimuli cannot be ignored, and attention is paid to them with or without a conscious decision to do so. Fortunately, such automatic processes use only a small amount of the brain's processing capacity. Effortful or controlled processes, on the other hand, which are not triggered automatically, require substantial capacity and thus compete with one another for the limited amount available. Interference between tasks can occur even when the total required effort is below capacity (Kahneman 1973). Furthermore, effortful processes have been shown (or assumed) to require intention, suffer during periods of increased stimulus load, and benefit from practice (Schneider and Shiffrin 1977; Shiffrin and Schneider 1977).

In one attempt to test empirically how locational information is processed, Lindberg and Garling (1983) found evidence that central processing capacity may be allocated

automatically to locational information, perhaps because of the high degree of stress associated with being lost. At the very least, they found that verbally instructing subjects to learn only a relatively small portion of the spatial information that other subjects were asked to learn is insufficient to produce a significant spatial knowledge difference between the two groups. An examination of the theoretical literature on the processing of spatial information suggests several possible explanations for these results: (1) the great difficulty involved in suppressing an automatic process (Schneider and Shiffrin 1977), (2) a high state of arousal making it difficult to filter out irrelevant information (Kahneman 1973), (3) the relative visual simplicity of the paths used in the experiment (culverts lying underneath the University Hospital of Umea), or (4) a combination of these factors. Certainly the first, and perhaps the second and fourth, of these explanations lends support to the theory that some central processing capacity is allocated automatically to locational information. The third, while not disproving the theory, does not support it. Additional research is needed to determine which of these explanations, or perhaps some other, is valid.

In another set of experiments, Thorndyke and Hayes-Roth (1982) found that subjects with increased navigational experience in a particular environment improved their performance at estimating Euclidean distances between objects and the relative orientations of objects. These results agree with other results previously discussed (e.g., Garling, Book, and Ergezen 1982; Gale, et al. 1990) and suggest that the acquisition of spatial knowledge, because it benefits from practice, contains elements of effortful processing. Downs and Stea (1977), in stating that *purpose* is always a part of the mapping process, also seem to lend their support to the theory that the processing of spatial information is an effortful process, because automatic processes do not require purpose. Therefore, it appears likely that some spatial learning tasks do require effortful processing, while others may not, though this issue is far from



resolved, and additional research should be undertaken to determine if Lindberg and Garling's hypothesis of some automatic processing can be supported.

The possibility that the processing of spatial information may be an effortful process has important implications for ATIS product development and use. These products may enhance the processing of spatial information by "preprocessing" information and thus providing the driver with information ready for quick and easy application, but they also can impede information processing by overwhelming the driver with excessively detailed, irrelevant information. The implications of both of these outcomes are clear.

If ATIS can enhance spatial-information processing through selected information delivery or preprocessing, then users immediately should gain increased spatial understanding and routing ability. In addition, such systems should liberate attentional capacity that drivers will be able to apply in other ways (such as driving more safely by paying closer attention to microlevel conditions such as car following distance). On the other hand, if drivers are provided information in such form or quantity that attentional effort is demanded to process it and make it useful, then users are more likely to dislike the system and, perhaps, may begin to avoid using it. Indeed, if an overabundance of attentional resources are required to process the ATIS information, then driving safety may be impaired significantly.

#### Good and Poor Cognitive Mappers

An interesting observation about spatial behavior that emerges out of the literature—an observation providing further evidence that some spatial learning tasks require effortful processing—is that individuals who are good navigators do not appear to possess an innate sense of direction; rather, they seem to work at having it. In one experiment (Kozlowski and Bryant 1977), subjects divided by self-reported sense of direction led through a maze showed

