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The Effects of Symbol Iconicity on the Integration of Spatial Knowledge Acquired
from the Fly-through Navigation of Simulated Environments

A Dissertation submitted in partial satisfaction
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in

Geography

by

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December 2001
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ABSTRACT

The Effects of Symbol Iconicity on the Integration of Spatial Knowledge Acquired from the Fly-through Navigation of Simulated Environments

by

David Lenn Dow

With the development of the computer and related technologies has come revolutionary changes in how we collect, process, analyze, and view data about the world around us. The potential use of "virtual reality", or computer generated simulated environments, for the display of geographic data raises issues regarding the appropriate representation of spatial data in support of spatial learning and decision making. Understanding the relationship between the methods of presenting spatial data and the acquisition and representation of that data in human spatial knowledge structures is at the core of cognitive studies in cartography and GIS.

This research examined the effects of the level of abstraction of surface feature representation on the perception, and subsequent storage of spatial information obtained in fly-through navigation of natural-terrain, virtual environments. Employing a number of spatial learning and memory tasks, commonly used in spatial knowledge acquisition and wayfinding research, this research evaluated the relationship between the representation of spatial information and subjects' integration of that information. In this research, four levels of abstraction were tested, representing different positions on the continuum of "iconic" to "abstract" representation. The most "iconic" of the representations used in this research employed unclassified aerial photographs "draped" over a digital elevation model. "Moderately iconic" representation employed prototypical texture "drapes" for each thematic land-use class, "cartographic iconic" symbology
employed pictoral symbols for each of the land-use classes, and "arbitrary cartographic" symbology employed color to represent land-use classes.

While overall, the findings of this research were not unexpected, it was found that performance of certain tasks (and thus, the spatial knowledge acquired) was, indeed affected by the symbols used to represent the land use of the study area. Additionally, this research has demonstrated how a variety of experimental tasks, more commonly associated with spatial knowledge acquisition and wayfinding research, can be used to evaluate the effects of differences in visual representation on the acquisition and use of spatial knowledge derived from computer generated environments.
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CHAPTER 1

Introduction

With the development of the computer and related technologies have come revolutionary changes in how we collect, process, analyze, and view data about the world around us. Satellites daily monitor the atmosphere, oceans, and continents of the earth, transmitting data around the clock to collection centers that distribute the data to scientists worldwide. With the availability of such wide ranging, immense, data sets have come new ways of storing, manipulating, and viewing the data. Hardware unheard of 30 years ago is now available, ranging from multi-million dollar “super computers” that can perform trillions of mathematical operations each second to desktop computers with the ability to perform hundreds of thousands of calculations per second. Database management systems capable of storing and manipulating large data sets are now commonplace. Image processing systems help analysts interpret satellite data, and geographic information systems allow users to perform spatial analyses only imagined some twenty years ago. Along with these
changes in how we obtain, process, store, and manipulate data have come new ways of viewing the data and the results of analyses based on those data.

Cartographers have historically concerned themselves with the production of paper maps; however, Robinson's (1952) *The look of maps: An examination of cartographic design*, signaled the beginning of the era of scientific, cartographic research. From the 1950's through the early 1980's this research largely employed a psychophysical research paradigm which was of little practical utility in either the design of maps, or the understanding of the map-use process (Petchenick, 1983). Since that time, however, the focus of cartographic research has shifted from a goal of finding the rules for creating perfect maps employing a communication model, to understanding the relationships between the cognitive processes of map users and the physical properties of mapped information using an information processing approach.

With the recent advances in technology, cartographic research has also expanded its focus from concern exclusively with printed maps to the new ways to view or 'visualize' data using cathode ray tubes (CRTs), projection devices, head mounted displays, haptic input and output, sound, and motion platforms. These devices allow animation of maps (or parts thereof), incorporation of sound, unlimited colors, stereoscopic viewing capabilities, and the ability to interactively change viewing perspectives. Application and development of these technologies falls under the general heading of "visualization" or "scientific visualization". Visvalingam (1994, p.19) defines visualization as "primarily a mental process which
serves a variety of purposes, including visual analysis. Visual analysis refers to the use of visualization as a distinct method of inquiry for provoking insight and for concept refinement." A slightly different definition of visualization can be found in Haber and McNabb (1990, p. 75) who refer to visualization as a process composed of "transformations that convert raw simulation data into a displayable image. The goal of the transformation is to convert information into a format amenable to understanding by the human perceptual system." McCormick et al. (1987, p. 3) further defines the discipline of scientific visualization as a "discipline concerned with developing the tools, techniques and systems for computer-assisted visualization. It studies those mechanisms in humans and computers which allow them in concert to perceive, use and communicate visual information." Earnshaw and Wiseman (1992) define scientific visualization as a process of exploring data and information graphically, as a means of gaining understanding and insight into the data.

While these definitions seem to describe a "new" research method for application in the sciences, visualization techniques such as model building have long been employed in molecular research (Watson and Krick's discovery of the structure of DNA), and in a purely mental sense by Einstein who reportedly stated that he could "see" how his theory of general relativity worked ten years before he could prove it mathematically. Likewise, the concept of data visualization is not new to fields of geography and cartography.
Much geographic inquiry is rooted in empiricism. It seeks to discover and provide explanations for the patterns and relationships which exist and the expectations which are violated in our physical and human environment. Geographers have traditionally used visual analysis because the display of data within a spatial framework enables us to recognize patterns almost instantly.

Cartographic maps, based on the geographical framework, have been widely used in geographic analysis. Maps reduce our worlds of enquiry into assimilable proportions and cast them into shapes from which we can derive information. The common frameworks for visual cross-referencing and for linking of data on different map coverages enable us to use our personal stores of loosely structured geographical knowledge during interpretive stages.

(Visalingam, 1994, p. 19)

Therefore, what is new to the fields of geography and cartography is not the process of visualization, rather, it is the range of representational possibilities brought about by the recent advances in computer hardware and software.

At the cutting edge of visualization research is the much hyped, but never achieved illusion created by the technology called “virtual reality” (VR). The illusion that is sought with this technology is one in which the simulated environments “look real, act real, sound real, and feel real (Sutherland, 1965).” According to Loeffler and Anderson (1994, p. xiv), virtual reality is “a three-dimensional, computer generated, simulated environment that is rendered in real time according to the behavior of the user.” Further, Loeffler and Anderson assert that of paramount importance is whether the simulated environment is realistic or highly abstract, maintaining that the complexity and multi-dimensionality of the interface must produce a sense of presence in that environment. This illusion has yet to be
achieved. While some applications have achieved the lesser goal of a suspension of disbelief by the user, none is so realistic that it actually looks, acts, sounds, and feels real. A more conservative term for this level of simulation is “virtual environment”. A virtual environment might then be defined as an interactive, animated display of data that allows users to achieve the feeling of immersion in the synthetic space.

With the increasing interest in the application of VR technologies to geographic data visualization has come a need to understand the relationship between the presentation capabilities of the technology, the cognitive abilities and mechanisms of the individual, and the spatial information and knowledge obtained by individuals using the technology. “Perhaps the fundamental question that all researchers would raise and that has barely been touched is, how do variations in the environment itself influence the nature of cue selection and the storage of environmental information?” (Golledge, 1987, p.164). While Golledge was more than likely referring to human perception and cognition in the natural environment, a similar statement could be made regarding virtual environments. Clearly, simulated environments are not perceived the same as the natural environment. Gibson (1979/1986) describes the perception of encoded information as “mediated” perception, recognizing that mapped information is different than information afforded by natural environments. The fact that mapped information is simplified, symbolized, and categorized, and that the mode of data acquisition utilizes different perspectives and scales, intuitively leads one to wonder about the similarities and
differences between spatial knowledge acquired in natural vs. mediated format.

Research supporting the existence of some of these differences can be found in
Thorndyke and Hayes-Roth (1982), Goldin and Thorndyke (1982), and Presson,

With the widespread interest in applying V.R. technology to the presentation
of spatial data, it is important that research address the fundamental issues
concerning the display and transformation of these data into spatial information and
knowledge. Specifically, this project will assess the effects of the level of
iconicity/abstractness of the symbology used to represent land cover classes on the
acquisition of spatial knowledge during fly-through navigation of large-scale virtual
environments. Recall tasks will be employed to assess how the representation of
data affects both the characteristics and quantity of landmark knowledge acquired,
the accuracy of distance and angular estimates, and subject’s ability to use this (and
other) information to accurately reproduce a path through the virtual environment.
The results of this research will benefit the application and development of
cartographic principles in the use of simulated environments for data display, as well
as, broadening the understanding of spatial knowledge acquisition within virtual
environments.

This research is concerned with the evaluation of spatial knowledge
acquisition when employing various cartographic techniques in a VR application and
is not a comparison between VR technology and other spatial learning tools.
Therefore, no recommendation will be made regarding the appropriate use of these technologies versus other, more common and less expensive tools, such as maps. As further research guides design and application of VR technology, it is hoped that such comparisons will become available. In light of the high cost of implementing VR technologies, it will be important to identify when that technology is appropriate, and when traditional maps, written narratives and other geographic information technologies are sufficient, lower-cost alternatives.
CHAPTER 2

Literature Review

Research issues relevant to this project include: 1) the mental representation of spatial knowledge, 2) the acquisition of spatial knowledge, 3) methodologies for assessing the contents of spatial knowledge structures, and 4) applied research on simulated environments and spatial cognition.

The Mental Representation of Spatial Knowledge

A great deal of the recent work in the area of spatial knowledge structures in humans has been associated with the cognizant map. The roots of that term can be traced to Tolman's (1948) "place learning" theory which proposed that a rat's ability to employ map-like representations within its nervous system could explain a demonstrated ability to develop shortcuts from previously experienced movements through a maze. While Tolman's research was conducted with rats, many researchers contend that humans also employ analogous structures and mechanisms. A number of alternative terms such as cognitive configurations, cognitive images,
cognitive schema, mental maps, mental images, and topological schema are also used to identify conceptually equivalent, or similar structures and mechanisms. Rather than attempting to identify all of the various terms found in the literature, and explain the nuances in concept that differentiate one from another, this review will concentrate on the assumed characteristics of spatial knowledge structures in humans. For a review of these terms and concepts the reader is directed to Kitchin (1994).

In a sense, human spatial knowledge structures can be considered analogous in general functionality to geographic information systems (GIS) (Golledge, 1992; Peterson, 1995). As is the case with GIS, the basic functions required of spatial knowledge structures in humans include the abilities to input or encode spatial information, store that information, edit and update information, apply that information in problem solving, and output the results. In GIS this output can be in the form of a map, in humans this output is often in the form of spatial behavior. The cognitive map is assumed to be the repository of multi-modally acquired information that results from the mapping of spatial and environmental information. Downing (1992, p. 442) states that cognitive maps “sustain impressions, thoughts, feelings, and ideas until, for some reason, consciously or unconsciously, the mind solicits, changes, and often distorts or manipulates its contents for some immediate purpose.”

The hierarchically differentiated models of spatial knowledge structures in
humans have become the accepted paradigm in spatial cognition research. According to these models, human knowledge structures can be explained by employing three general types of spatial knowledge that represent a progressively more complex, hierarchical, representation of geographic space. Two variations of these models are described in Siegel & White (1975) and Golledge (1991). According to Siegel & White (1975, p. 23), landmarks are unique patterns or configurations of perceptual events used as “proximate or intermediate course maintaining devices” during movement or travel. In children, landmark knowledge is believed to be the first type of knowledge to develop since it represents an early step in spatial awareness, the differentiation and identification of discrete environmental objects (Siegel et al., 1978). While Siegel & White identify the most basic type of spatial knowledge as “landmark” knowledge, Golledge asserts that landmark knowledge is actually a subset of what he calls “declarative knowledge.” It is this type of spatial knowledge that is found in small children who have not developed the ability to understand or incorporate higher levels of spatial knowledge and in adults when they are first exposed to novel environments. Golledge proposes that declarative knowledge is composed of geographic facts, and can be divided into three distinct types: 1) recognition of the existence of a place with no knowledge of its characteristics or location, 2) knowledge of some characteristics of a place (descriptive attributes), and, 3) relative, locational information about a place (always referenced to other places or features). This latter type of knowledge is often
referred to as landmark knowledge.

While both Siegel & White’s and Golledge’s definitions agree that landmark knowledge occupies a position as the least complex type of spatial knowledge, Golledge’s use of the term “declarative knowledge” has proven problematic for some. In psychological literature the term “declarative knowledge” refers to knowing the “what” of an object (Montello, 1999). While this definition seems to concur with Golledge’s classification scheme, the psychological definition of “declarative knowledge” would also include any explicit description (verbal, graphic, etc.) of routes or even metric space (Montello, 1999). In this context, the types of spatial knowledge described by Siegel & White (1975) and Golledge (1991) as “landmark knowledge” and “declarative knowledge” respectively, are “declarative knowledge” under the definition accepted in psychological literature. The converse, however, is not true. All knowledge that would be considered “declarative knowledge” under the definition accepted in the field of psychology would not be included under Golledge’s (1991) definition. In addition to the confusion that might develop regarding Golledge’s use of the term “declarative knowledge”, the inclusion of relative locational information in landmark knowledge could be considered controversial. In Siegel & White’s (1975, p. 23) description of landmark knowledge as “proximate or intermediate course-maintaining devices” that identify “specific geographical location[s]” it is implied that some sort of spatial differentiation between these locations must be present in the individuals who posses the
knowledge. It is unclear, however, at what point the differentiation of landmarks, and the relative locational information identified as a third type of declarative knowledge by Golledge (1991) actually become route or survey knowledge.

The second general type of spatial knowledge identified by both Siegel & White and Golledge, representing the second level on a scale of increasing complexity, is procedural or route knowledge. Route knowledge represents the linking together of the landmarks, or the geographic facts, found in declarative knowledge. Through this linkage individuals are able to travel between two places. At a minimum, Golledge (1991) describes route knowledge as containing a set of choice points, or landmarks; paths linking those landmarks; and the actions executed at the landmarks that are necessary to navigate along the path. Also included in this type of knowledge can be the procedures that are necessary to link landmarks in a given mode of locomotion.

The highest level of spatial knowledge, representing the most complete understanding of the relationships among objects, is configurational (survey) knowledge. While Scholl (1996) describes survey knowledge as a system that must contain Euclidean relationships (linear distances and directions) between relevant landmarks, Golledge (1991) maintains that distances need not be known. According to Golledge, configurational knowledge can consist of a network of routes that have been "threaded together", and may contain no more than topological relationships between elements of the network. On the other hand, the network of routes may
contain both topological and Euclidean information, exhibiting varying levels of metric precision.

A number of studies in fields including psychology, biology, and geography recognize this hierarchical model of spatial knowledge structures. From these disciplines come studies regarding the development of spatial knowledge structures and spatial abilities (Golledge, 1978; Golledge et al., 1985; Kostlyn, Pick, and Fariello, 1974; Liben, 1981; Liben and Downs, 1993; Rider and Rieser, 1988; Siegel and White, 1975; Shemyakin, 1962); the structure of knowledge obtained from text and language (Ehrlich and Johnson-Laird, 1982; Franklin, 1996; Franklin and Tversky, 1990; Freundschuh and Mercer, 1995; Taylor and Tversky, 1995); and the differences between knowledge obtained through direct environmental experience and map knowledge (Evans and Pezdek, 1980; Lloyd, 1989; Presson, DeLange, and Hazelrigg, 1989; Sholl, 1987; Sholl, 1995; Thorndyke and Hayes-Ross, 1982).

