SESSION I WELCOME

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SESSION II INVITED ADDRESSES

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The use of computer-controlled video disks in the study of spatial learning

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The empirical study of spatial learning has been constrained by a range of methodological and technical limitations. Part of these are due to constraints in the stimulus delivery systems for pictorial displays that are available to the researcher. Surrogate travel systems—based on model photography, off-line computer graphics, and on-line computer graphics—provide alternative research settings. Yet none of the systems provides for both detailed displays and ease of subject interaction, both of which prove important in the investigation of spatial learning. Computer-controlled video-disk systems do allow both detail and interaction, therefore providing a research tool in which spatial learning phenomena can be observed carefully. A pilot study of spatial learning using a video-disk system is briefly described to demonstrate the sorts of phenomena observable with such a system.

The study of visual information processing has engaged a great deal of interest in the experimental psychological research community in the last decade, as classic models of perception have been expanded to include "higher level" processing. Models of semantic information processing have been generalized to include pictorial as well as linguistic information, and the results of research investigations demonstrating the extremely large capacity of memory for pictures have been included by many theorists in their descriptions of the human cognitive apparatus. Yet, in the midst of the excitement surrounding the investigation of visual information processing, a number of constraints have limited the range of questions that have been amenable to well-controlled experimental analysis. In contrast to research in linguistic processing, which has been streamlined greatly by the use of minicomputers, picture processing research has not yet been widely sophisticated by this technology. Pictures remain expensive to generate, they remain cumbersome to present to subjects, and they continually prove unwieldy to evaluate outside of a recognition paradigm. And computer technologies available to most psychological researchers have fallen far short of solving these problems in a research setting.

SPATIAL LEARNING

This is particularly the case for research which addresses spatial learning, research which considers how people generate reference-free representations of spatial layouts and assesses the development of these representations over time, given individual egocentric views of an environment. This research has several requirements. (1) Subjects are presented with still as well as moving images. (2) Pictorial as well as spatial information is presented to subjects. (3) Alternative sequences of images are available. (4) Subjects interact in selecting views and in navigating through an environment. (5) The presentation of new information can be made contingent upon subject choices and information presented in the past.

It is clear that, even without such investigations, intuitions about the process of the development of spatial representations have guided many general psychological investigations of learning, as shared folklore recalling how each of us learns new places (one of the learning experiences we continue even as adults) provides insights into a range of experimental investigations. Yet, empirical research directly addressed to the investigation of spatial learning has typically been

constrained to single segments of the spatial learning issue or to simplified stimulus displays that are quite unlike environments. We do, for example, have extensive data from the cognitive mapping literature concerning the types of maps that people draw of environments that they have experienced, and we have evidence for the classes of distortions that are made in these maps (Downs & Stea, 1977; Lynch, 1960). We also have data about how people learn maps (Shimron, 1975; Thorndyke & Stasz, 1980) and on how orientation judgments are made relating already learned locations (Stevens & Coupe, 1978). In addition, models of spatial learning (Kuipers, Note 1) provide formalisms for the analysis of navigational processes. From the developmental literature, a great deal is known about how children learn simple environments, how they eventually integrate egocentric representations into a reference-free Euclidean framework (Piaget & Inhelder, 1956). From pictorial processing research we know that people are extremely accurate in remembering pictorial information; we have a sense of the transformations individuals are or are not sensitive to in encoding pictorial displays, and we know something about variables that influence pictorial recognition. Data is now becoming available on the pictorial features of objects experienced in daily life (Nickerson & Adams, 1979).

Yet, there is little data that directly addresses both spatial learning and pictorial learning. There are only a few experimental investigations of how information about single perspectives of objects are integrated into nonegocentric representations (Hochberg, 1968; Hochberg & Brooks, 1978). There is little, if any, research available which considers how spatial coherency of a display is developed from multiple views. In short, there is no significant amount of data that consider how information concerning both objects and planes are learned, not how this information is combined to yield a representation of a spatial layout, a representation which relates the domains of objects and planes in terms of locational information. This process is at the heart of the study of spatial learning.