no statistical differences in their abilities to point to an unseen target or estimate the distance to the target. After additional trials, however, the good-sense-of-direction subjects showed marked improvement in their abilities, whereas poor-sense-of-direction subjects failed to show any indication of gaining a more accurate representation of the area. Interestingly, this result also indicates that self reports of sense of direction are fairly accurate, though the authors note that other effects, such as subjects' humility/arrogance and adherence to gender-role stereotypes, were not tested. Similarly, Beck and Wood (1976) found that subjects' self reports of their *quantity* of spatial knowledge about a particular area are reliable, but that their self reports of the *accuracy* of that knowledge are not reliable. Furthermore, Streeter and Vitello (1986) found that self-reported levels of map experience are highly correlated with self-appraisals of navigational ability. Taken together, these results indicate some degree of accuracy and consistency in people's judgments of their own spatial knowledge, suggesting that studies relying to some extent on these measures are not lacking totally in internal and external validity.

If some cognitive-mapping tasks do include elements of effortful processing, as the available evidence suggests, then it should be possible to determine what "efforts" are made by relatively good cognitive mappers that are not made by relatively poor cognitive mappers. Toward this end, Thorndyke and Stasz (1980) studied the map learning procedures employed by three experienced and five inexperienced map users. By comparing the different techniques used by good and poor map learners—a distinction that proved to be unrelated to experience with maps—they outlined four general processes used to learn a map: attention, encoding, evaluation, and control, with each composed of several subprocesses. Other researchers (e.g., Wickens 1984) have arrived at a similar categorization.

The **attention** processes are those needed for perceiving a physical map and include eye fixation and shifting of focus, which can be accomplished through a number of sampling procedures (e.g., random and systematic). **Encoding** refers to how information is maintained in working memory, placed into long-term memory, and integrated with other information. Additionally, the authors distinguished between verbal and spatial encoding processes, with the former relying on semantic and linguistic information and the latter on shape and location information. The **evaluation** process consists of monitoring what has been learned, so that unknown information can be studied, and relies upon comparing what is already known with the sum of all available information. The **control** process directs the overall learning process and is responsible for determining which of the other processes to employ at a particular time. The existence of a control process was assumed by the authors without being observed directly in subjects' behavior.

Within the attention process, Thorndyke and Stasz found that subjects used a number of different sampling schemes to direct attention to various components of the map. Good learners pursued a more systematic sampling strategy than did poor learners, who tended to sample more randomly. Additionally, good learners tended to partition the map into discrete sections (e.g., by quadrant or feature type) and to focus on only one of these sections until it was learned. Again, poor learners either focused on random elements or failed to remain focused on the partitioned subset until that subset was learned. Finally, the researchers also found that good learners tended to be better at determining which parts of the map were still unknown and needed further study, while poor learners often studied the same map elements repeatedly, limiting their ability to learn the entire map in the allotted time period. Given the small sample size of this study ( $n=8$ ), however, the results should not be generalized too strongly or broadly.

In another study, Hardwick, et al. (1983) found evidence that better cognitive mappers attend to or receive different environmental clues than do poorer cognitive mappers. In their study, 59 subjects familiar with a test area were asked to draw a sketch map of the area, and the results of this exercise were used to separate subjects into three groups of differing cognitive-mapping ability. Next, subjects were exposed to a route through the area via the use of 60 color slides showing what a person would see at various points along the route. Finally, subjects were asked to choose nine slides from the 60 so that the nine would allow them to retrace the route. A significant difference in the number of "critical scenes" (intersections or other points of direction change) chosen was found between groups: the best cognitive mappers chose the most, and the worst chose the fewest. Referencing Moore (1976), the researchers suggest that poorer cognitive mappers may be hindered in their selection of useful environmental clues.

In a study of route following ability, Schraagen, et al. (1990) found that, when studying a route on a map, poor navigators spent significantly more time studying street names than did good navigators. Conversely, good navigators spent significantly more time studying topological relationships than did the poor navigators. Similarly, while driving, poor navigators devoted more attention to street names than did good navigators. During both map study and driving, however, both groups focused more attention on street names than on any other set of features. Also, the groups did not differ significantly in map-study time.