The Acquisition of Spatial Knowledge

Much of the research regarding the acquisition of spatial knowledge can be traced to the developmental theory proposed by Piaget and Inhelder (1967). According to this theory, humans progress in their ability to comprehend spatial relationships from infancy into adolescence and early adulthood. This ontogenetic progression (development over time), as interpreted by Hart and Moore (1973) and Siegel and White (1975) involves changes from "egocentric to allocentric knowledge,
from topological to fully metric comprehension of space, from knowledge structures dominated by landmarks to those where landmarks and connections between them are processed into routes, to full configurational understanding of the layout of a specific environment” (Montello, 1998). While this theory seems to indicate that once an individual reaches the highest stages of comprehension of spatial relationships (survey knowledge) all future knowledge will be understood at this level, this does not seem to be the case. Because of the “piecemeal” nature of spatial knowledge acquisition as experienced when an individual moves through a new environment, it is believed, in what Montello (1998) describes as “the dominant framework” (Montello, 1998, p. 143) that a microgenetic progression (progression with increased familiarity) occurs.

According to the dominant framework of microgenetic progression, adult individuals go through stages similar to those experienced in ontogenetic development. In this view of knowledge acquisition in novel environments, only landmark and route knowledge are collected in the early stages of microgenetic progression. It is only after landmark and route structures are sufficiently formed that metric knowledge is collected, eventually resulting in the creation of configurational representations (survey knowledge). In his criticism of the dominant framework, Montello, while acknowledging that individuals may not acquire complete survey knowledge of newly experienced environments upon first exposure to those environments, dismisses the assertion that individuals are incapable of
acquiring metric knowledge prior to establishing landmark and route knowledge structures (Montello, 1998). Regarding the microgenetic progression of spatial knowledge acquisition, Montello (1998, p.164) states:

1) “There is no stage at which only pure landmark or route knowledge exists, knowledge that contains no metric information about distance and direction (relative locations of places). Metric configurational knowledge begins to be acquired on first exposure to a novel place.”

2) “As familiarity and exposure to places increases, there is a relatively continuous increase in the quantity, accuracy, and completeness of spatial knowledge (a quantitative rather than qualitative shift).”

3) “The integration of knowledge about separately-learned places...into more complex, hierarchically-organized knowledge structures represents a significant and relatively sophisticated step in the microgenesis of spatial knowledge.”

4) “Individuals with equal levels of exposure to place will differ in the extent and accuracy of their spatial knowledge...especially...with respect to the degree of knowledge integration.”

Therefore, it can be expected that in experiments that attempt to measure the microgenetic acquisition and integration of spatial knowledge in novel environments:
1) the existence of metric information will not necessarily signal a configurational understanding of space, 2) over time the accuracy and completeness of spatial knowledge should occur, and 3) variation in rates of knowledge acquisition among subjects can be significant, especially with respect to the development of configurational knowledge.

In addition to the general models of spatial knowledge acquisition described above, it is important to recognize the effects of information sources and modes of spatial knowledge acquisition on the resulting spatial knowledge structure. In Montello and Freundschuh (1995), the authors identify four sources of spatial data: 1) direct environmental experience - the "original" source of spatial knowledge, 2) static pictorial representations, relatively small 2-D models, diagrams, maps, or even 3-D models of the environment, 3) dynamic pictorial representation, movies, videos, animations, or virtual environments that can show change in features over time, allow simulated movement through a temporally static landscape, or show both change in features and simulate movement; and, 4) language, spoken, written, or presented in some other symbolic form such as sign-languages for the deaf or Braille for the blind.

As important as the source of information about the environment may be, the mode of acquisition, or factors that differentiate these sources may be of greater consequence to the cognitive/perceptual process of spatial knowledge acquisition. Eight factors that must be considered in research regarding the acquisition of spatial
knowledge, or the nature of spatial knowledge structures are: 1) the sensory-motor systems used for information acquisition, including one or more of the following: vision, touch, hearing, vestibular, and kinesthetic senses, and to a lesser extent, smell; 2) static vs. dynamic information, 3) sequential vs. simultaneous acquisition, 4) symbols and their arbitrariness, i.e. does the source of information require translation of symbology?; 5) scale translation, i.e. are the data available at actual scale or is a scale translation necessary?; 6) viewing perspective, i.e. are the data viewed from a 'normal' horizontal perspective, a planimetric view (from directly above as is most often the case with maps), or from an oblique viewing angle?; 7) precision of representation; and 8) inclusion of detail (Montello and Freundschuh, 1995).

Theory regarding the visual perception of spatial information has taken two distinct paths in the field of psychology. These approaches, the cue approach and the ecological approach, differ in their positions regarding the sources of depth and distance information in the environment (Goldstein, 1996). According to cue theory, the effect that stimuli in the environment have on the image created on the retina determines the perceived depth or distance for the individual. The cues that are believed to influence perception of depth and distance include: the oculomotor cues, convergence and accommodation; pictoral cues including overlap, size in the field of view, height in the field of view, atmospheric perspective, familiar size (of objects), linear perspective, and texture gradient; the movement produced cues,
motion parallax and deletion & accretion; and binocular disparity and stereopsis (Goldstein, 1996).

The ecological approach (ground theory), proposed by J.J. Gibson, suggests that depth and distance estimates can be obtained directly from the information found in the optical array. This information is contained in stimulus texture gradients, flow patterns (during movement), and in an object's horizontal ratio (Goldstein, 1996). According to ground theory, retinal image and information processing are unnecessary to the perception of depth and distance. The information believed important to human navigation, from both the egocentric and allocentric perspectives, are available from visual flow in the form of perspective structure (the indicator of self-motion and self-to-object relationships) and invariant structure (the indicator of object-to-object relationship)(Sholl, 1996).

While the direct perception of some spatial properties can be explained using Gibson's "ground theory", cognitive issues, spatial memory, and internal representation of spatial information in humans are ignored in this approach.

Whether this reflects a defensible ideological position as articulated by his followers (Turvey, Shaw, Reed, & Mace, 1981), a pragmatic ordering of research priorities as indicated by Gibson himself (1950), or a fundamental naiveté as suggested by Marr (1982, p. 30) this almost blatant disinterest in the face of steady and almost brilliant progress in the fields of neuroscience and psychophysics strikes me as a major limitation, particularly now. (Nakayama, 1994, p.334)
"Visual systems like the fly's serve adequately and with speed and precision the needs of their owners, but they are not very complicated; very little objective information about the world is obtained" (Marr, 1982, p. 34). To accommodate human needs, more information than is provided in Gibson's approach is required. Marr (1982, p. 36), echoing Warrington and Taylor (1973) states:

[the] quintessential fact of human vision [is] that it tells about shape and space and spatial arrangement. Here lay[s] a way to formulate its purpose-building a description of shapes and positions of things from images. Of course, that is by no means all that vision can do; it also tells about the illumination of surfaces that make the shapes-their brightness and color and visual textures-and about their motion. But these things seem secondary; they could be hung off a theory in which the main job of vision was to derive a representation of shape.

Thus, while some spatial properties may be derived directly from the environment through visual perception, as asserted by Gibson, a cognitive process involving objects in space is required by humans.

To comprehend our environment, it is necessary for us to make sense of the vast number of "to whom it may concern" messages that emanate from the world in which we live (Golledge and Stimson, 1987, p 1). To take advantage of this information requires mechanisms that allow us to perceive, encode and store, manipulate and process, and develop knowledge that can be used to guide our actions. Echoing Kaplan (1976), Kitchen (1994, p.2) maintains that these abilities
"give man a selective advantage in a dangerous world" and represent a kind of knowledge that gives man a "sense of place necessary for survival."

In the field of cartography, the focus of most of the research has been directed toward either the map itself or the relationship/process that exists between the map and the user. To this end, most cartographic research has investigated issues associated with data acquisition from static representations (maps), in a simultaneous acquisition mode. Research by Jenks (1970, 1973, 1975), Dobson (1977, 1979), and Steinke (1979) attempted to "learn more about the map reading activity as it might be revealed by eye movement recordings... [and] determine if the presence or absence of certain map elements affects the way the map is read" (Steinke, 1987, p. 55). These studies attempted to determine how maps are scanned for information, if there are particular locations of high salience on maps, or if subjects employed uniform scan paths to explore maps. While these studies found some consistency regarding where subjects began their scans and confirmed subject’s abilities in finding and directing attention to elements containing the most useful information, little was learned regarding how subjects directed their scans so successfully. On this problem, Steinke (1979, p. 245) commented:

... cartographers... are concerned with cognitive images that are formed and the cognitive information that is produced when a person looks at a map. Eye movement recordings are of relatively little direct help to cartographers interested in these kinds of problems. These recordings do not allow us to
get inside a person’s brain to see how a cognitive image is formed or to learn about the nature of the image. From recordings we can tell where the person looked on the map but we can not tell what the person saw, nor what effect his seeing a part of the map had on his understanding of the real world.

Thus, simply knowing where a person looked on a map is far less important than what was learned by the individual looking at that map. How then, can visual variables be manipulated to “focus attention on elements that can assist in learning the environment portrayed in the map” (personal communication, Golledge, 1999), becomes the operative question.

MacEachren (1995, p. 270), credits Bertin with being the first to “formally propose a set of fundamental visual variables that serve as the building blocks for all map sign-vehicles.” These variables are the features and dimensions that are manipulated by cartographers to imbue meaning upon the signs (symbols) used on maps. The variables identified by Bertin (1967) include location, size, value, texture, color, orientation, and shape. To this basic list others have refined or added additional variables for consideration. Caivano (1990) for example, subdivided texture into three variable dimensions (directionality, size of the texture element, and density), while Morrison (1974), redefined Bertin’s seven variables into a system that included size, shape, color (hue, value, and saturation), and texture (pattern, arrangement, orientation). Regardless of whose taxonomy of visual variables is used, each represents the convergence of the capabilities of the human visual system and
the limitations of the particular cartographic medium (e.g., the use of the cathode ray tube (CRT) as a cartographic medium has led to the inclusion, by some, of motion as a cartographic variable).

These same variables are identified as "features" and "dimensions" in visual search research in psychology and cartography. This research, which is most widely identified with Treisman and Gelade's (1980) Feature Integration Theory of Attention (FIT), Treisman (1988), and Cave and Wolf's Guided Search Theory (1990), proposes the processes that are used to search for objects in a two-dimensional visual array. According to the FIT (Treisman and Gelade 1980, Treisman 1988, Treisman 1991), visual search can be broken down into two distinct types: the parallel search and the serial search. The parallel search according to FIT is an automatic, bottom-up process, in which objects in the visual field are mapped into 'feature maps in memory'. These 'feature maps' are created automatically, without the use of focal attention, and are distinct in the feature mapped.

According to Treisman (1980), the different features are color, brightness, spatial frequency, shape, size, orientation, and similarity of movement (very much like the Gestalt perceptual dimensions). One type of search that is of great interest in FIT is the "feature search." A "feature search" is conducted within only one feature map and is focussed on a particular dimension of that feature (e.g., a search for the dimension 'green' within the feature 'color'. According to FIT, the search should be very fast (almost instantaneous), should not be affected by the number of objects in
the field (distracters), should not require focal attention, and should encode additional information such as location.

In contrast to the “feature search” which is believed to employ parallel processing, the “conjunction search” employs serial search processes. Conjunction searches could be described as searches in which the subject is required to integrate information about specific dimensions from two or more feature maps. In these searches, specific combinations from each feature map are required (e.g., a green object with a particular orientation). The proposed mechanism for this type of search requires that focal attention be applied serially to each object in the visual field to ‘glue’ the conjunction together, thus, making the conjunction recognizable. Since this type of search requires the application of focal attention to each individual object in the visual field, the number of objects (or distracters) that are attended to will affect the time required for the search.

Another theory of visual search is the Guided Search Theory (GST) proposed by Cave and Wolfe (1990). While the GST finds its roots in Feature Integration Theory, the theories are in disagreement regarding the order, and strategies employed in visual search tasks. According to Guided Search Theory, the first part of a visual search does involve a parallel search; however, no identification or decision is reached at this stage. Instead the information in the various feature maps is combined into an “activation” map that is used in the serial search to find particular features or combinations. The “activation map”, then, is a probability map.
that is used to select the best places to begin focusing attention. If the desired conjunction is not found immediately, the next best place in the “activation map” is attended to, then the next, and so on. Whether the search is a “feature search” or a “conjunction search” it is within the serial search phase, based on the application of attention, that objects are identified or located. The quick reaction times and shallow slope of graphs depicting reaction time as a function of number of distracters describing feature searches in FIT are attributed to the efficient coding of unique dimensions from the feature maps to the activation map. This efficiency means that the number of probable locations is extremely small and the activation map is highly accurate in locating objects for attention.

A survey of these theories of spatial knowledge acquisition show that each (aside from Ground Theory vs. Cue Theory or Feature Integration Theory vs. Guided Search Theory) explains either a unique source of knowledge, mode of acquisition, or task domain. In both Ground Theory and Cue Theory the source is assumed to primarily involve the natural environment, although some application to mediated perception is assumed, while FIT and Guided Search have only been examined in the map or graphics domain. As both Ground Theory and Cue Theory involve movement through the environment, FIT and Guided Search are concerned with stationary information collection from scaled down representations of the environment. Finally, Ground Theory and Cue Theory are concerned primarily with the acquisition of speed, distance, and direction information while FIT and Guided
Search are concerned with the mental structures and mechanisms employed in object searches. To dismiss these theories as not applicable to the questions being asked in this research is, however, to suggest that perhaps human spatial abilities are so disparate and compartmentalized we must possess a different structure or mechanism for each ability. Instead, I suggest that each of the theories offer an explanation for a highly integrated, multi-modal collection, processing, and retrieval system. By integrating the findings from each of the previously mentioned theories and models we might conclude the following about that spatial information.

1) In some instances, spatial information is acquired through a direct perceptual process (as expressed in Ground Theory, Feature Integration Theory, and Guided Search Theory).

2) Higher-level abilities such as object recognition require cognitive processes and directed attention (as expressed in Cue Theory, Feature Integration Theory, and Guided Search Theory);

3) The ability to discriminate objects (landmarks) in the visual array, and the salience of objects is dependent on the unique combinations of variables (features and dimensions) present in cartographic symbols or real-world entities (as expressed in Cue Theory, Feature Integration Theory, and Guided Search Theory).
4) Senses used, mode of acquisition, and the task domain in which persons are engaged affect the data that are encoded.

5) Objects are stored in knowledge structures that integrate the information into more complex, complete, and accurate representations of spatial configurations.

In addition to the previously described research and theory of spatial data acquisition, there also exists a great deal of applied research on map reading and learning. Thorndyke and Hayes-Roth (1982, p. 560), in a comparison of spatial knowledge acquired from maps and navigation found that:

From a map, people acquire survey knowledge encoding spatial relations. This knowledge resides in memory in images that can be scanned and measured like a physical map. From navigation people acquire procedural knowledge of the routes connecting diverse locations... With moderate exposure, map learning is superior for judgements of relative location and straight-line distances among objects. Learning from navigation is superior for orienting oneself with respect to unseen objects and estimating route distances. With extensive exposure, the performance superiority of maps over navigation vanishes.

Sholl (1995, p. 177), explains that:

While both the environment and maps provide information about interrelations among elements comprising space, they differ in ways attributable to the symbolic function served by maps, including but not limited to, differences in scale, perspective, boundedness, and topological relation to the viewer. Maps are small in scale, providing an aerial
perspective of the layout of the environment, and have distinct boundaries... In contrast, environments are large in scale, are viewed from the ground, and are essentially unbounded (although they do contain natural and artificial barriers that can obstruct travel).

According to Sholl, while in the case of maps all of the spatial relationships are simultaneously accessible and can be encoded by shifting visual fixation from one part of a map to another, in the environment the interrelationships among landmarks and surfaces enfold over extended temporal and spatial intervals. Not mentioned by Sholl, but undoubtedly important, is the orientation of maps (typically aligned with the top of the map representing north). Inclusion of this information promotes alignment of landmarks and surfaces using cardinal directions resulting in an allocentric frame of reference.

Other research on map learning includes Sholl and Egeth (1982) and Thorndyke and Stasz (1980) who attempted to determine “to what extent do the cognitive processes underlying map learning performance overlap those processes required for map-reading?” While Thorndyke and Stasz expected that expert map-readers would prove better map learners than naïve map-readers, there was no apparent relationship between map-reading ability and map-learning ability. Of the eight subjects tested, the map-reading experts ranked first, sixth, and eighth in terms of map-learning performance. While both good and poor learners recalled an equal number of verbal elements they differed in the number of spatial elements they could recall. Regardless of map reading ability, Thorndyke and Stasz found that the
best map learners employed spatial learning strategies (i.e., imagery, relational encoding, chunking or regionalizing, and pattern encoding).