Why do we have such sparse evidence relating object and planar aspects of spatial learning? A primary reason is, of course, that the phenomena of interest to researchers are different: Map learning, map drawing, and picture recognition are clearly of interest in their own right, and each is clearly very relevant to particular theoretical issues. Yet, other reasons include a set of methodological constraints and technical limitations involved with the study of spatial learning. It is this set of issues that are the concern of this paper.

METHODOLOGICAL AND TECHNICAL CONSTRAINTS

The methodological constraints on the investigation of spatial learning are numerous. Let me bring attention to two major issues at this time. The first centers around the complexity of measuring visual recall and a consider-

ation of the great differences between visual recognition and visual recall in assessing memory for visual materials. This is, of course, an interesting issue in its own right. Verbal recall of visual information provides an excellent domain for the study of cross-modality descriptions. Drawing is a process of visual recall that provides fascinating observations of the interaction of rendering conventions, past experience in drawing, and memory of visual information. It also provides for an interesting hybrid of recall, in the initial drawing, and recognition, in the evaluation, alteration, and continuation of a drawing. Yet, in the investigation of spatial learning, the complexities of visual recall are more cumbersome than interesting. Drawings are difficult to elicit and to score, verbal descriptions are frequently vague and imprecise, not necessarily due to the memory for the visual information, and simple recognition measures provide only a very rough measure of spatial knowledge.

A second class of methodological constraints on studies of spatial learning involves those constraints that are experienced in any field investigation. Attempted typically to add a sense of realism to an investigation, field research is hampered by the realism that it introduces. It is very difficult, for example, to follow individuals through an environment very carefully as they are learning it. This is partly because of: the range of events in the environment that are unrelated to the major issues of interest (e.g., traffic), the obtrusiveness of such monitoring, the difficulty of systematic questioning and testing at crucial points in the learning process, and the difficulty of recording the precise nature of the experience of the viewers, in terms of where they went and what they saw.

Technical limitations of standard delivery systems for the delivery of stimulus materials also add to the constraints of the study of spatial learning. These constraints, listed in Table 1, deal with the content of displays, the techniques available for presentations, and the capabilities for response recording. Constraints on the content of displays address the range of media considerations (availability of line drawings or detailed photographs, color or black and white pictures, still or moving images) that affect the nature of the pictures that can be presented to subjects. Presentation issues address the techniques available for sequencing pictures and the controls available to both the subject and experimenter in the sequencing of the presentations. The recording of response issues includes concerns about the gathering of responses following pictorial presentations, particularly those that are generative.

Table 1 shows that the flexibility of researchers in presenting complex displays in any sort of sequential form or in any interactive context is extremely limited by these delivery systems. In response to these constraints and the methodological concerns discussed earlier, researchers typically study picture recognition when they study picture memory, and they study picture memory rather than such things as pictorial

Table 1
A Consideration of Standard Pictorial Display Systems in Terms of Content, Presentation, and Response Recording Characteristics

Display System			
Tachistoscope	Slide Projector	Movie Projector	Videotape Recorder
Content			
<ul style="list-style-type: none"> -still pictures only -pictures generated independently of the system 	<ul style="list-style-type: none"> -still pictures only -pictures generated independently of the delivery system 	<ul style="list-style-type: none"> -still or moving images, particularly with analyst projectors -pictures generated independently of the system, typically at great cost 	<ul style="list-style-type: none"> -still or moving images, although there is typically noise with still images -pictures generated independently of the system, at great cost -editing in preparation is expensive
Presentation			
<ul style="list-style-type: none"> -excellent control of the onset and offset of single pictures -experimenter interaction required 	<ul style="list-style-type: none"> -onset and offset computer controllable using shutters -random access limited to small number of slides -alternative sequencing awkward -time for advance of slides mechanically limited -predetermined sequences easy 	<ul style="list-style-type: none"> -difficulties in computer control -timing limited by mechanical properties of film and projector 	<ul style="list-style-type: none"> -computer controllable only at great expense
Response Recording			
<ul style="list-style-type: none"> -no pictorial generative response capability -responses made independently of the delivery system 	<ul style="list-style-type: none"> -remote control by subject of forward and reverse -responses typically made independently of the delivery system 	<ul style="list-style-type: none"> -no subject control -responses made independently of the delivery system 	<ul style="list-style-type: none"> -remote control by subjects of forward, reverse, and stop frame -response is typically made independently of delivery system