Delving further into subjects' navigational errors, the researchers found three causes of error: (1) insufficient map inspection, (2) memory failure, and (3) insufficient visibility of the environment (i.e., searching for the correct sign or landmark, but being unable to locate it). Only in the number of memory failures did the good and poor navigators differ significantly. Assuming that the researchers adequately distinguished the three types of error, their results

suggest that poor navigators may build flawed cognitive maps and thus are unable to recall pertinent spatial information. Other explanations also are possible, and further research on this issue is needed. One particularly interesting question is whether or not the poor navigators, like the poor map learners of Thorndyke and Stasz (1980), failed to employ useful sampling and partitioning processes when studying the map, thereby hindering their encoding abilities.

Some studies have attempted to measure differences in cognitive-mapping style and ability among different subgroups of the population. Investigating differences based on gender appear to be particularly interesting to some researchers. In a study of university students relying upon subject-drawn sketch maps for data, McGuinness and Sparks (1983) found that females focused more on the locations of landmarks and the distances between landmarks, while males focused more on the topographic network, including roads and other paths, in which buildings are located. From this result, the researchers concluded that females pursue a bottom-up strategy in building cognitive maps, and males pursue a top-down strategy. They go on to conclude that the strategy used by males would appear to be superior for wayfinding purposes, as males' maps include a larger number of paths. Unfortunately, the study did not include actual wayfinding tasks, making it difficult to support the authors' interpretation of the results. Furthermore, the authors failed to control for potentially confounding factors, such as female perceptions that certain paths may be unsafe (especially at night) and, therefore, not a part of their cognitive map of the area.

Another problem common to studies of gender differences in cognitive mapping concerns a failure to account for differences in spatial experience. Historically, in the U.S., for example, males have engaged in more exploration of their environment due to job demands and other social conventions. Schraagen, et al. (1990), for example, found significant gender differences in navigational performance, but their male subjects averaged nearly twice the

average yearly driving mileage than did their female subjects. In studies that control for amount of spatial experience (e.g., Lynch 1977), males and females have displayed equal cognitive-mapping abilities. Evans (1980), in his review article of environmental cognition, surveyed numerous studies in the area and concluded that the preponderance of the evidence indicates few gender-based differences in environmental cognition. Therefore, it appears that additional research is required to settle outstanding questions on this topic. Future studies, however, should avoid past failures to control for possible confounding factors, notably gender-based differences in interaction with the physical environment.

The effects of age on cognitive-mapping abilities also have been studied in some detail, and much literature on cognitive mapping in children already has been presented in this review. In addition to this literature, there also exists a literature on the cognitive-mapping skills of older adults. In general, these studies indicate that the elderly perform spatial tasks slower and less accurately than do younger adults (Evans 1980). In an effort to gain a deeper understanding of how spatial information may be best presented to the elderly, Kirasic and Mathes (1990) found that map study and verbal description were the most effective means of conveying route-execution (choosing the most efficient route that links together a number of stores in a suburban shopping mall) information; videotape and verbal description plus mental imagery were less effective. For the other spatial tasks tested--scene recognition, route planning, and map placement--the method of information presentation was not a significant effect. In addition, the researchers found that subjects who performed poorly on the route execution task spent significantly more time standing without scanning the environment. As a result, these subjects may have been less adept at gathering environmental clues that may have aided their spatial behavior.

ATIS should be designed in such a way that they provide benefits to both good and poor cognitive mappers. ATIS products may be able to reduce the sources of navigational error described earlier (i.e., insufficient map inspection, memory failure, and insufficient visibility of the environment). To the extent that ATIS preprocess spatial information and can be tailored to respond to specific queries, they should be able to reduce the number of errors caused by insufficient map inspection. Unless the results of the ATIS data search can be displayed effectively and efficiently to the user, however, then the potential for error remains. Alone, ATIS cannot prevent users from overlooking displayed information, but ATIS products can be developed in such a way that information transmission is simplified to the point that these errors are minimized.