**Methodologies for Assessing the Process of Spatial Knowledge Acquisition**

The observation of human behavior in the environment is one method used to discover or uncover not only the patterns of movement when confronted with a navigational task but also to observe reactions to various stimuli that may be encountered in travel. This technique can be employed in both familiar and unfamiliar environments, and can employ either naturally occurring, or simulated (controlled) settings. While these methods are widely used (Zannaras, 1973; Piaget and Inhelder, 1956), the procedures are generally more involved than simply watching and recording. To get at the cognitive underpinnings of particular actions, choices, and structures subjects are often asked to: perform particular tasks which may involve simulating route travel using maps, identifying locations or objects from maps, arranging objects within the confines of an analog modeling context, or locating objects during travel. The skills that are assessed in these studies include cognitive, concrete, psycho-motoric, motoric, abstract, and relational types with the external form of the tasks ranging from observations to viewing photos, charts, tables, and models (Golledge 1976).
The analysis of external representations or “spatial products” (Liben 1981b) is another widely used method in human behavioral research. External representations include: sketch maps (Blades, 1990; Klett and Alpaugh, 1976), written reports or descriptions, oral reports, lists of remembered objects, reports of procedural knowledge, analysis of object arrangement on models of the environment. These self-report methods have been used to identify both the “information trace” and the “process trace” of individuals (Pick et al., 1995), shedding light on both the contents and mechanisms under investigation. The information obtained using these methods include knowledge of the types of environmental cues attended to by subjects, what locations or features along paths are critical in a procedural knowledge sequence and what types of knowledge are not coded in spatial memory. Additionally, ranking of features and verbal estimations of distance have proved useful when applied within the context of multidimensional scaling. Self-report methods such as oral reports and descriptions allow for the discovery of affective impressions of the environment that might be missed or misinterpreted during observation of movement in the environment.

While the analysis of external representations is regarded as an important source of data regarding knowledge structures, it is not without problems. Several problems associated with map products made from memory are: 1) the schematic and incomplete in nature of the sketch maps; 2) the recognition that sketch maps are not analog representations of a person’s spatial knowledge of a place; 3) that sketch
maps generally contain a large amount of error in the metric information (be it from error in perception, storage or recall); 4) that sketch maps are subject to both quantitative and qualitative change over time; and 5) variations in subject's artistic abilities. Recognizing the existence of these problems Blades (1990), none the less, reports that certain landmark and route features remain stable in subject's memories over the course of a week's time (as described using sketch maps). According to Blades, while familiarity with a location affected the quantity of spatial information included in a sketch map, the number of landmarks and the shape of the routes themselves remained relatively stable over a short period of time (one week). While these findings speak to the stability of certain components of spatial knowledge, it is believed that with time the hierarchical structure of spatial memory will become more schematic with the lower members of the hierarchy being lost. Additional problems with the use of sketch map methodology are the effect that individual graphical ability will have on which features will be drawn, which will not, and which features are recognizable to the researcher, as well as, questions relating to the interpretation of features from these various representations. As Golledge (1976) points out, Euclidean metric measurements seem inappropriate to the study of sketch maps. Without understanding the scale transformation employed "subconsciously" by the subject, the researcher can only assume that the metric information is in error, and therefore, inadequate for detailed interpretation.
In research investigating the perception of distance in natural environments, viewed from a fixed vantage point, Loomis et al. (1992) employed several self-reporting techniques to measure subjects' accuracy. These tasks included a matching task, a "blind walking" task, and a continuous pointing task. In both the "blind walking", and pointing tasks blindfolded subjects were asked to either reproduce the perceived distance to the previously viewed object by walking that distance, or point at the object while walking on a line parallel to the object (a form of triangulation). Pointing, as a means of determining accuracy of subject's mental representation of spatial configurations has been employed by a great number of researchers including Thorndyke and Hayes-Roth (1982), Tillauka and Wilson (1998), and Jacobson et al. (1998).

Another method used to gain insight into both content and processes employed in spatial knowledge acquisition and storage is Protocol Analysis (PA) which is the analysis of a subject's thought processes elicited while he/she is performing a mental task. Protocol Analysis is a qualitative method that attempts to collect verbal information from subjects either while engaged in the activity of interest, immediately after performing the task (utilizing short term memory), or after the task has been completed and the information has been stored in long term memory. PA shares many of the criticisms that are lodged against all methods that employ verbal reports and self-reports in general: that these methods are simply "variants of the discredited process of introspection" (Erikson and Simon 1984, p.2)
and "... is worthless for verification" in the discovery of psychological processes. In response to these criticisms Erikson and Simon respond:

"More recent research based on explicit information processing models of the cognitive process has caused thinking-aloud verbalization to be viewed in a new light. It is now standard procedure to make careful verbatim transcripts of the recorded tapes, thus preserving the data in as "hard" a form as could be wished. At the same time, information processing models of the cognitive process provide a basis for making and encoding explicit and objective, so that the theoretical presuppositions entering into that process can be examined" (Erikson and Simon 1984, p.3).

According to Erikson and Simon, by careful attention to design PA can indeed result in discovery and verification of underlying cognitive processes.

While PA is not appropriate for investigating all psychological issues (e.g., reaction-time in stimulus-response/psychophysical testing), it can be an appropriate method for studying issues related to choice behavior, preference, cognitive processes that are directly accessible to subjects, or process/procedural behavior such as is used in expert systems development. Issues of concern which point to some of the possible weaknesses of PA include: 1) the completeness of subject’s reports; 2) inferences drawn by the researcher from the verbal reports; 3) the lack of ability of subjects to verbalize about the process; 4) reluctance of subjects to
verbalize (or withholding of information); and 5) inducing responses consistent with what the subject believes you wish to know.

Applied Research on Simulated Environments and Spatial Cognition

The interest in using simulated environments for training purposes is probably most evident in the field of flight simulation. In some studies, much like the psychophysical research in cartography conducted between the late 1950's and the early 1980's, the focus is on maximizing human performance, rather than understanding the cognitive capabilities and processes employed by users of the simulations. An example of this approach can be found in Kleiss's (1995) research, which employed multidimensional scaling techniques to identify the relative importance of the graphical properties used in simulated low-altitude flight to pilot's simulator control capability. Rather than trying to identify relevant cognitive factors, this study focused on identifying the elements of the environment that could best be manipulated to increase user performance. Along that line, one suggestion of Kleiss's research was that "designers of flight simulator visual scenes should focus specifically on rendering elements of terrain shape and objects in scenes" (Kleiss, 1995, p.711). Kleiss (1995) investigated the "relevant" properties of simulated visual scenes for making size and distance estimations under static and dynamic presentation modes. The properties that were investigated included:
1) hilly/mountainous versus flat (the degree of terrain vertical development);

2) objects versus no objects (object density has been identified as an important factor affecting performance in flight simulation);

3) known size references versus no known size references (the apparent size of familiar features is used by pilots as a cue for distance);

4) texture/detail versus no texture/detail (apparent detail is used by pilots as a cue for distance);

5) complex versus simple (a measure of scene complexity);

6) regular versus random (the orderliness or predictability in the positioning of scene elements);

7) high contrast versus low contrast.

Using a multi-dimensional scaling technique Kleiss found that in a dynamic presentation condition terrain vertical development was the most important scene property necessary for controlling attitude in flight simulators. While some research (Engle, 1980; Kleiss and Hubbard, 1993; Martin and Rinalducci, 1983) indicates that performance in flight simulators improves with increases in object density, Kleiss (1995) found that irregular clustering of objects and variations in the size of objects in clusters resulted in optimum performance. These findings, consistent with the results of Barfield, Rosenberg, and Kraft (1989), indicate that “the important
property of terrain shape relates to smaller-scale terrain elements rather than large
vertical obstructions."

Kleiss's "human factors" approach, then, is an example of empirical,
applications research as opposed to theoretical research. Examples of the latter
would be the work of Aks & Enns (1996) and Goldin & Thorndyke (1982). In these
studies, the focus of the research was on the effects of variables (e.g., texture
gradients, perspective (radial spreading), and compression (foreshortening), modes of
data acquisition, etc.) on the properties of the perceived objects or the resulting
knowledge structures. Other studies of human perception/cognition or
performance in simulated environments investigate: the interaction between visual
target detection and the presence or conspicuity of borders in the simulation (Monk,
1981); the alignment effect when navigating in a virtual environment with map-
acquired knowledge (May, Peruch, and Savoyant, 1995); the task and information
variables that contribute to human performance in low altitude flight (Flach and
Warren, 1995); the importance of textural features to image classification tasks
(Haralick, Shanmugam, and Dinstein, 1973); the use of virtual environments for
learning 'complex scientific concepts' (Dede et al., 1997, Dede, in press); and the
effects of level of immersion on the accuracy of spatial knowledge acquired in a
simulated architectural environment (Henry and Furness, 1993).
CHAPTER 3
Methodology

Introduction

This research examines the effects of the level of abstraction of the representation of surface features on the integration of spatial knowledge acquired in fly-through navigation of large-scale virtual environments. Specifically, this project addresses the effects of the level of iconicity/abstractness of the symbology used to represent landcover classes ("draped" over a terrain model) on the integration of spatial information including: directional/angular information, distance/length information, topographic/landform information, thematic (land use/land cover) information, route learning and recall, and subjects' confidence when performing locational and route reproduction tasks.

It is hoped that this research will benefit the application and development of cartographic principles in the use and development of simulated environments for data display, as well as, broadening the understanding of spatial knowledge acquisition within virtual environments. While much of the research conducted
using conventional map products has resulted in the adoption of practices known as “cartographic conventions”, it remains unclear which of these “conventions” are appropriate for application in simulated environments, or in modes that include movement of the user’s point-of-view.

In this study, land use/land cover information was “draped” over a 3-dimensional terrain relief model using four different methods: 1) geospecific texture, defined by Suter and Nuesch (1995, p. 91) as “icons of a part of the earth’s surface, i.e. satellite images and aerial photographs... recorded directly by a sensor.” 2) geotypical texture (Suter and Nuesch, 1995, p. 91), “small photo patches representative of some type of landcover” 3) cartographic-iconic symbols as textures (e.g. tree shaped symbology representing the class “forest”), and 4) cartographic-abstract symbols as texture(e.g. arbitrary symbology such as dot patterns or colors to represent different categories). These four methods represent distinctly different levels of abstraction ranging from what Robinson and Petchenick (1976, p. 61) call a mimetic image symbol (one in which the map mark “retain[s] some graphic characteristic that can be visually or conceptually related to the referent”) to arbitrary symbology.

As these four methods represent different levels of abstraction, they also offer, or afford, different visual cues, which are used by subjects to perform the various tasks required in this research. Clearly, along the continuum from the “mimetic” (Robinson and Petchenick, 1976, p. 61) air-photo, to the arbitrary, and
symbolic use of hue to identify "type", the quantity, meaning, and utility of many of
the "to whom it may concern" messages (Golledge and Stimson, 1987, p 1) are
altered. Just how this alteration occurs, and what effect this has on the utility of the
information being translated into knowledge by individuals will surely be a matter of
great interest and debate as visualization using simulated environments becomes
more widespread.

Rather than addressing the questions surrounding the change in meaning
derived from the simulated environments, as might be the focus in semiotic research,
this research focuses on the effect that different types of symbology have on the
quantity and accuracy of spatial knowledge integrated during the fly-through
navigation of simulated environments. For the purposes of this research, subjects' 
accuracy in: retrieving distance and angular information from long term memory,
retrieving thematic (categorical, land use/landcover) information from memory, and
route learning and reproduction were compared for each method. Additionally,
subjects' confidence in the accuracy of their route reproduction, and accuracy in
locating "choice points" associated with the routes were analyzed.

**Subjects**

Twenty-four subjects, 16 male and 8 female, were recruited for participation
in this research. Twenty were graduate students from the Department of
Geography, San Diego State University, two were undergraduates from the same
department, and two were college graduates of other institutions with extensive experience with maps, as well as, experience in air-photo interpretation. To participate in this research, subjects were required to have a minimum of 60 days of experience using: maps, remotely sensed data or satellite imagery. Information regarding educational background and experience was collected using a questionnaire (Figure 1) prior to the subject’s selection for participation.

Subjects were paid $30.00 to participate in the research, which consisted of four, forty to forty-five minute “blocks.” Between each “block” subjects allowed to rest for as long as necessary before proceeding with the experiment.

**Materials**

Three terrain models and nine “drapes” were created for use in this research. One terrain model and one “drape” were used for the subject’s flight training, the other terrain models and eight “drapes” were used in the data collection portion of the research.
Figure 1. Research Subject Questionnaire

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<th>Research Subject Questionnaire</th>
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**Subject Name**

**Subject #**

1. **Sex:**  
   - Female  
   - Male

2. **Age:**

3. **Education Level:**  
   - Undergrad  
   - Grad

4. **Major:**

5. **Map use/production experience:**  
   Number of days experience using or producing topographic or thematic maps (any day that you used a map for study, research, navigation, etc. is considered 1 day).

6. Circle the courses you have completed:
   - Geog. 380 - Map Investigation
   - Geog. 381 - Maps and Graphic Methods
   - Geog. 484 - Geographic Information Systems
   - Geog. 488 - Remote Sensing of the Environment
   - Geog. 581 - Cartographic Design
   - Geog. 584 - Geographic Information Systems Applications
   - Geog. 588 - Intermediate Remote Sensing of the Environment
   - Geog. 682 - Advanced Automated Cartography
   - Geog. 683 - Advanced Geographic Information Systems
   - Geog 688 - Advanced Remote Sensing

7. List any other training or experience you have received in these areas (include experience or training in orienteering or navigation please):

**NOTE:** This information will remain confidential. Any reference to your responses in this questionnaire or in research tasks will employ a Subject # for identification purposes.

***No persons with pilot training will be accepted as a subject in this research.***  
***Persons who experience color-blindness will not be accepted as subjects in this research.***  
***A minimum of 60 days of map experience, and at least 2 courses in GIS, cartography, or remote sensing will be required for participation.***
To allow comparison between subject's responses for each of the four rendering methods being studied, both terrain maps and land use "drapes" were derived from the same source, covering the same geographic extent. Selection of the study area for this research was based on the following criteria:

1) The study area must contain six different land use classes at no more than the Anderson II level of classification (a level of classification readily available from the air-photos used in this research),

2) The study area should be of sufficient size to allow a five minute fly-through at a simulation speed of at least 100 miles per hour (at scale),

3) The study area should have sufficient topographic relief to permit the use of topographic features as landmarks or anchors,

4) The study area should be of sufficient topographic relief and be of sufficient size to force a sequential acquisition of spatial knowledge. Subjects must not be able to see more than one change in route direction (choice point) ahead of any other choice point,

5) The study area should not be familiar to subjects involved in the research,

6) The study area should, if possible, be selected from existing data sources and available at low, or no cost.
Based on these criteria, an area was selected from the Tijuana River Watershed Database, a joint database development project of the Department of Geography, San Diego State University and El Colegio de la Frontera Norte, Baja California. The study area covers approximately 72 square kilometers with dimensions of 12,000 x 6,000 meters, containing a small portion of the urban environment of southeastern Tijuana, Mexico with the remainder being made up of the rural and natural landscape south of the city.

The terrain of the study area includes two major valleys running in a predominantly east/northeasterly direction flanked on either side by hills and mountainous terrain with relative relief of several thousand feet. The land use of the area is a mix of six types, divided into 86 polygons (categorized on a modified Anderson Level 1 system), ranging from approximately 4% to 44% coverage (Table 1) (Figure 2).

Table 1. Land use categories, polygons, and coverage in the study area.