conversations, pictures in problem solving, or pictorial sequencing. The study of spatial learning, for example, is typically constrained to map learning or to memory for environments that were experienced in a range of uncontrolled situations before the research assessment took place. Any complex study of spatial learning (i.e., one which addresses eye-level views as well as map overviews, and one which assesses problem solving as well as picture memory) is not well studied with such systems.

SURROGATE TRAVEL SYSTEMS

Surrogate travel systems, made possible by newly developed technologies, offer the researcher a number of alternatives in the study of spatial learning (Hooper, Note 2). These systems, developed not in the context of psychological research (though aided by it) but in applied domains such as flight simulation, architecture, geography and engineering design, provide the psychological researcher with a range of abilities in stimulus presentation and response recording. They provide the ability, for example, to generate controlled environmental sequences and to observe subject responses to these, in some cases in an interactive framework. The major intent of these systems is to provide the viewer with the information available in an environment without having been there, to provide a trip through the

environment. In both architectural and engineering design, these simulations enable judgments of designs before they are constructed. Flight simulations eliminate the large costs to the learner for errors that would exist in flight situations; in the geographical context, simulations provide viewers with a preview of an area which can enhance navigational planning.

Table 2 lists the attributes of three classes of surrogate travel systems. Each description is based on a particular project that I have worked with in attempts to develop a controlled investigation of spatial learning. The descriptions are, therefore, idiosyncratic to the use of the systems in studying spatial learning. (Figure 1 provides examples of still output from each of these systems.)

The first of these projects, the Environmental Simulation Project, was set in an architectural context. Directed by Donald Appleyard and Ken Craik, the intent of the project was to develop a system which made realistic displays of proposed development in an area so that community members would have the knowledge required to participate actively in environmental decision making. To accomplish this, Appleyard and Craik constructed a model photography system which made eye-level movies of architectural models through a computer-controlled periscope. The displays generated in this fashion were extremely realistic; they could be viewed either in real time on a black and white

Table 2

A Consideration of Alternative Pictorial Display Systems in Terms of Content, Presentation, and Response Recording Characteristics

Display		
Model Photography (Environmental Simulation Laboratory)	Off-Line Computer Graphics (Dar El Mara Movie Map)	On-Line Computer Graphics (Saratoga Data Base)
Content		
<ul style="list-style-type: none"> —still or moving pictures —pictures generated by the system —displays limited by the detail on the model —manipulable with changes in the model —choice of angle of view and sequencing computer controllable 	<ul style="list-style-type: none"> —still or moving pictures expensive —detail expensive in terms of manipulations available —displays described precisely —pictures generated by the system —displays readily manipulable 	<ul style="list-style-type: none"> —still or moving pictures expensive —detail unavailable if real-time manipulation is required —displays described precisely —pictures generated by the system —displays manipulable
Presentation		
<ul style="list-style-type: none"> —in most applications, limited by other display systems (e.g., slide or movie projectors, videotape recorder) —timing controlled independently of system 	<ul style="list-style-type: none"> —limited by other display systems (e.g., movie projectors or videotape recorders) —timing precisely controlled 	<ul style="list-style-type: none"> —flexible as a function of either subject choices or experimental design —timing precisely controlled
Response Recording		
<ul style="list-style-type: none"> —subject interaction limited by the fragileness of the model —responses typically recorded independently of the system 	<ul style="list-style-type: none"> —no subject interaction —responses recorded independently of the system 	<ul style="list-style-type: none"> —extremely flexible subject interaction —subject responses can be recorded directly by the system

video monitor, or off-line as a color film. Appleyard and Craik validated their technique by comparing responses to movies made using the simulation system (either black and white video or color film) with movies made in the environment modeled for simulation filming. In addition, they compared responses to each of the movies with the responses made by subjects who were driven through the environment in a car. (An existing environment rather than a proposed environment was used for this validation effort, of course.) The Simulation Project generated both a model photography system for environmental representation and a research project of the evaluation of the representations generated. [Appleyard and Craik (1978) and McKechnie (1977) provide details of this project. Hooper (Note 3) provides examples of the output of the system.]