ATIS may serve best to reduce incidents of memory failure. Each system should have a feature that provides users with the opportunity to recall information as desired. Given the abilities of computers versus humans, memory requirements are best assigned to the machine, freeing human information-processing capacity for other tasks. There would appear to be less of a chance of memory error on the part of ATIS than on the part of humans, and the likelihood of human memory error can be reduced greatly with electronic backup.

Some ATIS products also have the capability of providing users with richer information about their current environment. That is, while the user may not be able to see the environmental cues necessary for effective navigation, the ATIS product may be able to provide these cues, at least in some situations. This is particularly true for advanced navigation/location ATIS products. These products have the potential to increase the effective visibility of environmental cues by providing them directly and specifically to the user.

ATIS development and evaluation should be mindful of the four general processes identified for spatial learning (i.e., attention, encoding, evaluation, and control). Toward this end, ATIS products should minimize the amount of attention required for information perception, as high attentional demands by ATIS could result in unsafe vehicle operation or user displeasure with the product. ATIS can enhance information encoding by matching information content and format with existing cognitive structures and expectancies. Similarly, ATIS should focus on augmenting human capacities rather than duplicating human functions that are performed well or efficiently.

Ultimately, ATIS products may prove to be best at enhancing the evaluation function by acquiring, organizing, and analyzing information more effectively and efficiently than humans can. ATIS products should be developed and evaluated with the human and machine control process in mind. Information content, context, order, and function all are critical components of the control process for both humans and machines, and the needs of both must be considered at each step of the development and evaluation processes.

### **Map Reading**

It is quite difficult, and perhaps fruitless, to separate studies of map learning and use from studies of map reading. After all, in the real world few people read maps for no utilitarian purpose. Nonetheless, map learning and map reading are different tasks and seem to involve somewhat different processes. Therefore, a summary of some of the research that focuses primarily on map reading will aid in providing a richer understanding of cognitive mapping and spatial behavior.

From a cartographic perspective, researchers have developed a fair amount of knowledge on what constitutes a readable map. It is known, for example, that the use of



reference grids makes a map easier to use, and that cluttered maps hinder map learning and recall (MacEachren 1991). Eley (1991), in a study asking subjects to match land-surface diagrams to topographic maps, found that when more and more information was placed on a map, subjects still studied the map only long enough to perform the given task; excess information apparently was disregarded. This result supports findings that, given limited processing capacity, selectivity is required to cope with the volume of available spatial information (Downs and Stea 1977; Schneider and Shiffrin 1977). Selectivity is used to determine both what is encoded in the cognitive map and what is retrieved and manipulated, thus serving to filter out potentially distracting and superfluous information. How this is accomplished may consist of a procedure like partitioning, in which the learner focuses on a subset of available information (Thorndyke and Stasz 1980). Whether selectivity is an automatic or effortful process remains an unanswered question, though the study by Thorndyke and Stasz suggests that it may be effortful, because different subjects pursued different attention and partitioning schemes. Of course, only with great care may one generalize from a contrived task such as copying a map to real-world spatial problem solving. Thus, ATIS products should provide only the information necessary for the given human function being enhanced by them. Extraneous information should be avoided. To best accomplish this, ATIS designers should consider separating functions to reduce information overload and the subsequent filtering requirements.

### **Predicting Spatial Abilities**

Complementing studies of the characteristics of good mappers and what cognitive processes they employ, some studies have attempted to predict mapping behavior based on underlying cognitive skills. Thorndyke and Stasz (1980), for example, found that subjects' ability to learn information from a map can be predicted from their psychometrically defined visual memory ability, an ability that varies from person to person. They hypothesize that this is

because visual memory ability is required to encode spatial configurations (Thorndyke and Goldin 1981). Furthermore, Goldin and Thorndyke (1981) have found supporting evidence that good map learners indeed do possess superior visual memory ability.