<table>
<thead>
<tr>
<th>Land use Category</th>
<th>Number of Polygons</th>
<th>Percent of Study Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>24</td>
<td>17.5</td>
</tr>
<tr>
<td>Industrial/Commercial</td>
<td>19</td>
<td>7.3</td>
</tr>
<tr>
<td>Disturbed</td>
<td>21</td>
<td>14.8</td>
</tr>
<tr>
<td>Natural</td>
<td>13</td>
<td>44.0</td>
</tr>
<tr>
<td>Agriculture</td>
<td>7</td>
<td>12.5</td>
</tr>
<tr>
<td>Water</td>
<td>2</td>
<td>3.9</td>
</tr>
</tbody>
</table>
Figure 2. Land use of the study area.
Of the two terrain models used in data collection, one is a model of the study area in a "real world" orientation, the other is a "mirror image", "flipped" along an east-west axis (e.g., terrain features that actually exist in the north-west portion appear as "mirror images" of themselves in the north-east corner). These terrain models were derived from a portion of a 30 meter Digital Elevation Model (DEM), which was converted into a Triangulated Irregular Network, and written into the Virtual Reality Markup Language (VRML) format files, using *Arches* 7.4 GIS software. The source of the elevation data used in this study was derived from 1:50,000 scale maps, with a contour interval of 30 meters.

The eight "drapes" used in the data collection portion of this study reflect four methods of rendering, or symbolizing, the land use/land cover information for the study area, with two conditions each. The first, with a visible path for subjects to use as the basis for route learning, the angular recall task, the length/distance estimation task, the landform and land use memory task; and the second, without a visible path for use in the path reproduction task, and confidence assessments.

The imagery used for the creation of the "geospecific drapes" and the "geotypical drapes" was derived from hi-resolution, true-color, aerial photography, flown by NOAA in July of 1994. The two, 36 inch by 36 inch, true-color photographs of the study area were scanned at 600 dots per inch (dpi), joined and georeferenced using *ERDAS Imaging* geoprocessing software, and resampled to a
final resolution of 72 dpi using a bilinear interpolation method using *Adobe Photoshop*. While employing a higher resolution might seem to have been preferable, comparison of the 72 dpi images (24 megabytes in size) and 144 dpi images (96 megabytes in size) showed no appreciable difference in quality when animated using the *World Tool Kit* software during the pilot study. It was also found during the pilot study, that the real-time rendering became “jumpy” when the drapes exceeded 96 megabytes in size. Regardless of whether this phenomenon resulted from software or hardware limitations, texture-map size and resolution was limited.

The “drapes” for the most iconic of the methods, the “geospecific” method (Figure 3), were constructed from aerial photography of the study area with lines delineating the boundaries of classified land use polygons. While it was hoped that the land use polygon delineation might provide spatial information that the subjects could use in recall tasks or navigation, it was in no way expected to provide the same type of land use information as the classified and symbolized methods. The polygon delineation did, however, provide the spatial framework within which subjects’ land use interpretation was conducted. By providing spatial delineation, subjects were forced to determine which of the six land use/land cover classes existed within each area.

Since the aerial photography was not ortho-rectified, the boundaries of the land use polygons had to be manually “corrected” to agree with visible features, rather than with the georeferenced boundaries of the land use coverage used for
creation of the "drapes" for the other three methods. This procedure involved the "heads-up" digitizing of the boundaries using both the aerial photography and the existing land use coverage as backgrounds, mapping the land use boundaries to the features visible in the imagery.

While the "geospecific" method utilized aerial photography for the entire study area, the "geotypical" method required the selection of small portions of the image that could be considered prototypical of the six land use categories found in the study area. These images were resampled to 133% to increase the clarity of the symbols, and the color was altered to increase contrast between "types." The category "natural" was given a dark green tint, "agriculture" a lighter green, "disturbed" brown, and "water" a more uniform blue tint. Since the categories "industrial" and "residential" contained more visually recognizable features than the other four categories, and had distinct tonal qualities, no color was added for these categories (Figure 4). Also, to avoid any further alteration of scale, multiple copies of the small, prototypical texture maps for each land use category were produced, mosaiced, and used as the fill pattern for the appropriate polygons in the land use map of the study area (Figure 5).

The area symbols used for the "cartographic-iconic" method were created in Macromedia FreeHand using hand-drawn, "iconic" representations of visual features for each land use category. In all cases the "iconic" symbols represented the features as they might be viewed orthogonally, and not from an oblique perspective. The
decision for this rested in the confusion that might occur if perspective-view symbols were used (Figure 6). To create a "drape" using perspective dependent symbols, the cartographer would have to orient every symbol individually to avoid illogical or confusing signs (e.g., upside-down trees on a hillside, buildings laid on their sides or roofs, depending on the subject’s point-of-view, etc) when the texture map is "draped" over the terrain model. As with the "geotypical" method, color was also used in this method. Additionally, pattern and size of the symbols was used to provide clarity (Figure 7).

The fourth, and final method used in this research, "cartographic-arbitrary", represents the opposite end of the spectrum from the "mimetic" images used in the "geospecific" method. For this research, the common cartographic practice of using color to symbolize nominal data was used. While a truly arbitrary application of the various dimensions of color might have been used in this research, it was decided that a more conventional (intuitive) approach would be used. Rather than try to "trick" subjects by switching the color scheme from the one used in the "geotypical" and "cartographic-iconic methods, dark green was used to represent "natural", lighter green for "agriculture", brown for "disturbed", blue for "water", gray for "industrial", and magenta for "residential" (Figure 8). While the color scheme remained consistent, the actual colors were varied with the hue and saturation increased for use in the "cartographic-arbitrary" method (Figure 9).
Figure 3. Geospecific “drape” with path visible.
Figure 4. Geotypical symbols.

Natural  
Water  
Residential  
Disturbed  
Industrial/Commercial  
Agriculture
Figure 5. Geotypical "drape" with path visible.
Figure 6. Cartographic-iconic symbols.

Agriculture  Natural

Disturbed  Water

Residential  Industrial/Commercial
Figure 7. Cartographic-iconic “drapé” with path visible.
Figure 8. Cartographic-abstract symbols.

Industrial/Commercial  Agriculture

Natural  Residential

Water  Disturbed
Figure 9. Cartographic-abstract “drape” with path visible.
For the purposes of this research, a version of each of the previously described "drapes" was created with a visible "path" added, for subject’s to use for route learning and estimation and memory tasks. These paths were identical for each of the four methods with the "choice points" located (relative to the land use polygons) in the same position for each method. The paths consisted of five segments of varying lengths between 2000 and 5900 meters (each) in length, with angles of between 30 and 115 degrees at each of four "choice points" (Figure 10 & 11). To prevent subjects from recognizing that the same study area was used for all four methods, the "drapes" for the "geotypical" and "cartographic-iconic" methods were "flipped" on the east-west axis for use with the "mirrored" terrain model (Table 2).

Table 2. Study area orientation and fly-through sequence.

<table>
<thead>
<tr>
<th>Symbol Representation Method</th>
<th>Terrain Model and &quot;Drape&quot;</th>
<th>Fly-through Sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geospecific</td>
<td>normal</td>
<td>normal</td>
</tr>
<tr>
<td>Geotypical</td>
<td>mirrored</td>
<td>reversed</td>
</tr>
<tr>
<td>Cartographic-iconic</td>
<td>normal</td>
<td>reversed</td>
</tr>
<tr>
<td>Cartographic-abstract</td>
<td>mirrored</td>
<td>normal</td>
</tr>
</tbody>
</table>

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Figure 10. Geometry of the geospecific and cartographic-iconic paths.

Figure 11. Geometry of the geotypical and cartographic-arbitrary paths.
Procedure

The data collection for this research was conducted in the Visualization Lab at the San Diego Supercomputer Center, located on the campus of the University of California San Diego, using a Silicon Graphics "Octane" computer. Subjects viewed the fly-throughs on a high resolution, wide aspect (12" x 18") color monitor, offering a "window on the world" VR experience. The simulation was created from a C++ application written (APPENDIX II) for the *World Tool Kit release 9* (Engineering Associates Inc., 1999), a virtual reality development package. Based on the results of the pilot study, the parameters used in subject's fly-throughs were set as follows: the elevation was "fixed" at 300 meters (at simulation scale), with an apparent speed of approximately 120 miles per hour, and a 40° viewing angle (orthogonal view would be 90°). For the purposes of this research, subject's control during data collection consisted exclusively of directional control (using left and right arrow keys).

The tasks performed by subjects included: distance estimation (both relative and based on a standard scale), angular estimates (recall of the visible intersection between "legs" of the path) as described graphically on a "compass rose", memory of land use categories contained in polygons along each leg of the fly-through, memory of landform or topographic features along each leg of the paths, and a path reproduction task in which subjects tried to reproduce the route taken through the virtual environment without the actual path being visible. All of these tasks utilized
self-reporting techniques including written response to questions on forms, graphic representations (e.g., a line on a circle representing the change in bearing from one leg to the next, or sketch maps of the route traveled), and verbal responses (open-ended responses to specific questions).

The testing was divided into four “blocks”, each using a different representation method, but employing the same instructions, tasks, and within-block order, as in the other “blocks.” The sequence of the “blocks” was counterbalanced between subjects, with the 24 subjects accounting for all possible orders.

Prior to beginning the first “block”, subjects were given a detailed explanation of the purpose of the research, and the tasks and procedures they would encounter during each “block” of testing. Subjects were shown examples of the forms they would be using for recall tasks and were informed of every question that they would be asked during the testing, as well as when these questions would be asked. Additionally, subjects were given an opportunity to practice the navigational control skills they would need to use during testing. These skills included “flying” a straight route to a given point, accurately following a path seen on the “ground”, and estimating when “they were directly over” a turning point (since the fly-through involves movement at altitude, and the viewing angle was “fixed” at 45°, it was impossible for subjects to see when they were directly over a turning point). Subjects were allowed to practice for as long as they (we) felt it was necessary to achieve competency in flight control (usually five to ten minutes).
Each “block” consisted of three fly-throughs, two in which the “drape” included the path, one with the path not visible. The following is a description of the foci, conditions, and procedures used in each of the four “blocks” of testing. Prior to each fly-through, subjects were reminded of the foci of that fly-through, and shown examples of the forms to be completed during that portion of the testing.

Begin “BLOCK”

Fly-through #1

Foci

- learn the route by following a path on the ground
- estimate angular change in bearing at “choice points”
- estimate length of path segments in familiar units

Conditions

- path visible
- subject controls flight direction

Procedures

- subject uses arrow keys to rotate point-of-view (POV) until first segment of path is seen straight ahead
- subject indicates readiness to begin forward motion by saying “go”


➢ when the subject estimates that he/she is directly over the "choice point" he/she says "stop", and forward motion is stopped
➢ subject uses arrow keys to rotate point-of-view (POV) until the next segment of path is seen straight ahead (takes 10 to 20 seconds)
➢ subject completes "angle/distance" form (Figure 12)
➢ subject indicates readiness to begin forward motion by saying "go"

Repeat the previous procedures for each segment of the path

➢ After completing the final "angle/distance" form for the path, subject completes "relative distance" form (Appendix )
➢ Subject completes a sketch-map of the shape of the entire route just learned

Fly-through #2: same "drape" & starting position as #1

Foci

➢ learn the route as investigator follows a path on the ground
➢ learn the "type" of as many land use polygons as possible
➢ learn the location of as many landform/topographic features as possible

Conditions

➢ path visible
➢ investigator controls flight direction

Procedures

➢ investigator uses arrow keys to rotate point-of-view (POV) until first segment of path is seen straight ahead
subject indicates readiness to begin forward motion by saying “go”

investigator follows the visible path, seen on the surface of the terrain, as accurately as possible (keeping the path aligned with the center of the screen)

when the investigator estimates that he is directly over the “choice point” forward motion is stopped

investigator uses arrow keys to rotate point-of-view (POV) until the next segment of path is seen straight ahead (takes 10 to 20 seconds)

subject completes “land use/landform (topo)” form (Figure 13). These forms are unique to the rendering method and path segment and include a depiction of the path segment just traveled and the boundaries of land use polygons within approximately 400 meters around the path

subject indicates readiness to begin forward motion by saying “go”

Repeat the previous procedures for each segment of the path

After completing the final “land use/landform (topo)” form for the path, subject completes a sketch-map of the shape of the entire route just learned, including as much land use information and landform/topo information as possible, in the correct position relative to the remembered route

Fly-through #3: “drape” without path & starting position is the same as #1 and #2

Focus

Reproduce the route learned in the previous two fly-throughs as accurately as possible, stopping as close to the “choice points” as possible
Conditions

- path not visible
- subject controls flight direction

Procedures

- subject uses arrow keys to rotate point-of-view (POV) until he/she believes he/she is aligned with the first segment of the route
- subject indicates readiness to begin forward motion by saying “go”
  - subject reproduces the route as accurately as possible (keeping the remembered route aligned with the center of the screen)
  - when the subject estimates that he/she is directly over the “choice point” he/she says “stop”, and forward motion is stopped
- subject uses arrow keys to rotate point-of-view (POV) until next segment of path is seen straight ahead (takes 10 to 20 seconds)
- subject verbally responds to a series of questions (Appendix ) regarding land use and landform (topographic) features used to accurately follow the path and accurately locating the choice points. Subject also rates his/her confidence in accuracy in performing route and locational tasks
- subject indicates readiness to begin forward motion by saying “go”

Repeat the previous procedures for each segment of the path

END OF “BLOCK”
Figure 12. Angle/distance form.

GT Leg 1: Length and Angle

Estimate the length of the leg of the path you just flew in feet, yards, meters, miles, or kilometers.

Place a mark on the compass (the graduated circle) indicating the change in heading from the first leg of the path to the second.
Figure 13. Land use/landform (topography) form.

Identify as many landuse/landcover polygons as you can remember (please do not guess).
Identify the location of as many landform features as you can accurately remember (make a mark at the location and label it).
Subjects’ responses regarding angular changes in bearing were determined through direct measurement of the their graphic depiction of the recalled angle, using a protractor, and were recorded to the nearest degree. Length/distances estimates were converted from decimal miles and kilometers to meters. Subjects’ “land use/landform (topo) forms” were first “graded” for correct identification of land use polygons, then counts were made of the number of landform (topographic) features recalled, the total number of land use polygons identified, and the number of those polygons correctly identified. Since subject’s landform (topographic) feature responses were based on subjective interpretation and classification (e.g., hill vs. mountain vs. rise, large hill vs. small mountain) no attempt was made to determine “correctness”, limiting the types of questions which could be addressed using these data. Additionally, coordinate files created during subjects’ navigation of each simulated environment were converted to ASCII format and used to “generate” Archivo coverages. These coverages contain detailed information of the routes “learned” and the routes “recalled” (reproduced), as well as the “learned” and “recalled” locations of “choice points.” Subject’s confidence, expressed on a scale from one to ten (one = no confidence, ten = absolute certainty), regarding how accurately he/she followed the learned route, and how accurately he/she was in locating the “learned choice points” during the route reproduction task.

Subjects’ verbal protocols were coded using a system similar to ones described in Montello, Pick, and Sullivan (1994) and Hoffman and Pike (1995). The
categories used in this coding include: locational method, category of visual feature, characteristics of the feature, quantity and type of adjectives applied to the feature, and the orientation of the locational term used to locate the feature APPENDIX.

While a great deal of analysis is possible using these data and the sketch map data, they are not included in this analysis.

**Research Questions**

Does the level of iconicity, or the symbols used as thematic “drapes” in fly-through navigation of simulated environments affect:

1) subjects’ ability to accurately recall relative directional changes while involved in a route learning task?

2) Subjects’ ability to accurately estimate distance/path-length in standard units while involved in a route learning task?

3) The quantity or accuracy of topographic/landform information and land use information recalled?

4) Subjects’ accuracy in learning, and later, locating specific “choice points” along a route?

5) Subjects’ accuracy in reproducing a route from memory?

6) Subjects’ confidence in performing point location and path reproduction tasks?