The Dar El Mara movie mapping effort provided an opportunity to use off-line computer graphics. The context of this project was geography, as the intent of the effort was to generate a map of a place which combined eye-level and overview information in a dynamic presentation to provide a viewer with more of a sense of a place than would be provided in a standard flat paper map. The generated color graphic display showed first an overview of a town (the imaginary town of Dar El Mara) and then an eye-level movie of a trip through the town. The amount of detail in the resulting displays was far less than that in the model photography displays, as the displays appeared as "cartoonish" rather than "photographic." Yet even to generate this level of detail, off-line production was necessary, as one frame at a time in a moving sequence was generated and recorded as a frame on a 16-mm movie. The resulting movie was then shown to subjects

using a 16-mm movie projector. [System details can be found in Levin (1978). Ciccone, Sandee, and Weltman (1978) provide an evaluation of the system. Hooper (Note 3) provides example output of this system.]

The on-line computer graphics used to study spatial learning were generated using an Evans and Sutherland Picture System 2. The output of this system, which was controlled interactively by the subject by touches on a tablet, was a wire frame display. No surfaces were indicated, and no hidden lines were removed. The real-time interaction—choices of location of view and object of view in three-dimensional space—did not allow such sophistication in the display. The tradeoff in detail provided the viewer with unlimited choice in viewing position and object to be viewed in a real-time fashion. [Details of the system and observations of subject interaction with the display system can be found in Hooper and Myers (Note 4). Examples of output can be seen in Hooper (Note 2, Note 3).]

There are great content differences in these systems as compared with the standard systems. For one thing, both still and moving displays are available with each of the systems. In addition, the graphics are all generated with the systems; there is no need for off-line generation as each system is designed for graphic generation. This means that displays that are transformations of each other can be easily generated; details can be included or excluded, different points of view can be chosen, and locations of objects can be systematically changed. (Of course, this generation is often quite expensive, in terms of both finances and time of digitizing or model building.) Presentation is well controlled with all of the systems, given the computer control of the generation

Ways to show places

Interactive

Non-Interactive

Photographic

Rendered

Figure 1. Graphic output from the four surrogate travel systems.

of the displays. Yet, with the exception of the on-line computer graphics, the delivery of images to a subject is dependent upon the standard systems described in Table 1. (On-line interaction with the model photography system is cumbersome and limited by the frailty of the model; it has not been streamlined in the system as it exists, although it is clearly a possible extension of the current system.) This means that alternative sequencing, or individual choice of view and sequence of exploration, is greatly limited with the first two systems. In addition, response recording with the first two systems is limited by the standard delivery systems. But with the on-line version this is not the case, as the subjects' interactions with the system can be recorded and the system can be set up to directly record a range of response types. Although the tradeoff for this ability is great, in terms of the scarcity of detail in the display, this system is the only one that enables the experimenter to observe subject's interactions with the displays and to observe subjects actively involved in learning a place rather than learning the preselected contents of a movie.

A COMPUTER-CONTROLLED VIDEO DISK SYSTEM

The new optical video-disk technology allows the experimenter the luxuries of interaction without the tradeoffs of detail in the display. As shown in Table 3, an experimenter using a video-disk system under computer control can present subjects with either still or moving images. New displays can be made easily, contingent upon either subject responses or predetermined branching structures, and subject interaction with up to 54,000 images (the content of the disk) is readily available. In addition, given that the contents of a video

disk are generated independently of the system, the content is not limited to any particular media. Detailed photographic still or moving images can be stored on a disk, as can computer-generated graphics, renderings, and verbal displays. And although expensive in generation initially, the ready availability of multiple copies makes the careful generation of a disk very cost effective in the long run. It also provides a convenient way to standardize research materials across experiments and across laboratories.