In some ways contradictory to the studies by Thorndyke and his collaborators, Sholl and Egeth (1982) administered various Educational Testing Service tests of spatial, verbal, and mathematical ability to subjects and attempted to correlate these results with the results of a map-use test. To the authors' surprise, for some factors verbal and mathematical abilities proved to be stronger predictors of map-use than did spatial abilities. They note, however, that these results may be peculiar to their subjects (all ROTC students) or to the type of map (topographic) that they used in the test. Overall, they found that individual differences in map reading were only partially explained by individual differences in spatial ability. Comparing these results to the work by Thorndyke and his colleagues, indications emerge that map learning and map reading may result from separate cognitive processes. Bovy and Stern (1990) speculate further on this dichotomy, and postulate that map reading consists primarily of path following, while map learning relies more heavily on spatial memorization. In sum, further research is needed to better explore the distinctions between map learning and map reading. It seems clear, however, that ATIS products must be developed to accommodate a wide variety of skills and users. Two approaches may accomplish this end. First, ATIS products may be developed for the "least-common denominator," or the least-skilled user. This approach has the potential for alienating more-skilled users, while providing marginal utility for less-skilled users. A more enlightened (though probably more expensive) alternative is the development of adjustable ATIS that can be customized by users to meet their individual abilities and needs.

### **Methodological Difficulties with Cognitive-Mapping Studies**

Beyond the already discussed criticisms of some studies that detect differences in cognitive-mapping skills based on gender, researchers also have discussed other methodological shortcomings of cognitive-mapping studies. The purpose of discussing the methodological weaknesses of cognitive-mapping studies is not to invalidate all such research, but, rather, to caution against the temptation to generalize too broadly from the results of interesting, but limited, studies.

In particular, Evans (1980) has stressed the potential shortcomings of subject-drawn sketch maps. The quality of these maps, he argues, depends to a large extent on a subject's drawing ability. As Gale, et al. (1990) have argued, being able to draw a map of a route does not imply an ability to follow the route; likewise, being able to follow a route does not imply an ability to draw the route. Additionally, Evans notes that features drawn on a sketch map are not statistically independent of one another, and that the more features one already has drawn the fewer degrees of freedom left to add more features correctly (i.e., once part of a sketch map is drawn, the remainder of the drawing is constrained by what is already there)—a criticism also made by Downs and Stea (1977). For example, if one is asked to sketch a map of the streets and buildings in some city's downtown and begins at a scale too large for the paper, then features added near the end necessarily will be distorted in relation to the rest of the drawing if all is to fit.

When working with young children as subjects, the difficulties caused by using sketch maps are particularly problematic (e.g., Evans 1980). Other methodological problems also arise, or are made clearer, when the subjects are children. Such difficulties include the effects of subjects' linguistic competence (e.g., responses may not reflect true knowledge or ability) and the confounding of age and experience. And while the effects of these problems are

heightened when the subjects are children, they also are of concern with adult subjects. The inability to separate spatial imagery and verbal representation is especially troublesome (Downs and Stea 1977).

### **Use of Spatial Knowledge**

From accumulated spatial knowledge, people are capable of engaging in a wide variety of spatial activities, including traveling from home to work, giving directions, and judging the topography of a trail to be hiked. Of these spatial activities, perhaps none is more important than wayfinding, "the process of figuring out how to get from one place to another, of remaining oriented while driving (or using another method of transit) toward a goal" (Petchenik 1989). Not surprisingly, a large literature exists on how people choose routes, follow routes, etc. (e.g., Bovy and Stern 1990). What is of interest here, however, is to explore which cognitive mapping processes and broader spatial behaviors are brought into play when one embarks on a trip. Contrary to the route-choice literature, the use of spatial knowledge, rather than trip characteristics, will be the focus of this section.