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Analysis

The one between-subjects variable that was tested for in this research was the order in which the 4 test blocks were administered. The Independent Variable for the within subjects tests was the “type” (treatment) of land use/land cover drape used in the simulated environments and the shape of the “path” that was followed. Since the four paths were geometrically equivalent and were not varied between subjects in the four test blocks, the path shape is confounded with “type”, and cannot be considered separately. By using 24 subjects, all combinations of order were tested. None of the test blocks was altered within subjects.

The Dependent Variables for the within subjects tests were:

Geometric Analysis

A. Angular accuracy

This analysis addressed the accuracy of the recalled angle collected approximately ten seconds after viewing, upon completion of each “leg” of a five “legged” route. Accuracy, as measured in absolute degrees of error for the entire route, was used in the analysis.

B. Distance/Length

This analysis addressed the accuracy of the estimated length of the route flown by the subject. The length estimates were made using a standard length, miles or kilometers, converted to meters.
The errors, in meters, were totaled for the central three legs of the route and were normalized so that the effects of scale could be removed from the analysis of the independent variable.

*Landmark Analysis*

A. **Topographic features**

This measure addressed the question of how many topographic/landform features were remembered approximately ten seconds after viewing them in a fly-through. Responses were collected as subjects completed each leg of a five "legged" route, then totaled for the entire route. These responses were not "graded" for correctness due to the subjective nature of landform identification and classification.

B. **Thematic features**

This analysis focussed on the quantity of land use/land cover polygons correctly identified approximately ten seconds after viewing them in a fly-through. Responses were collected as subjects completed each leg of a five "legged" route, then totaled for the entire route.

*Path Reproduction/Route Learning*

In measuring precision, or error, in subject’s ability to reproduce learned routes or in locational tasks it was necessary to quantify the precision
with which subjects could actually follow visible paths, or stop directly over
"choice points." If, for example, a subject’s error in locating a choice point
(by stopping the fly-through directly over that “choice point) was 50 meters
when the point was visible, that subject could not be expected (other than by
chance) to locate the actual point with more accuracy when the point was not
visible. For that reason, an accuracy factor was established for each subject
that reflected the subject’s ability to control his/her location in this research
(perhaps this factor reflects the subject’s conception of “accuracy”).
Subject’s control ability (SCA) was defined, then, as the largest error in
distance (from all four test “blocks”) between the actual location of a turn
point (as found on the path on the terrain’s surface) and the position of that
same point on the subject’s route while the path was visible (Figure 14).
A. "Choice point" recollection accuracy

In this analysis, accuracy is characterized as the total difference ("error" in meters), for each block, between the location identified during the route-learning fly-through (with the "path" visible) and the recall-fly-through ("path" not visible), minus SCA.
B. Route Accuracy

This analysis addressed subject’s ability to accurately reproduce the learned route through the environment in a fly-through with no “path” visible. Error is measured as the ratio of the length of path falling outside of the epsilon band to the length of the subject’s route within the epsilon band, using only the three middle legs of the route (Figure 15). The epsilon band is a uniform buffer, of consistent width, surrounding the subject’s recorded route traveled while the path was visible. The width of the epsilon band is that subject’s SCA (the maximum difference between each subject’s estimate of the location of the choice points and the actual location, with the points visible. This error represents a very conservative measure of subject’s ability to a position themselves directly over a given point.
Figure 15. Determination of subject’s total route error by “block.”

Confidence of Accuracy

A. Locating “choice points”

This analysis addressed subject’s confidence estimates while locating the five choice points for the entire route (in each block), in the path reproduction task. Confidence is measured on a scale of one to ten, with one representing “no confidence” and ten representing “certainty.”
B. Following the route

This analysis addressed subject's confidence of accuracy while performing the route reproduction task. As was case with "choice point confidence", confidence is measured on a scale of one to ten, with one representing "no confidence" and ten representing "certainty."

The statistical approach used in the analysis was a multivariate approach to repeated measures, included in *SPSS 10 for Windows* (SPSS inc., 2001) as a "General Linear Model." This research employed a 1x4 factorial design, with 24 repeated measures. Employing this approach, the within subject effects were tested at a .95 level of confidence, using the "Pillai's Trace" statistic. Post-hoc tests were used to identify, in a pair-wise fashion, between which of the four cases of independent variables significant differences occurred. The same approach was applied to the between group variable, "order" of the test "blocks", for each dependent variable.
CHAPTER 4

Results

Introduction

This chapter reports on the results and analyses conducted on data collected from subjects between December 27, 2000 and February 8, 2001. As previously described in Chapter 3, twenty-four subjects participated in this research, each spending approximately three and one-half hours completing the four test “blocks.” In each test “block” subjects completed a number of tasks designed to address the overarching question posed by this research, “what effect does the level of symbolic iconicity have on the integration of spatial data acquired in fly-through navigation of simulated environments?” More specifically, this research addresses the following questions, does the level of iconicity, or the symbols used as thematic “drapes” in fly-through navigation of simulated environments affect:

1) Subjects’ ability to accurately recall relative directional changes while involved in a route learning task?

2) Subjects’ ability to accurately estimate distance/path-length in standard units while involved in a route learning task?
3) The quantity or accuracy of topographic/landform information and land use information recalled?

4) Subjects' accuracy in learning, and later, locating specific "choice points" along a route?

5) Subjects' accuracy in reproducing a route from memory?

6) Subjects' confidence in performing point location and path reproduction tasks?

Organizationally, this chapter is divided into four analytical sections, an introduction and a summary. The four analytical sections of this chapter include: 1) Geometric Analysis, 2) Landmark Analysis, 3) Path Reproduction/Route Learning, and 4) Confidence, each with a number of subsections and analyses (Table 3). Within each of these sections is a brief introduction including a description of the procedures, an explanation of the analyses and the results, and a discussion of the findings including any relevant literature, if any exist. Additionally, at the end of this chapter a summary of the findings is presented, specifically addressing where significant main effects were found, relative to the six research questions investigated in this study.
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<th>Analysis</th>
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<td>Error in angular recall: by “block” order</td>
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<td>Total number of features recalled: by “block” order</td>
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<td>Total number of land use features recalled: by treatment</td>
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<td>Total number of land use features recalled: by “block” order</td>
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<td></td>
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<td>Ratio of correct/total land use recalled: by treatment</td>
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<td></td>
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<td>Ratio of correct/total land use recalled: by “block” order</td>
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<td>Topographic/Landform Features</td>
<td>Total number of topo features recalled: by treatment</td>
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<td></td>
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<td>Total number of topo features recalled: by “block” order</td>
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<td></td>
<td></td>
<td>Ratio of recalled topographic/total recalled features: by treatment</td>
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<td></td>
<td></td>
<td>Ratio of recalled topographic/total recalled features: by “block” order</td>
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<td>Path Reproduction/</td>
<td>“Choice Point” Accuracy</td>
<td>Distance error in locating “choice points”: by treatment</td>
</tr>
<tr>
<td>Route Learning</td>
<td></td>
<td>Distance error in locating “choice points”: by “block” order</td>
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<td>Route Accuracy</td>
<td>Error in accurately reproducing the learned route: by treatment</td>
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<td>Error in accurately reproducing the learned route: by “block” order</td>
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<td>Confidence</td>
<td>“Choice Point” Confidence</td>
<td>Confidence in accurately finding the “choice points”: by treatment</td>
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<td>Confidence in accurately finding the “choice points”: by “block” order</td>
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<td>Route Confidence</td>
<td>Confidence in accurately reproducing the learned route: by treatment</td>
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<td>Confidence in accurately reproducing the learned route: by “block” order</td>
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Geometric Analysis

Angular Estimates

As a means of answering the first research question, i.e. does the level of iconicity, or the symbols used as thematic "drapes" in fly-through navigation of simulated environments affect subject's ability to accurately recall relative directional changes while involved in a route learning task, total error of estimates for each treatment were analyzed. These estimates, measured to the nearest degree from graphic representations of the recalled angle, represent the total absolute-error per "block" (treatment), of the recalled angles collected approximately ten seconds after viewing each angle (four angles total per "block") (Table 4).

In the analysis of angular recall by treatment, a $p$ value of .80 was calculated, using "Pillai's Trace" test of significance. At the 5% rejection level, therefore, significance was not found, thus, retaining the null hypothesis (that there was no difference in the total angular error based on treatment).

Table 4. Descriptive statistics: total error in angular estimates, by treatment.

<table>
<thead>
<tr>
<th></th>
<th>Min.</th>
<th>Max.</th>
<th>Mean</th>
<th>Std. Deviation</th>
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</thead>
<tbody>
<tr>
<td>Geospecific</td>
<td>22</td>
<td>164</td>
<td>67.1</td>
<td>31.54</td>
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<tr>
<td>Geotypical</td>
<td>30</td>
<td>204</td>
<td>62.0</td>
<td>38.90</td>
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<tr>
<td>Carto-iconic</td>
<td>26</td>
<td>109</td>
<td>62.5</td>
<td>24.42</td>
</tr>
<tr>
<td>Carto-arbitrary</td>
<td>4</td>
<td>97</td>
<td>59.5</td>
<td>25.19</td>
</tr>
</tbody>
</table>
Since the order in which the four “blocks” (each block tested a different treatment) were administered was counterbalanced among subjects there was no need to account for the potential effect of order of treatment on the total error of angular estimates. While the order of treatments was accounted for in the research design, the order of testing was not. Therefore, an analysis was conducted to determine if the order of testing had a significant effect on subject’s total error of angular estimates (e.g., did subject’s accuracy improve due to familiarity with the test, etc. or did accuracy decline, due to fatigue, etc?) (Table 5). As in the previous analysis, a multivariate approach to repeated measures was applied to the angular error data. This time, however, the independent variable being “block order” rather than treatment. In the analysis of angular recall by order, a p value of .38 was calculated. At the 5% rejection level, therefore, significance was not found, thus, retaining the null hypothesis (that there was no difference in the total angular error based on order).

Table 5. Descriptive statistics: total error in angular estimates, by “block” order.

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<tr>
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<th>Max.</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
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<tbody>
<tr>
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<td>67.9</td>
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<tr>
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<td>4th</td>
<td>19</td>
<td>98</td>
<td>60.5</td>
<td>20.60</td>
</tr>
</tbody>
</table>

Unlike research in which angular estimates were elicited from subjects to quantify the accuracy of spatial information integration (Thorndyke and Hayes-Roth, 78
1982; Levine, Jankovic, and Palij, 1982; Presson and Hazelrigg, 1984; Presson, DeLange, and Hazelrigg, 1989; Sholl, 1987; Tlauka and Wilson, 1998; and Jacobson et al. 1998), subjects participating in this research actually saw the angle as a visible feature approximately ten seconds prior to graphically representing the angle on a test form. In this context, the graphic representations of recalled angles reflect subjects’ ability to visually perceive an angle, store the image of that angle in memory, and subsequently recall and reproduce the angle as a graphic representation. While the difference between the actual angle and the graphic representation of the recalled angle does not necessarily represent the angular error of a subjects' perception or spatial knowledge structure (error in graphic representation is a potential source of at least a part of the error), it does give an indication of the magnitude of error that might be expected from a subject in an angular recall task.

Since no significant difference was found in subjects’ total error in graphically representing the angles found at “turning points” along the paths, based on the symbolic iconicity (treatment), it can be conclude that overall, background textures acted as neither distracters or aids in angular recall in this study. While it might be expected that a regular pattern (streets, etc.) in imagery or cartographic symbols might prove useful in an angular estimation task, the general lack of such “reference features” in the imagery and cartographic symbols directly adjacent to the “choice points” may have prevented any possible benefit.
Length/Distance Estimates

While quantifying the angular error of subjects’ estimates used in the previous section allowed direct measurement of subjects’ graphic depictions of a recalled angle, determination of length/distance error was not as straightforward. Since the instruction given to subjects during testing was to “Estimate the length of the path [route] you just flew in feet, yards, meters, miles or kilometers”, the estimate elicited was not of the path that was visible on the ground, rather, it was an estimate of the route learned as subjects followed the path. The routes subjects traveled were recorded as a series of coordinates into ASCII files as subjects flew through the simulated environments in the first fly-through of each “block”, and were generated into Archico coverages for use in a number of analyses. For the purposes of this research, error in the estimated length for each treatment was established as the sum of the absolute difference between subject’s length estimate for each leg and the length of the actual route traveled for each leg.

During the analysis of subject’s data it was discovered that the application program prematurely terminated the recording of coordinates in the ASCII files. The resulting Archico coverages confirmed the problem, with each path missing approximately ½ of the final “leg.” While only the final segments of subject’s routes was affected, to maintain geometric equivalence between each of the four “blocks”
(with direction of travel reversed for two “blocks”) both the first and fifth “leg” had to be omitted from the analyses.

In analysis of errors in length (or distance) estimates, involving the use of a standard unit, subject’s error can be traced to a number of different sources (Montello, 1991). One source of error, a systematic error, is linked to inaccuracy in the perceptual or cognitive “length” (or scale) of the reference unit. The second, a random error, results from applying an accurate reference unit inaccurately. A third is the error in the spatial knowledge structure itself. To eliminate the effect of scale on estimates, a technique employed by Montello (personal communications, 2001) was adopted, producing a “scale free” total error per test “block.” This technique (Figure 16) involves determining a scale correction factor for each fly-through of each subject, correcting length estimates for each leg using that factor, subtracting the estimated length from the actual “leg” length, and summing the absolute value of the results, thus, establishing a “scale corrected” route error. The “normalized” value that results from this technique is suitable for the multivariate approach to repeated measures analysis, which is used for analysis of within subject factors.

Figure 16. Calculation of the “scale free” error of length estimate.

\[ e = \mathcal{E} \left| X_n - \left( Y_n \left( \frac{\bar{X}}{\bar{Y}} \right) \right) \right| \]

- \( X \) = actual length of each “leg” (route traveled)
- \( Y \) = verbal estimate of length of each “leg” (in meters)
- \( e \) = “scale free” error of estimate for the test “block”
Proceeding under the assumption that among the 24 subjects (12 estimates per subject) the random errors (the second "source of error" form above) canceled themselves out, only the third source of error, the error in the subject’s spatial knowledge structure, remained. This is the error, then, that was analyzed to determine whether or not the cartographic treatment had a significant effect on subject’s length/distance estimates.

Since the technique used to establish the total, "scale free", error of subject’s length/distance estimates uses the sum of absolute values of error estimates, the distribution of values for each test "block" is not normal. The distributions, in fact, resemble the right side of a normal distribution. Although one assumption of the MANOVA technique, thus an assumption of the multivariate approach employed in this research, is that the distributions are normal, a classic study by Norton (1952) found that "departures from normality of distribution (even gross ones) had little effect on the F distribution" (Barker and Barker, 1984, p. 25).

The analysis of "scale free" length/distance estimates resulted in a p value of .38. At the 5% rejection level, therefore, significance was not found, thus, retaining the null hypothesis (that there was no difference in the "scale free" estimated length of the "legs" of the routes based on treatment) (Table 6).
Table 6. Descriptive statistics: “scale free” length estimate error, by treatment.

<table>
<thead>
<tr>
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<th>Min.</th>
<th>Max.</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geospecific</td>
<td>466</td>
<td>6339</td>
<td>2228.2</td>
<td>1380.40</td>
</tr>
<tr>
<td>Geotypical</td>
<td>322</td>
<td>5363</td>
<td>2118.3</td>
<td>1031.84</td>
</tr>
<tr>
<td>Carto-iconic</td>
<td>862</td>
<td>6066</td>
<td>2723.0</td>
<td>1566.54</td>
</tr>
<tr>
<td>Carto-arbitrary</td>
<td>450</td>
<td>5258</td>
<td>2543.5</td>
<td>1052.84</td>
</tr>
</tbody>
</table>

Results of the analysis of the “scale free” error in length/distance estimates by “block” order, however, showed an overall increase in accuracy with each test “block” (Table 7). With a calculated $p$ value of .03, employing “Pillai’s Trace” test of significance at the .05 rejection level, we must reject the null hypothesis, recognizing that overall, subjects were able to more accurately estimate lengths/distances with repeated exposure to the test procedures or practice. Further analysis, employing Bonferroni’s pairwise comparisons, at the 5% rejection level, shows the only significant difference is between the first and fourth “block” ($p = .02$). While the results in Table 7 show consistently increasing accuracy through the four “blocks”, the high error in the first “block” suggests that the increases in accuracy may, to a large degree, be the result of familiarity with the test procedures, and only minimally to increased ability over time.
Table 7. Descriptive statistics: “scale free” length estimate error, by order.