The Aspen Project at M.I.T, directed by N. Negroponte and A. Lippman (Lippman, Note 5) provided an opportunity for the study of spatial learning using a computer-controlled video-disk system. Briefly described, this project was developed to allow people to explore a town before they even visited it. It was an experiment in a new map form, a movie map which provided subjects with dynamic interaction with detailed images. The material stored on the disk dealt with the town of Aspen, Colorado, and it included cultural data, still images, printed materials, and maps. Most relevant to the current discussion, however, the disk included pictures of the town taken with 16-mm movie cameras mounted on a truck which was driven up and down all of the streets of Aspen. The pictures, taken every 9 ft, provided a set of alternative trips through the environment. Leading turns at all intersections were filmed in the same manner so that, once the information was stored on the video disk, viewers could explore the town as they chose, making a personalized movie by choosing to go straight ahead, left, or right at any intersection and by controlling the speed of their own travel.

The limit of this system was that the viewer could choose only from the views that were filmed initially. Hence, in contrast to the on-line computer graphic system described earlier, subjects could not choose any location of view and point of view in the Aspen system. As described earlier, the trade-off included the detailed imagery available to the subject, the ease of recording subject travel, and ease of subject interaction.

Of course, it is rather nonsensical to argue that a video-disk system is a valuable tool to the psychological researcher simply because it allows the researcher to solve some technical problems inherent in other delivery systems. This makes the system admirable, but it doesn't necessarily prove it to be a good research setting for the study of spatial learning. The strongest argument to be made in this regard is that interaction with the system is equivalent to interaction with environments, and, hence, that study of system interaction is the same as direct study of environmental learning, with the advantages of a controlled setting. This argument in its strongest form is clearly inappropriate. Subjects can tell the difference between manipulating a video-disk system and moving through the world. Additionally, predominately visual information is presented with the video disk, whereas exploration in environments provides other sensory inputs, including kinesthetic and olfactory

Table 3
A Consideration of a Computer-Controlled Video-Disk Display System in Terms of Content, Presentation, and Response Recording Characteristics

Computer-Controlled Video-Disk System (The Aspen Project)
Content
<ul style="list-style-type: none"> —still or moving pictures —disk preparation expensive initially, although multiple copies are readily available —detailed displays —displays are media independent —large number of images on a single disk (54,000) —not easily changed
Presentation
<ul style="list-style-type: none"> —ease in the control of sequencing —timing precisely controlled with computer —response-contingent displays easy
Response Recording
<ul style="list-style-type: none"> —recording of responses possible with system —flexible subject interaction —direct recording of subject selection

sensory data. And, objects surround the observer in the environment, whereas they are viewed on a single screen in a standard video-disk display.

The fact that the disk experience and the environmental experience are not equivalent does not rule out the usefulness of the disk to the researcher. For it is the phenomenon of learning about spatial layouts that is of interest, to many psychologists at least, and hence the criteria for a research setting is that the kinds of learning observed are the ones that are of interest for a range of theoretical and practical reasons.

ASPEN: A PILOT STUDY

In order to assess the Aspen video-disk system as to its effectiveness in replicating basic spatial learning phenomenon, I conducted a pilot study at M.I.T with the assistance of Robert Mohl. In this study we observed eight people who explored Aspen using the system for a period of approximately 2 h each. As subjects operated the system we video recorded the information they selected (recording the video from the video disk, which was also presented on the display screen) and audio recorded their comments as they moved through the town. This provided a record of each subject's experiences and of individual strategies used in moving through the town. Midway through the experimental sessions and at the end of the sessions, subjects were asked to draw a map of the town, to indicate which of a set of buildings shown as still photographs they had seen on their travels, and to indicate where each of the buildings was located.