In one study of route choice from a cognitive perspective, King and Rathi (1987) asked subjects to plan a trip in an unfamiliar area using only a standard road atlas. They then compared the chosen routes with the assumed optimal route (shortest) suggested by an automobile club and found that the selected routes were, on average, 12.1 percent longer than the optimal route, with no significant differences based on age, gender, or geographic location. King and Rathi blame the relative lengthiness of the chosen routes on drivers' inability to use maps adequately. To the extent that their explanation is valid, their study highlights the shortcomings of many people's cognitive maps and map-reading abilities and indicates that educational efforts to improve mapping abilities could be a net benefit for society. There are, however, other possible explanations, most notably drivers' employing

criteria other than shortest time or distance when choosing their routes, and the route-choice literature contains numerous studies that lend credence to this hypothesis. Benshoof (1970), for example, found that the ability to avoid traffic is a strong criterion in route-choice decisions. Most likely, both explanations, and perhaps others, have some validity; again, further research is required to settle this issue.

Many of the studies on the uses of spatial knowledge, particularly those associated with ATIS, present subjects with spatial information via two or more means and evaluate the differences in how this information is put into use. Garling (1989) presented one group of subjects with quantitative data on the distances between a number of different points and presented other subjects with a pictorial representation of the relative locations of the points. He found that subjects who were given only numerical data employed a locally minimizing distance heuristic—connecting the current location to the nearest remaining location—when linking the points into a single trip. This approach does not, however, minimize total distance traveled. Those presented with a pictorial representation of the locations, however, chose a route that more nearly minimized *total* distance. Garling also found that distance and direction information often was sufficient to allow for the minimization of total distance, particularly if subjects could use this information to construct their own maps. These results indicate that subjects were reasonably skilled at choosing "good" routes when given sufficient information on which to base a decision. This finding is important for those who wish to provide the public with travel information, because it provides some measure of travelers' background ability to choose good routes when given quality information and indicates that such information, rather than explicit route guidance, may be the most appropriate means of disseminating travel information.

Clearly, ATIS has the potential to provide a wide range of information for an even wider range of users. The type and potential use of information is an important design consideration for all ATIS products. The utility of ATIS products will be maximized to the extent that users can customize their system. This customization, however, should be guided carefully by the product. Through an interaction with the ATIS product, the user should be able to select ATIS functions that best accommodate his or her needs and skills.

#### *Automobile Travel and Spatial Behavior*

With the dawn of ATIS, many researchers have turned their attention to studies of map use and spatial behavior in the vehicular environment. In one study that may be viewed as a baseline for comparing vehicles equipped with advanced electronics, Schraagen (1990) tested for differences in driving performance—measured by the number of navigational errors—within subjects exposed to both normal road maps marked with a highlighted route and the same maps enhanced by the addition of small stickers. The stickers were placed at some (not all) choice points where a change in direction was required and had the name of a road that matched a visible road sign at the junction point printed on them. Subjects studied a map before beginning each trial and were allowed to stop the car and check the map again whenever they felt a need to do so. When using maps enhanced with stickers, subjects made significantly fewer errors, leading the researchers to conclude that the stickers aided navigation, particularly at complex intersections.

In another study attempting to establish a baseline with which to compare future ATIS advancements, this time concentrating on verbal presentation of motorist information (e.g., using radio, phone, television, and computers), Spyridakis, et al. (1991) surveyed 3,893 Seattle-area commuters. They found that commercial radio is by far the most popular means (used by 97.6 percent of respondents) for receiving traffic information, and that the development of

a radio station dedicated to travel information is by far the most popular first choice for future improvements in the provision of verbal travel information. Additionally, a little more than one-half of the respondents reported preferring to receive information before beginning their trip, as opposed to during the trip. No results on navigational performance based on information source, however, were reported.