<table>
<thead>
<tr>
<th></th>
<th>Min.</th>
<th>Max.</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
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<td>6339</td>
<td>3095.2</td>
<td>1502.51</td>
</tr>
<tr>
<td>2nd</td>
<td>450</td>
<td>6049</td>
<td>2236.4</td>
<td>1390.5</td>
</tr>
<tr>
<td>3rd</td>
<td>466</td>
<td>5143</td>
<td>2220.4</td>
<td>1103.1</td>
</tr>
<tr>
<td>4th</td>
<td>322</td>
<td>3221</td>
<td>2061.0</td>
<td>826.4</td>
</tr>
</tbody>
</table>

This is not to say, however, that subjects accurately estimated lengths, only that the level of iconicity or the method of symbolic representation was not the cause of inaccuracy. Table 8, describes the scale at which subjects perceived the environments. The perceived scale values were established by dividing one by the “scale correction factor” \((1/\bar{X}/\bar{Y})\) used in the calculation of “scale free” error of distance estimates (Figure 16). Since one of the mechanisms by which distance estimates are made is the size of familiar objects (Predebon, 1991; Predebon, 1992; Predebon, 1993; Higashiyama and Shimano, 1994; Vishton and Cutting, 1995; Goldstein, 1996), subjects’ perception of scale has a direct impact on the precision of spatial knowledge acquisition from virtual environments. Table 8 shows that 14 of the 24 subjects perceived the scale for the four “blocks” in the research at smaller than actual scale, while ten perceived them at a larger scale, with the “best” estimate showing a 6% error and the “worst”, a 1700% error. While the range of perceived scales is large, most estimates were within 50% of actual scale with the mean (due to
the 1700% outlier) being 2.42. Additionally, the range and standard deviation values in Table 8 reflect the consistency of the perceived scale among each of the four test “blocks.” While subject number 19, for example, maintained a fairly constant perception of scale (standard deviation of .06 among the four “blocks”) based on length estimates, subject 20’s estimates ranged from 1500% to nearly 2100% of actual scale, with a standard deviation of 2.55.

**Table 8. Descriptive statistics: subject’s perception of scale in the four test “blocks.”**

<table>
<thead>
<tr>
<th>Subject</th>
<th>Range</th>
<th>Mean</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
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<td>4</td>
<td>.27</td>
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<td>.15</td>
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<tr>
<td>5</td>
<td>.67</td>
<td>.84</td>
<td>.30</td>
</tr>
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<td>.71</td>
</tr>
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<td>.48</td>
<td>.10</td>
</tr>
<tr>
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<td>2.07</td>
<td>3.28</td>
<td>1.02</td>
</tr>
<tr>
<td>9</td>
<td>.44</td>
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<td>.21</td>
</tr>
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<td>1.34</td>
<td>4.68</td>
<td>.55</td>
</tr>
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<td>11</td>
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<td>.86</td>
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<td>5.69</td>
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<tr>
<td>24</td>
<td>.18</td>
<td>.94</td>
<td>.08</td>
</tr>
</tbody>
</table>
Landmark Analysis

While the data used in the "geometric analysis" were collected in subject's first fly-through of each block, the data employed in the "landmark analysis" were collected during subject's second fly-throughs. During the second fly-through of each block subjects were asked to remember the location of as many land use/land cover polygons and topographic/landform features as possible. Unlike the estimation tasks involved in the "geometric analysis", involving the calculation of cognitive distance and angular perception and recall, the "landmark analysis" investigated the volume and composition of subject's spatial knowledge, insofar as they related to the general categories of "land use features" and "topographic features."

In addition to the differences in tasks subjects performed in the first two fly-throughs it must be recognized that there existed a substantial difference between the tasks performed in the geospecific method and all other methods. The geospecific method of rendering (use of an air-photo) prevented the use of prototypical or homogeneous symbology to represent specific classifications. Even with the inclusion of polygon boundaries delineating the various land use polygons, subjects were confronted with the task of performing air-photo interpretation, into predetermined categories, literally "on-the-fly." Without any further explanation of
the potential problems associated with this type of task, it is obviously a different task than performed in the other three “blocks.”

In each of the other three test “blocks” the task was simply recognition of the six symbols and the memorization of the classification of particular polygons, for later recall. While it is true that the topographic/landform feature identification task was also an air-photo interpretation task it should be recognized that this task was held constant in each of the four test “blocks.” Additionally, subjects were not asked to “fit” the landforms into predetermined categories, as was the case with land use identification task for the geospecific test “block.”

Examination of subject’s “total features remembered by treatment” (Table 9) reveals substantial personal differences in the number of features recalled (reported), as well as wide variation in the range of features each subject remembered per treatment. Subject number six, for example, recalled the most features (on average) across the four treatments, with an average of 57.3, and totals ranging from a low of 40 to a high of 67. Subject ten, on the other hand, averaged only 18.5 features per treatment, with a high of 20 for the geotypical “block” and a low of 16 for the cartographic-iconic method. The statistical analysis of the total number of features recalled by treatment, employing the “Pillai’s Trace” test of significance, resulted in a $p$ value of .007. At the 5% rejection level, therefore, significance was found, and the null hypothesis was rejected, thus, indicating a significant difference in the total number of features remembered based on the method of rendering. Pairwise
comparisons, adjusted for multiple comparisons using the Bonferroni method, show
significant differences between the geospecific method, and both the geotypical and
cartographic-iconic methods (Table 10). In each case the difference of the mean
between the geospecific method and the other two methods was greater than seven
(seven fewer recalled features for the geospecific method) (Table 11), a difference of
approximately 17 percent. This difference is not surprising, however, in light of the
increased difficulty of the task in the geospecific “block” vs. all others.

Table 9. Total features recalled, by treatment.

<table>
<thead>
<tr>
<th>Subject</th>
<th>G S</th>
<th>G T</th>
<th>C I</th>
<th>C A</th>
<th>Mean</th>
<th>Std. Dev.</th>
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</tr>
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</table>
Table 10. Bonferroni pairwise comparisons with significance at the .05 level. From the repeated measures test of total features recalled, by treatment.

<table>
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<td>.01</td>
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<tr>
<td>G_T</td>
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</tr>
<tr>
<td>C_I</td>
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<td></td>
<td>.31</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th></th>
<th>Total Features Recalled: By Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min.</td>
</tr>
<tr>
<td>Geospecific</td>
<td>18</td>
</tr>
<tr>
<td>Geotypical</td>
<td>20</td>
</tr>
<tr>
<td>Carto-iconic</td>
<td>16</td>
</tr>
<tr>
<td>Carto-arbitrary</td>
<td>22</td>
</tr>
</tbody>
</table>

In addition to the analysis of “total features remembered: by treatment”, these data were analyzed for “block” order. This analysis attempted to discover whether subjects increased the total number of features recalled, through increased familiarity with the environments or the test procedures. With a p value of .143, at the 5% rejection level, the null hypothesis was retained, indicating no significant difference in the total number of features subjects recalled, based on order.
Land use/Land cover Features

Again, supporting the notion of the increased difficulty (or subject’s lack of confidence in their classifications) of the landmark task in the geospecific “block”, the total number of land use features recalled in the geospecific “block” was significantly lower than in the other three methods. With a mean value of 23.5 land use features recalled in the geospecific “block” vs. 31.3, 31.5, and 33.5 land use features recalled for the geotypical, cartographic-iconic, and cartographic-arbitrary test “blocks” (differences of over 25% between the geospecific method and each of the other methods) (Table 12). With a calculated $p$ value of less than .01, employing “Pillai’s Trace” test of significance, at the .05 rejection level, the null hypothesis was rejected, thus indicating a potential link between treatment and the total number of land use features recalled. Further analysis, employing Bonferroni’s pairwise comparisons, at the 5% rejection level, indicated that the null hypothesis was rejected for the geospecific vs. each of the other methods, i.e. the total number of land use features recalled for the geospecific “block” was significantly different from all other treatments. The null hypothesis was, however, retained in pairwise comparisons between all other methods, indicating no significant effect of symbolic iconicity on the number of land use features recalled for the geotypical, cartographic-iconic, and cartographic-arbitrary test “blocks” (Table 13). Additionally, analysis of test “block”
order on the total number of land use features identified, resulted in a p of .74, thus retaining the null hypothesis (that "block" order has no effect on the total number of land use features recalled).


<table>
<thead>
<tr>
<th>Total Land Use Features Recalled: By Treatment</th>
<th>Min.</th>
<th>Max.</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
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</tbody>
</table>

Table 13. Bonferroni pairwise comparisons with significance at the .05 level. From the repeated measures test of total land use features recalled, by treatment.

<table>
<thead>
<tr>
<th></th>
<th>G_T</th>
<th>C_I</th>
<th>C_A</th>
</tr>
</thead>
<tbody>
<tr>
<td>G_S</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
</tr>
<tr>
<td>G_T</td>
<td>.99</td>
<td>.51</td>
<td>.39</td>
</tr>
<tr>
<td>C_I</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Perhaps more important than the total number of landmark features recalled (reported), are the number of correctly identified land use/landcover features identified, and the proportion of land use features that were correctly identified. For the purposes of this research, correctly identified land use features were polygons on the test form (Figure 13) labeled with the correct land use "type." Since subjects were tested to ensure their ability to remember the six land use classes used in this
research prior to the beginning of each test “block”, only polygons containing these
classes were counted as correct (e.g., “forest” or “scrub” is not acceptable for the
class “natural”). An examination of the descriptive statistics associated with subject’s
accuracy in recalling land use features from fly-throughs reaffirms earlier findings
regarding the relative difficulty (or uncertainty) when performing land use
identification and recall tasks employing the geospecific “drapes.” Previously, it was
noted that the total number of land use features recalled in the geospecific “block”
was significantly lower (approximately 25%) than each of the other test “blocks”; this
analysis indicates that of the reduced quantity recalled, an average of less than 57%
of those features are accurately recalled (Table 14). A statistical analysis of both the
total number of correctly recalled land use polygons and the percent of correctly
identified land use polygons [(total land use polygons recalled/correct)*100],
employing “Pillai’s Trace” test of significance, at the .05 rejection level, resulted in
calculated p values of less than .01 for each. Therefore, the null hypothesis was
rejected in both cases, confirming the significant effect of treatment on both the
total number of correct land use polygons and the percentage of correctly recalled
land use polygons. Further analysis of the total number of correct land use polygons
identified by subjects, employing Bonferroni’s pairwise comparisons, at the 5%
rejection level, showed a significant main effect in all but the geotypical and
cartographic-iconic comparison (Table 15). Additionally, Table 16 shows that the
percent land use features correctly identified in the geospecific test “block” was
significantly different (lower), than all other methods (see Table 14); the geotypical
"block" was significantly different than the geospecific and cartographic-arbitrary
(higher than geospecific and lower than cartographic-arbitrary (see Table 14); the
cartographic-iconic “block” significantly different (higher) than the geospecific
“block”, and; the cartographic-arbitrary “block” higher than both “image based”
“blocks.” With calculated p values of .59 for the total number of correct land use
polygons recalled, and .44 for percent correctly recalled land use polygons, “block”
order was found to have no significant effect on results.

Table 14. Descriptive statistics: total number of correct land use features and
percent land use features correctly identified, by treatment.

<table>
<thead>
<tr>
<th></th>
<th>Number Correct</th>
<th></th>
<th></th>
<th>Percent Correct</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
<td>Mean</td>
<td>Std. Dev.</td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>Geospecific</td>
<td>4</td>
<td>25</td>
<td>13.0</td>
<td>5.50</td>
<td>30.3</td>
<td>80.0</td>
</tr>
<tr>
<td>Geotypical</td>
<td>11</td>
<td>40</td>
<td>23.0</td>
<td>7.92</td>
<td>47.6</td>
<td>90.9</td>
</tr>
<tr>
<td>Carto-iconic</td>
<td>7</td>
<td>49</td>
<td>24.2</td>
<td>9.63</td>
<td>44.4</td>
<td>100</td>
</tr>
<tr>
<td>Carto-arbitrary</td>
<td>14</td>
<td>51</td>
<td>27.7</td>
<td>9.46</td>
<td>60.5</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 15. Bonferroni pairwise comparisons with significance at the .05
level. From repeated measures test of the total land use features
correctly recalled, by treatment.

<table>
<thead>
<tr>
<th></th>
<th>G_T</th>
<th>C_I</th>
<th>C_A</th>
</tr>
</thead>
<tbody>
<tr>
<td>G_S</td>
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<td>.00</td>
<td>.00</td>
</tr>
<tr>
<td>G_T</td>
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<td>.00</td>
<td>.00</td>
</tr>
<tr>
<td>C_I</td>
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<td>.00</td>
<td>.00</td>
</tr>
</tbody>
</table>
Table 16. Bonferroni pairwise comparisons of repeated measures test of the % correct of total land use features recalled, by treatment, with significance at the .05 level.

<table>
<thead>
<tr>
<th></th>
<th>G_T</th>
<th>C_I</th>
<th>C_A</th>
</tr>
</thead>
<tbody>
<tr>
<td>G_S</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
</tr>
<tr>
<td>G_T</td>
<td></td>
<td>.99</td>
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<tr>
<td>C_I</td>
<td></td>
<td></td>
<td>.06</td>
</tr>
</tbody>
</table>

Topographic/Landform Features

During the second fly-through of each test “block”, subject’s instructions were twofold, first, “learn the path”; and second, learn (remember) as many topographic/landform features and land use/land cover features as possible. Individual differences in the use, and meaning of terms describing the topographic/landform features, and the “fuzziness” of the metric used to describe locations of those features, i.e. shapes sketched on the land use identification form and the use of terms such as “near”, “by”, “in”, resulted in an inability to accurately assess the extent to which subject’s memory of the location of the features was correct. Therefore, unlike the analysis of recalled land use features, which included analyses of both total, and correct features recalled, the topographic/landform analysis was limited only to total number of features recalled and the percent of the total features recalled that were topographic/landform features.

The statistical analysis of the total number of landform (topographic) features recalled, by treatment, employing the “Pillai’s Trace” test of significance,
resulted in a $p$ value of .001. At the 5% rejection level, the null hypothesis is rejected, thus, recognizing the significant effect of symbol iconicity (treatment) on the total number of landform (topographic) features recalled. Further analysis of the total number of correct land use polygons identified by subjects, employing Bonferroni's pairwise comparisons, at the 5% rejection level, identified the significant differences as being between the number of topographic features identified in the geospecific and the cartographic-iconic test “blocks”, and the geotypical and cartographic-iconic “blocks” (Table 17). An examination of the descriptive statistics associated with subject's total topographic/landform features recalled (Table 18), further illustrates the differences identified in the pairwise comparisons. With means of 9.33 and 8.58, and standard deviations of 3.84 and 3.32 for the geospecific and geotypical “blocks” respectively, vs. a mean of 6.5 and standard deviation of 2.3 for the cartographic-iconic block, the differences are clear.

In the analysis of subject's total topographic features recalled using “image based” symbols (geospecific and geotypical) vs. the “cartographically based” symbols (cartographic-iconic and cartographic-arbitrary), it was found that significant ($p = .001$) differences did, indeed exist. Again, referring to Table 18, it is notable that the cartographic “blocks” resulted in, on average, fewer topographic features recalled than the “image based blocks” (combined means of 13.5 vs. 17.9).
Table 17. Bonferroni pairwise comparisons of topographic/landform features recalled, by treatment, with significance at the .05 level.