The observations proved to be extremely positive as an evaluation of the disk system, as subjects engaged in activities consistent with intuitions and research about how people learn places. As an example, consistent with general concepts of learning, subjects initially moved about in a somewhat random fashion, learning only general features of the town. Then, as they encountered familiar areas, they integrated their experiences and moved through the town in a more systematic fashion. In addition, subjects made a number of errors in their explorations that are consistent with other data on place learning. As examples, objects viewed first from one direction and then the other were frequently not recognized to be the same objects, and hence inaccurate parallel structures were derived and opportunities for integration were missed. Curves that took viewers to the right or left without their making a decision were frequently forgotten and inconsistent representations were then forged; representations were challenged and reconfigured only after a large number of inconsistencies were observed. In addition, external landmarks, the mountains in the case of Aspen, were frequently confused with one another, and these landmarks then provided subjects with compelling but inaccurate orientation information.

Another observation that provides assurance that the disk system is valuable in studying spatial learning was that subjects engaged strategies much like those reported by individuals interviewed about how they learn places, strategies which are also consistent with general models of learning. One popular approach was the "mother-child" strategy. Subjects using this strategy moved very slowly and conservatively through the town, backtracking frequently to their original position, or, as they learned the town, to places that had known connections to the original position. An alternative was the "roam far and wide" strategy. Subjects using this strategy moved very quickly through the town, in search of landmarks, of edges of the town, and anything else noteworthy. Only after establishing these major features did they attend to the local features or objects.

It was also encouraging to note that world knowledge gathered in actual movement through towns greatly influenced the explorations. Subjects were continually looking for a downtown section or trying to figure out the nature of the town's economic base. In addition, they attempted to make inferences about the activities of the town from cues such as the mountains and the kinds of buildings in the town; they attempted to find interesting places, and they made judgments about whether or not they would want to visit the town.

The map drawings also indicated that subjects using the video-disk system were thinking about Aspen much as they would if they had been there, and the recognition data indicated that they were effective in learning the objects in the town. In the map drawings, one found the same kinds of distortions as noted in the cognitive mapping literature (the advantage being that in the video-disk system experiences that generated the maps could be documented). Local features of different regions were indicated frequently, even though the regions were not accurately related to one another on the map. Additionally, entire segments of the town were completely omitted, even though they had been explored. Parallelism was assumed in many cases in which it was inappropriate. Distinctive objects were included on the map, whereas ordinary appearing objects were omitted. Frequently two different objects were assumed to be the same due to overgeneralization. This resulted in globally inconsistent representations.

The parallelism of these and other observations with observations made in other contexts suggests that the use of a video-disk system to study spatial learning can be very productive. Phenomena noted in other well-investigated contexts appear in a setting in which detailed observations can be made and control over environmental presentations can be obtained. In this particular example, the observations have lent support for a "tabletop model" of spatial learning which I am now evaluating. The model asserts basically that in initial spatial explorations viewers learn the appearance of a set of objects in the environment. As these objects are

reencountered, a subset is recognized. Recognition of objects at different times provides the viewer with information about the coincidence of different routes, and the locations of the objects recognized become constrained. An object that earlier was simply next to a second object or along the route between two other objects is now both next to the second object and between the two other objects. As these kinds of constraints are placed on object locations, information about the characteristics of the plane on which the objects are located (the tabletop) are derived. This plane then provides a context for the placement of other objects that are encountered. Whereas the initial objects encountered are strung together by adjacency relations and constrained by consideration of multiples of these relations, later objects are learned directly as objects located upon a plane (a tabletop) whose characteristics have been derived from consideration of initial experience.

Evaluation of such a model is, of course, only one of the many possible applications of the video-disk technology to the study of learning. This technology provides a general arena in which the phenomena observed in the field relevant to spatial learning can be replicated, and it provides a tool in which high levels of control can be accomplished without sacrificing realism of display. For psychological researchers the video disk provides a delivery system that moves beyond the capabilities of standard media and, in many dimensions, beyond available computer graphic systems in the display of complex materials. It is one of the new technologies that not only is elegant but also promises to facilitate psychological researchers' abilities to address classes of research questions that to date have been difficult, if not impossible, to approach.

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