Expanding the research focus to compare the provision of information in more than one form, Mark and McGranaghan (1988) surveyed guests who attended either one or both of two departmental parties with the goal of determining whether the guests preferred verbal (or written) instructions or a map as a navigational aid for reaching the parties. For the first experiment, guests were provided with both a map and a set of written instructions, which were based upon a frame developed by Mark (1985). For the second experiment, guests were left to obtain their own navigational aids, including asking someone for directions.

Among their results, the authors found that guests were far more likely to use navigational aids *before* departing than during the trip. Also, those who reported less map use, in general, when traveling to new cities were more likely to make mistakes en route. Furthermore, 40 percent of those expressing a preference preferred verbal instructions to a map, though insufficient data was available to determine which form of navigational aid resulted in fewer routing errors. Interestingly, when asked to "indicate" their route to the parties, only 11 of 55 respondents drew a map, and 44 gave a verbal response, usually a list of the streets taken. The authors note, however, that 30 of these 44 responses could not be used to recreate the route without the aid of a map--printed or cognitive--due to a lack of turn or directional information. Although these results are provocative, this study is fraught with methodological weaknesses, including a lack of topographical similarity between the two target locations and a high percentage of Ph.D.-level geographers in the sample.

In a more controlled and reproducible attempt to address many of the same issues, Streeter, Vitello, and Wonsiewicz (1985) divided 57 subjects into four navigational conditions (taped (verbal) instructions, customized map, taped instructions and customized map, and a New Jersey road map along with a statement of the city and address of the target location), two familiarity conditions (familiar and unfamiliar), and three route conditions (limited access, moderately difficult local, and complicated local). In producing the taped instructions, the researchers followed a fixed format that included turning instructions, names of streets, landmark information, and a "too-far instruction," which was designed to let a driver know when a turn had been passed.

In analyzing their data, the researchers found that the tape-only group drove fewer miles to reach the destinations, spent less time driving, and made fewer errors. Also, drivers reported that the tapes were the clearest and easiest to use form of route information. Interestingly, many drivers reported not liking the too-far instruction, but drivers in the tape condition drove fewer miles past key junctions than did other drivers. Thus, there is some indication that drivers could respond with unfavorable attitudes to a piece of spatial information that has practical usefulness; the challenge, then, is to present such information in a pleasing form. After the tape-only group, the tape-and-customized-map group achieved the second-best performance, followed by the customized-map group, with the control group (state map) last. Though not considered in this study, the use of in-vehicle directional arrows (as is done in the All-Scout system) is another candidate means for presenting navigational information. Future studies comparing such systems should include this approach in the design.

### **Conclusion**

While it is evident from the literature that few definitive conclusions can be drawn regarding human spatial behavior, some convergence of research results and theory is



emerging. Foremost among these loci of convergence, it could be argued, is the recognition that individual differences in the encoding and processing of spatial information abound. Whether because of differences in navigational experience, attention processes, age, or other variables, the population as a whole exhibits a wide range of spatial ability, spatial knowledge, and spatial behavior. For the developers of new technologies (e.g., ATIS) that are designed at least in part to provide spatial information, the implications of this conclusion are clear and inescapable: no single technological approach is likely to satisfy the needs and wants of all or even a large majority of the population. Systems that provide individuals with a variety of options for receiving traveler information would appear to have a clear edge over systems designed to provide information by, say, electronic map only.

Along with the recognition of individual differences in the processing of spatial information should come the recognition that drivers are not merely passive users of ATIS, but, rather, they are active participants in the system, receiving information, processing it, acting, and making further informational requests. Furthermore, drivers' needs for information may change (and probably will) during the course of a trip. For example, diversion from a known route may produce a need for more information and ATIS display of more environmental cues. Additionally, as ATIS serves not only to supplement human spatial knowledge but also as a source of spatial knowledge, drivers' use of ATIS will change over time, as their spatial knowledge increases because of the ATIS itself and because of navigation experiences in formerly unfamiliar environments brought about by using the ATIS.