<table>
<thead>
<tr>
<th></th>
<th>G_T</th>
<th>C_I</th>
<th>C_A</th>
</tr>
</thead>
<tbody>
<tr>
<td>G_S</td>
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<td>.01</td>
<td>.12</td>
</tr>
<tr>
<td>G_T</td>
<td></td>
<td>.01</td>
<td>.23</td>
</tr>
<tr>
<td>C_I</td>
<td></td>
<td></td>
<td>.99</td>
</tr>
</tbody>
</table>

Table 18. Descriptive statistics: total topographic features recalled, by treatment.

<table>
<thead>
<tr>
<th>Total Topo Recalled: By Treatment</th>
<th>Min.</th>
<th>Max.</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geospecific</td>
<td>3</td>
<td>20</td>
<td>9.3</td>
<td>3.84</td>
</tr>
<tr>
<td>Geotypical</td>
<td>3</td>
<td>17</td>
<td>8.6</td>
<td>3.32</td>
</tr>
<tr>
<td>Carto-iconic</td>
<td>2</td>
<td>13</td>
<td>6.5</td>
<td>2.30</td>
</tr>
<tr>
<td>Carto-arbitrary</td>
<td>1</td>
<td>12</td>
<td>7.0</td>
<td>2.77</td>
</tr>
</tbody>
</table>

While the counterbalanced approach taken in this research resulted in an ability to perform analyses based on the treatment, the effect of order of test “block” (1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup>, or 4<sup>th</sup>) was still of interest. The statistical analysis of the total number of landform (topographic) features recalled, by order, resulted in a p value of .012. With the rejection level of .05, the null hypothesis was rejected, indicating that “block” order had an effect of the total number of landform features identified. The pairwise comparison (Table 19) shows the significant differences between the first “block” and the third and fourth “blocks.” Contrary to what would be expected if subjects were accumulating topographic knowledge as they progressed through
the test protocol, the significant effect of order is traceable to a general decrease
in the number of topographic features recalled (Table 20). Rather than reflecting
on differences in the treatments, these results seem to indicate changes in test-
taking strategy, or possibly the onset of fatigue with the task of sketching
locations and identifying topographic/landform features (Table 20). Unlike the
identification task for land use/land cover features (prompted responses), which
involved labeling delineated polygons (with the path just followed also visible on
the form), subjects had to locate topographic features on the form, relative to the
path and the delineated polygons. This significant decrease in the number of
topographic features recalled occurred while analyses of the overall number of
features recalled, the total number of land use features recalled, and the number of
correct land use features recalled showed no significant effect of order, thus,
bolstering the argument for a strategic change, rather than a change based on
fatigue.

Table 19. Bonferroni pairwise comparisons of
topographic/landform features recalled, by order,
with significance at the .05 level.

<table>
<thead>
<tr>
<th></th>
<th>2nd</th>
<th>3rd</th>
<th>4th</th>
</tr>
</thead>
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<tr>
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<td>.02</td>
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<tr>
<td>2nd</td>
<td>.99</td>
<td>.99</td>
<td></td>
</tr>
<tr>
<td>3rd</td>
<td>.99</td>
<td>.99</td>
<td></td>
</tr>
</tbody>
</table>
Table 20. Descriptive statistics: total topographic features recalled, by order.

<table>
<thead>
<tr>
<th></th>
<th>Total Topo Recalled: By Order</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min.</td>
<td>Max.</td>
<td>Mean</td>
<td>Std. Deviation</td>
</tr>
<tr>
<td>1st</td>
<td>5</td>
<td>20</td>
<td>9.3</td>
<td>3.84</td>
</tr>
<tr>
<td>2nd</td>
<td>1</td>
<td>17</td>
<td>8.6</td>
<td>3.32</td>
</tr>
<tr>
<td>3rd</td>
<td>3</td>
<td>13</td>
<td>6.5</td>
<td>2.30</td>
</tr>
<tr>
<td>4th</td>
<td>2</td>
<td>10</td>
<td>7.0</td>
<td>2.77</td>
</tr>
</tbody>
</table>

The final portion of the "Landmark Analysis" focused on the percent of total features recalled that were topographic features. The purpose of this analysis was to address questions regarding the composition, or ratio of land use/landform features to topographic features, and whether the method of symbolizing land use information affected that ratio. Working under the assumption of limited computational and memory resources available for cognitive tasks (Sweller, 1988; Sholl, 1993), the analysis focused on the ratio (measured as a percent) of topographic features to total features (rather than correct features). The rational behind this decision was that, whether the recalled land use information was correct, or not, it was utilizing cognitive resources.

Employing the "Pillai's Trace" test of significance, at the .05 rejection level, a significant difference was found ($p = .000$) in the percent of topographic features recalled (as a proportion of total features recalled) based on treatment. The pairwise comparison of the data (Table 21) found significant differences between the geospecific treatment and each of the other treatments, with the only other
significant difference between the geotypical and cartographic-iconic “blocks.” An examination of the descriptive statistics associated with the percent of topographic features (Table 22) shows that subjects recalled an average of 29.8% topographic features in the geospecific test “block” vs. 21.75%, 17.57%, and 17.76% for each of the other test “blocks.” The previously reported finding of significantly fewer features total features recalled (by treatment) in the geospecific “block” vs. the geotypical and cartographic arbitrary test “blocks” (and non-significant, but considerably fewer in the cartographic-iconic “block”) combined with the current findings, suggests that subjects adopted a strategy of increased focus on topographic/landform features to compensate for the uncertainty in land use polygon identification/classification. “Block” order was found to have no significant effect (“Pillai’s Trace”: \( p = .163 \).

**Table 21. Bonferroni pairwise comparisons of the percent of topographic/landform features recalled, by treatment, with significance at the .05 level.**

<table>
<thead>
<tr>
<th></th>
<th>G_T</th>
<th>C_I</th>
<th>C_A</th>
</tr>
</thead>
<tbody>
<tr>
<td>G_S</td>
<td>.01</td>
<td>.00</td>
<td>.00</td>
</tr>
<tr>
<td>G_T</td>
<td></td>
<td>.00</td>
<td>.07</td>
</tr>
<tr>
<td>C_I</td>
<td></td>
<td>.99</td>
<td></td>
</tr>
</tbody>
</table>
Table 22. Descriptive statistics: percent of total features recalled that were landforms (topographic), by treatment.

<table>
<thead>
<tr>
<th></th>
<th>Percent Topo Recalled: By Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min.</td>
</tr>
<tr>
<td>Geospecific</td>
<td>7.5</td>
</tr>
<tr>
<td>Geotypical</td>
<td>10.8</td>
</tr>
<tr>
<td>Carto-iconic</td>
<td>10.7</td>
</tr>
<tr>
<td>Carto-arbitrary</td>
<td>5.3</td>
</tr>
</tbody>
</table>

Path Reproduction/Route Learning

The path reproduction/route learning portion of this analysis was concerned with the accuracy with which subjects were able to apply the spatial information acquired in the previous two fly-throughs (of each test “block”) to the accurate reproduction of the learned route, and the location of the “turning points” on the route. As was the case with all other analyses in this research, the underlying question was: does the level of iconicity, or the symbols used as thematic “drapes” in fly-through navigation of simulated environments affect subject’s ability to perform spatial memory and reproduction tasks? To this end, the measure of a subject’s accuracy at locating the turn points for a “block” was the sum of the difference between each of a subject’s recalled turn points and the corresponding turn point from that subject’s first fly-through, minus an adjustment for the control ability. Subject’s control ability (SCA) was defined as the largest error in distance between the actual location of a turn point (as found on the path on the terrain’s surface) and
the position of that same point on the subject’s route while the path was visible.

While subjects, arguably, could have located the turn points more accurately, the
locations identified by subjects in their first fly-throughs of each “block” (with the
path visible) were chosen with the explicit instruction to follow the route as
accurately as possible. The identified differences therefore, represent the limits of a
subject’s actual ability, his/her understanding of the term “accurately”, his/her
willingness to try to be accurate, or some combination thereof (Table 23). By using
the largest error in locating a turn point from all four “blocks” of a subject’s test, it
was hoped that a more conservative estimation of the subject’s ability would result,
with fewer Type1 errors introduced into the research.

Table 23. SCA values used in “choice point” accuracy and route accuracy
analyses.

<table>
<thead>
<tr>
<th>Subject #</th>
<th>map units</th>
<th>meters</th>
<th>Subject #</th>
<th>map units</th>
<th>meters</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>261</td>
<td>134</td>
<td>13</td>
<td>202</td>
<td>104</td>
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<tr>
<td>2</td>
<td>287</td>
<td>148</td>
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<td>250</td>
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<td>15</td>
<td>294</td>
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<td>259</td>
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<td>232</td>
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<td>5</td>
<td>201</td>
<td>104</td>
<td>17</td>
<td>353</td>
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<td>357</td>
<td>184</td>
<td>24</td>
<td>261</td>
<td>134</td>
</tr>
</tbody>
</table>
As a measure of subject’s route reproduction accuracy, a deterministic application of the epsilon band model of linear uncertainty was employed. The original intent of this model was to identify areas in which a linear feature would accurately appear based on the uncertainty of the various parameters (round-off error, digitizing error, generalization errors, etc.) on the locations of end points of a linear feature (Alesheikh, Blais, Chapman, and Karimi, 1999). This research utilized each subject’s SCA to generate an epsilon band, proceeding under the assumption that any line segment, or portion thereof, falling within the epsilon band (buffer) would be considered “accurate”, any portion outside “inaccurate.” Utilizing this rational, analyses of subject’s route accuracy was, ultimately, an analysis of the relative length of recalled paths falling outside of the epsilon band.

Both the analysis of “choice point” accuracy and “route” accuracy required subjects to complete one fly-through from memory (reproduction task) for each of the four test “blocks.” The inability, therefore, of two subjects to even attempt one fly-through, and four other subject’s inability to complete at least one fly-through each, resulted in the use of only 18 of the 24 subjects in this analysis. Of the six subjects excluded from this part of the analysis, both of the subjects unable to attempt the reproduction task, and one of the subjects unable to complete the task failed in the geotypical “block”, two failed to complete the cartographic-iconic “block”, and one the geospecific “block.” While conceptually, the error in both location of choice points and in reproducing the route from memory for subjects
unable to even attempt a fly-through should be counted as "maximum" for each choice point (and each "leg" of the route), a ratio scale value for error was required for statistical analysis. The inability to determine an appropriate ratio scale value for the subject’s missing values, therefore, requires that six “repeated measures” be excluded from the analysis.

“Choice Point” Accuracy

Analysis of subjects’ “choice point accuracy” is concerned with subject’s ability to accurately recall and locate the turn points, learned in their first fly-through of each virtual environment. With a calculated $p$ value of less than .01, employing “Pillai’s Trace” test of significance, at the .05 rejection level, the null hypothesis was retained, thus indicating that treatment has no effect on subjects’ accuracy in locating “choice points.” An examination of each subject’s total error in locating the “choice points” (these values reflect total error, by “block” after subtracting the SCA from each of the four “choice point” identifications) illustrates the differences in subject’s ability and consistency in performing the task (Table 24).
Table 24. Subject’s error in locating “choice points” by treatment, in meters (SCA removed).

<table>
<thead>
<tr>
<th>Subject</th>
<th>G S</th>
<th>G T</th>
<th>C I</th>
<th>C A</th>
<th>Mean</th>
<th>Std. Dev.</th>
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</thead>
<tbody>
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<td>2545</td>
<td>1628</td>
<td>1624.2</td>
<td>694.25</td>
</tr>
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<td>1955</td>
<td>661</td>
<td>292</td>
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<td>2530.38</td>
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<td>1412.51</td>
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<td>2056</td>
<td>918.5</td>
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<td>1225.5</td>
<td>931.80</td>
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<td>2959</td>
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<td>436.14</td>
</tr>
<tr>
<td>20</td>
<td>400</td>
<td>2016</td>
<td>622</td>
<td>1146</td>
<td>1046.0</td>
<td>718.33</td>
</tr>
<tr>
<td>21</td>
<td>0</td>
<td>176</td>
<td>1275</td>
<td>216</td>
<td>416.8</td>
<td>579.81</td>
</tr>
<tr>
<td>22</td>
<td>1536</td>
<td>15</td>
<td>1214</td>
<td>512</td>
<td>819.2</td>
<td>685.75</td>
</tr>
<tr>
<td>23</td>
<td>0</td>
<td>52</td>
<td>1476</td>
<td>166</td>
<td>423.5</td>
<td>1551.43</td>
</tr>
<tr>
<td>24</td>
<td>803</td>
<td>957</td>
<td>2790</td>
<td>2130</td>
<td>1670.0</td>
<td>436.14</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mean</th>
<th>1253.7</th>
<th>1221.6</th>
<th>1731.0</th>
<th>1415.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Std. Dev.</td>
<td>1439.36</td>
<td>993.46</td>
<td>1186.71</td>
<td>1128.35</td>
</tr>
</tbody>
</table>

While the analysis of subject’s “choice point” accuracy found no effect of treatment on the total error per “block”, with a rejection level of .05, and a p value of less than .00, “block” order was found to have a significant effect. The results of a pairwise comparison of factors using the Bonferroni adjustment for multiple comparisons (Table 25) reveals that the significant effect of order is found most
strongly between subject’s first “block” (regardless of treatment) and their second “block”, with no significant difference between the first and third “blocks”, and a significant difference once again, appearing between the first and fourth “block.” An examination of the descriptive statistics of subject’s error in finding turning points during a path reproduction task clearly shows the pattern of differences (Table 26). In subject’s first “block” the mean error is the highest at 4301.67 (equivalent to 2216 meters in real-world units), dropping to 2174.56 (1120 meters), 2538.33 (1308 meters), and 1897.83 (978 meters) in subsequent trials. This reduction in error suggests that after subjects completed their first block they: 1) weren’t satisfied (or comfortable with their performance in the reproduction task); 2) identified which part of their task completion strategy should be modified; and 3) implemented the modification in subsequent trials.

Table 25. Bonferroni pairwise comparisons of the error in finding turning points during a path reproduction task, by order, at the .05 level of significance.

<table>
<thead>
<tr>
<th></th>
<th>2nd</th>
<th>3rd</th>
<th>4th</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>.01</td>
<td>.35</td>
<td>.01</td>
</tr>
<tr>
<td>2nd</td>
<td></td>
<td>.99</td>
<td>.99</td>
</tr>
<tr>
<td>3rd</td>
<td></td>
<td></td>
<td>.99</td>
</tr>
</tbody>
</table>
Table 26. Descriptive statistics: subject's error in finding turning points during a path reproduction task, by order (SCA removed).