Similarly, another important point of convergence is the understanding that how to best provide and describe spatial information depends to a large extent on the spatial task for which that information is provided. If a traveler wants to know how to get from A to B, then one mode of information provision is best, but if a traveler wants to know where he or she is in

relationship to the overall geography of a city, then another mode of information provision is best. This observation further supports the conclusion that the most useful ATIS will be flexible enough to offer information in a variety of formats, enabling the user to choose the format to be used at any given time.

Beyond simply noting that some forms of information are better than others for the performance of particular spatial tasks, the available literature also provides strong evidence for determining which forms of information provision are best in real circumstances. Although the first tendency is to think of spatial information in pictorial form, some spatial tasks are best accomplished through linear, verbal means. Such spatial information, then, more closely resembles Neisser's concept of an orienting schema than it does a map-in-the-head. Following a route between two places falls into this category, as evidenced by the studies done by Mark and McGranaghan (1885) and Streeter, et al. (1985).

Complementing the finding that in general verbal instructions are superior for route-following tasks, subjects registered a preference for verbal, rather than pictorial (e.g., a map), sources of information to aid their navigation. This outcome appears especially valid when it is considered that route knowledge is often gained by navigational experience (a source of primary spatial knowledge, which often is thought of as being encoded as an orienting schema). If navigational knowledge is encoded in a linear form, then it makes intuitive sense that information offered as a navigational aid is best given in a verbal manner. Clearly, insufficient data exist to prove this point, and further research in this area is urgent and necessary before ATIS that meet the needs and desires of potential customers may be designed and deployed.

For non-navigational spatial tasks, however, the pictorial provision of spatial information would appear to be best. For example, if a traveler would like to know the location of the nearest gas station, then a picture of the locations of service stations overlying a map of the street network would be best. Such a presentation can be accomplished quite easily with current electronic-mapping technology. Another task that is best accomplished through a map is zooming, which allows the map user to examine information at either a larger or smaller scale.

Remembering the importance of individual preferences, however, suggests that even information designed to support a specific task probably should be available in a number of different formats, even when one format appears to be superior for a certain function. Therefore, the ability to switch easily between verbal and pictorial formats clearly is important if travelers are to best take advantage of multiple format options. Such a smooth interface would, for example, allow one to identify the closest gas station and then to receive verbal instructions on getting there, perhaps along with some indication of traffic conditions along the suggested route.

The evidence that some spatial learning tasks require effortful processing leads to another key issue in the design of ATIS: the extent to which using ATIS will interfere with the already demanding driving task. This issue raises numerous and important safety questions (e.g., will drivers pay less attention to microlevel traffic conditions while gazing at an electronic map?) that are best answered from a human-factors engineering perspective. The spatial-information processing perspective of this work, however, does suggest at least four key questions that should be tested: (1) Is there a significant difference in required effort between verbal and pictorial formats? (2) Does the processing of spatial information become more automatic (and less effortful) over time, as drivers become accustomed to new forms of

spatial information provision? (3) Do the temporal changes in required effort differ among information-provision formats? (4) Recalling the distinctions between good and poor cognitive mappers, is there a difference in effort required for processing spatial information between good and poor cognitive mappers?

Finally, one other key point must not be neglected. Despite all the studies investigating map use and map learning, the average person rarely consults a map. Petchenik and Clawson (1984) found that the typical adult in the U.S. uses a map approximately three times per year, although some do use a map far more often--on the order of twenty times per year. The major hypothesis that derives from this finding is that drivers likely will be willing to pay only a small amount for map-based navigational information. On the other hand, other forms of traveler information (e.g., verbal advice or in-vehicle arrows indicating suggested turns) may encounter a higher willingness-to-pay. Just how much drivers will pay for particular systems, however, remains an open and critical issue that needs to be addressed at the earliest possible date.

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