<table>
<thead>
<tr>
<th>Subject</th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
<th>4th</th>
<th>Mean</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>868</td>
<td>1456</td>
<td>2545</td>
<td>1628</td>
<td>1624.2</td>
<td>694.48</td>
</tr>
<tr>
<td>2</td>
<td>5825</td>
<td>1955</td>
<td>292</td>
<td>661</td>
<td>2183.4</td>
<td>2530.52</td>
</tr>
<tr>
<td>3</td>
<td>3061</td>
<td>339</td>
<td>419</td>
<td>2531</td>
<td>1587.6</td>
<td>1412.70</td>
</tr>
<tr>
<td>7</td>
<td>2746</td>
<td>879</td>
<td>1231</td>
<td>296</td>
<td>1287.9</td>
<td>1045.48</td>
</tr>
<tr>
<td>11</td>
<td>2680</td>
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<td>2332</td>
<td>1859</td>
<td>2301.8</td>
<td>336.92</td>
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<td>2649</td>
<td>3986</td>
<td>646</td>
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<tr>
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<td>1716</td>
<td>1347</td>
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<td>0</td>
<td>765.6</td>
<td>896.76</td>
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<tr>
<td>14</td>
<td>2902</td>
<td>1571</td>
<td>2273</td>
<td>490</td>
<td>1809.1</td>
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</tr>
<tr>
<td>15</td>
<td>1033</td>
<td>286</td>
<td>2058</td>
<td>299</td>
<td>918.5</td>
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<tr>
<td>16</td>
<td>2436</td>
<td>606</td>
<td>391</td>
<td>1469</td>
<td>1225.3</td>
<td>931.90</td>
</tr>
<tr>
<td>17</td>
<td>2995</td>
<td>2228</td>
<td>4571</td>
<td>2044</td>
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<td>1150.85</td>
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<tr>
<td>18</td>
<td>3684</td>
<td>783</td>
<td>570</td>
<td>431</td>
<td>1367.1</td>
<td>1551.48</td>
</tr>
<tr>
<td>19</td>
<td>955</td>
<td>848</td>
<td>180</td>
<td>122</td>
<td>526.1</td>
<td>436.10</td>
</tr>
<tr>
<td>20</td>
<td>2016</td>
<td>1146</td>
<td>400</td>
<td>622</td>
<td>1046.2</td>
<td>718.17</td>
</tr>
<tr>
<td>21</td>
<td>1275</td>
<td>216</td>
<td>0</td>
<td>176</td>
<td>416.9</td>
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<td>819.2</td>
<td>685.66</td>
</tr>
<tr>
<td>23</td>
<td>166</td>
<td>52</td>
<td>1476</td>
<td>0</td>
<td>423.5</td>
<td>705.14</td>
</tr>
<tr>
<td>24</td>
<td>2130</td>
<td>957</td>
<td>803</td>
<td>2790</td>
<td>1669.9</td>
<td>953.16</td>
</tr>
</tbody>
</table>

Mean: 2216.2, 1120.3, 1307.7, 977.8
Std. Dev.: 1299.61, 777.64, 1384.27, 896.76

Route Accuracy

This analysis is concerned with subject’s accuracy in reproducing a learned route, as represented by the total length of the route found outside of the epsilon band representing SCA (subject’s control ability). As subject’s location
of “choice points” and selection of routes between those points were both derived from the same fly-through (in each “block”) it might seem reasonable to assume that similar patterns (significant effects) would be found in the analyses; this however, is not the case. The error in locating “choice points” was based only on the total linear distance, the route error reflects the cumulative effect of the two-dimensional (locational) error of choice points on the accuracy of the recalled route combined with the error from not traveling in a straight line between “choice points.” While any turns between “choice points” increases the traveled distance between the points, the measure of inaccuracy of route reproduction used in this study, when subjects whose routes are “outside” of their epsilon band correct course and return to their learned route their overall error will decrease. There is, of course, a point of diminishing returns when the error of navigating in a straight line, outside of the epsilon band, is less than “zigzagging” in and out of the epsilon band. Since subjects were unaware of the extent (or existence) of their epsilon band (an area in which any deviation from the learned route would be considered correct) there was no concern that subjects employed any particular strategy in the route reproduction task, other than trying to reproduce the route they learned, as accurately as possible. Table 27 shows subject’s total route error for each “block” (treatment). Since each subject represents a unique order of testing (exposure to the different treatments) it is not possible to analyze these data at a disaggregate level. These data do, however, illustrate the magnitude and
range of error in subject's attempts at accurately reproducing a learned route through the simulated environments in each test "block." Figures 17 and 18 are illustrations of the learned routes with the associated epsilon band (buffers), and the "error" portions of the recalled routes for each test "block", for subject #21 (the subject with the lowest overall route error) and subject #2 (the subject with the greatest overall route error). Examination of the route error in Figure 17 shows the effect that inaccurate recollection of "choice point" locations can have on route accuracy. For example, an error of 335 meters for one "choice point" in the geotypical test "block" (176 meters outside of the epsilon band) results in 1369 meters of route error. This error would, no doubt have been larger if subject #21 had navigated using the curved paths evident in subject #2's fly-throughs (Figure 18). While subject #2 was capable of navigating on relatively consistent headings, as evidenced by the learned route, the recalled route seems to indicate uncertainty, and an adoption of a "search" strategy to locate the "choice points." Subject #21's recalled paths, on the other hand, indicate a deliberate effort to navigate to specific, known (or believed) locations ("choice points").

To address the question: Does the level of iconicity, or the symbols used as thematic "drapes" in fly-through navigation of simulated environments affect subject's accuracy in reproducing a route from memory, the statistical analysis, employing a multivariate approach to repeated measures at a .05 level of significance was conducted. With a calculated p value of .82, the null hypothesis
was retained; indicating that treatment does not affect the accuracy in reproducing a route from memory. Unlike in the analysis of "choice point" accuracy, however, with a calculated p value of .99, no effect of order was found in subject's route reproduction accuracy.

Table 27. Descriptive statistics: subject's error in the route reproduction task (SCA removed).

<table>
<thead>
<tr>
<th>Subject</th>
<th>Route Error by Treatment (meters)</th>
<th>Mean</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>G S</td>
<td>G T</td>
<td>C I</td>
</tr>
<tr>
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<td>9404</td>
<td>11951</td>
</tr>
<tr>
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<td>11152</td>
<td>2197</td>
</tr>
<tr>
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<td>7071</td>
<td>2829</td>
<td>2213</td>
</tr>
<tr>
<td>7</td>
<td>8244</td>
<td>7208</td>
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<tr>
<td>24</td>
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<td>7940</td>
<td>10018</td>
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</table>

Mean 5512.1 6292.0 6795.5 6625.0
Std. Dev. 3895.55 3301.18 3160.38 3229.25
Figure 17. Subject #21 route error (lowest overall error).

Geospecific Test "Block" - 0 meters error

Geotypical Test "Block" - 1359 meters error

Cartographic-Iconic Test "Block" - 9594 meters error

Cartographic-Abstract Test "Block" - 736 meters error
Figure 18. Subject #2 route error (highest overall error).

Geospecific Test "Block" - 12548 meters

Geotypical Test "Block" - 11152 meters

Cartographic-Iconic Test "Block" - 2197 meters

Cartographic-Abstract Test "Block" - 11266 meters
Confidence

At the end of each “leg” of the route (at the recalled “choice point” location), during the reproduction task, subjects were asked a number of questions regarding landmarks used to navigate that leg of the route, and their confidence in their accuracy. The confidence assessments were broken-down into two categories; confidence in accurately reproducing the route learned in the first fly-through of that “block”, and accuracy in locating the correct turning point. Since this research is concerned with differences based on treatment, aggregate measures by test “block” were used in the analysis. As was the case in the analysis of error in the route reproduction task, this analysis required subjects to have completed all “legs” in each of the four test “blocks.” Therefore, the same six subjects excluded from the analysis of error in route reproduction were excluded from this analysis.

“Choice Point” Confidence

Statistical analysis of subject’s confidence in their accuracy at finding the turning points learned in the first fly-through of each test “block” found no within-subject effect of either treatment ($p = .78$), or “block” order ($p = .46$). Therefore, the average confidence, for accurately locating each of the five turning points in each “block” was not affected by the treatment or the order of testing. This, however, is not to say that subject’s were not more (or less) confident in performing tasks either later in the testing, or in one “block” over another. Since the estimates were aggregated for each “block”, extremely high or low confidence estimates can skew
the average for a subject within a particular test “block.” Additionally, while subjects "scaled" their confidence estimates in each test “block” (relative to each other) it is unclear whether the “scaling” between “blocks” was consistent. Unfortunately, subjects were not asked to rank (or rate) their overall confidence with estimates for each method.

Route Confidence

As was the case with the analysis of confidence for “choice points”, the statistical analysis of subject’s confidence in their accuracy at following the route learned in the first fly-through of each test “block” found no within-subject effect of either treatment ($p = .54$), or “block” order ($p = .11$). Questions regarding the meanings of these findings, however, remain as a result of the same methodological problems indicated in the previous section (subject’s confidence of accuracy in finding “choice points”). In both cases, it should be recognized that a person’s confidence in performing a task can be different than their confidence in the accuracy of performing that task, that there is no absolute (consistently scaled) metric for these measures, and that aggregate measures of confidence can be misleading.

Summary of Results

The analyses found in four preceding sections have focused on the effect that the level of iconicity of the areal symbols used to represent land use categories has on subjects’ ability to perform specific tasks, using spatial memory. In these
analyses, subjects' ability to accurately perform the tasks was statistically compared among the four treatments to determine whether treatment had a main effect on accuracy. Additionally, the "block" order for each subject was analyzed to determine if familiarity with the testing, changes in strategy while performing tasks, or fatigue might have a significant effect on subjects' performance. Following, are summaries of the findings for each of the four preceding sections: Geometric Analysis, Landmark Analysis, Path Reproduction/Route Learning, and Confidence. For each section the research questions addressed in that section is restated, the results of the statistical analyses are reported, and a brief explanation/interpretation of the results is given. The following table (Table 28) offers an overview of the tests and findings.
<table>
<thead>
<tr>
<th>Section</th>
<th>Focus</th>
<th>Analysis</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometric Analysis</td>
<td><strong>Angular Estimates</strong></td>
<td>Error in angular recall: by treatment</td>
<td>no</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Error in angular recall: by “block” order</td>
<td>no</td>
</tr>
<tr>
<td></td>
<td><strong>Length/Distance Estimates</strong></td>
<td>“Scale free” length estimate error: by treatment</td>
<td>no</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“Scale free” length estimate error: by “block” order</td>
<td>no</td>
</tr>
<tr>
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<td><strong>Total Recalled Features</strong></td>
<td>Total number of features recalled: by treatment</td>
<td>yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total number of features recalled: by “block” order</td>
<td>no</td>
</tr>
<tr>
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<td><strong>Land use/Land cover</strong></td>
<td>Total number of land use features recalled: by treatment</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Total number of land use feature recalled: by “block” order</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Number correctly recalled: by treatment</td>
<td>yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number correctly recalled: by “block” order</td>
<td>no</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Percent of correct/total land use recalled: by treatment</td>
<td>yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Percent of correct/total land use recalled: by “block” order</td>
<td>no</td>
</tr>
<tr>
<td></td>
<td><strong>Topographic/Landform</strong></td>
<td>Total number of topo features recalled: by treatment</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Total number of topo features recalled: by “block” order</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Percent of recalled topographic/total recalled features: by treatment</td>
<td>yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Percent of recalled topographic/total recalled features: by “block” order</td>
<td>yes</td>
</tr>
<tr>
<td>Path Reproduction/</td>
<td><strong>“Choice Point” Accuracy</strong></td>
<td>Distance error in locating “choice points”: by treatment</td>
<td>no</td>
</tr>
<tr>
<td>Route Learning</td>
<td></td>
<td>Distance error in locating “choice points”: by “block” order</td>
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</tr>
<tr>
<td></td>
<td><strong>Route Accuracy</strong></td>
<td>Error in accurately reproducing the learned route: by treatment</td>
<td>no</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Error in accurately reproducing the learned route: by “block” order</td>
<td>no</td>
</tr>
<tr>
<td>Confidence</td>
<td><strong>“Choice Point” Confidence</strong></td>
<td>Confidence in accurately finding the “choice points”: by treatment</td>
<td>no</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Confidence in accurately finding the “choice points”: by “block” order</td>
<td>no</td>
</tr>
<tr>
<td></td>
<td><strong>Route Confidence</strong></td>
<td>Confidence in accurately reproducing the learned route: by treatment</td>
<td>no</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Confidence in accurately reproducing the learned route: by “block” order</td>
<td>no</td>
</tr>
</tbody>
</table>
In the "Geometric Analysis" section of this study, subject’s angular estimates and length/distance estimates were examined to determine whether the level of iconicity, or the symbols used as thematic "drapes" affected:

1) Subjects’ ability to accurately recall relative directional changes while involved in a route learning task, or;

2) Subjects’ ability to accurately estimate distance/path-length in standard units while involved in a route learning task (research questions 1 and 2).

Employing a multivariate approach to repeated measures analysis at the .05 rejection level, no significant effect of treatment was found for either the angular recall task or the distance/path length estimation task. The lack of significant difference (between treatments) in the angular recall task, which measured subject’s ability to visually perceive a single angle, store the image of that angle in memory, and subsequently recall and reproduce the angle as a graphic representation, indicates that overall, background textures acted as neither distracters or aids in angular recall in this study. While the statistical analysis of the “scale free” errors of subject’s length estimates resulted in a calculated $p$ value of .07, at the .05 rejection level, no statistically significant effect was found. Thus, the level of iconicity did not affect subject’s ability to accurately estimate distance/path-length in standard units while involved in a route learning task. In the analysis of the effect of "block" order, however, it was found that order had a significant ($p = .03$) effect on accuracy of estimates. Descriptive statistics (Table 7, pg. 84) show the largest increase in
accuracy occurring in the second block, with smaller, but consistently improving accuracy in subsequent "blocks." These results seem to indicate that subjects accuracy resulted from familiarity with the testing (refining the test taking strategy after the first "block"), and that with practice, accuracy in distance estimation tasks can increase.

The analyses conducted regarding land use/land cover features and topographic/landform features focused on how the level of iconicity, or the symbols used as thematic "drapes" affected the quantity or accuracy of topographic/landform information and land use information recalled (research question 3). Overall, treatment was shown to have a significant effect on:

1) the total number of landmarks recalled,
2) the total number of land use/land cover polygons recalled,
3) the number, and proportion of land use/land cover polygons correctly identified,
4) the number of topographic/landform features recalled, and
5) proportion of topographic features to total features recalled.

More specifically, the geospecific treatment was found to result in subjects recalling significantly fewer landmarks overall (total of land use and topographic features), fewer land use polygons, a lower percentage of correctly identified land use polygons to total recalled land use polygons, a reduced number of topographic features
(compared to the cartographic-iconic method), and a lower proportion of topographic features to total features recalled.

In addition to the significant differences in subject’s (landmark) task performance in the geospecific “block” vs. other methods, significant differences were also identified between other treatments, in several of the tests. The use of the cartographic-abstract symbology resulted in a significantly higher number of correctly identified land use polygons than in the other three methods, and a markedly higher proportion of correctly identified polygons than in the other three methods. Table 12 (pg.91) shows that the total number of correctly identified land use polygons increases as the level of iconicity decreases, as does the percentage of correctly identified land use polygons. Whether these results indicate a decrease in ambiguity of the symbology (e.g., differences in relationships between the sign-vehicles (symbols) and their interpretants, requiring a more complex “translation” schemata as might be suggested in a semiotic analysis), the increased efficiency and accuracy of perceptions (searches) when fewer visual “dimensions” are used (as explanations derived from Feature Integration Theory or Guided Search Theory might propose), or simply a recognition of the dominance of color in the perception and cognition of visual information, the practical implications are the same. In fly-through applications using simulated environments, where the task domain includes the recognition
and recall of nominal scale (areal) data, the use of hue to establish "type" is the most effective method.

Addressing research questions four and five (does the level of iconicity, or the symbols used as thematic "drapes", affect subject's accuracy in learning, and later, locating specific "choice points" along a route, or subject's accuracy in reproducing a route from memory?), a multivariate approach to repeated measures analysis, conducted at the .05 significance level, found no statistically significant affect of treatment on either subject's accuracy in locating "choice points" or accuracy in reproducing a learned route. Likewise, in response to research question six, which addressed the effect of treatment on subject's confidence in performing point location and route reproduction tasks, no significant effect of treatment was found. Since research questions five and six involved a measure of "confidence of accuracy" the finding of no main effect can be interpreted several ways. If we were to assume that subjects understood their estimates to be assessments of their accuracy, the fact that no main effect was found in either of the reproduction tasks would suggest that subjects correctly assessed their accuracy. If, on the other hand, subjects understood their task to be a ranking of their confidence, we should not necessarily expect a relationship between the accuracy in route reproduction tasks and subject's confidence. Subjects could have either high or low confidence regardless of how accurate their route reproduction or "choice point" location tasks are. Thus, we can not use the results of these analyses to determine which treatment,
if any, subjects were more confident in, or whether different treatments resulted in subjects more accurately assessing their ability to reproduce a route or accurately locate a “choice point.”

In addition to the within-subject analyses employing the independent variable of treatment (level of iconicity), the between variable of “block” order was also analyzed. Since each subject represented a unique treatment order, no between subject analyses of the effect of treatment were conducted. Analyses of “block” order, comparing task results based on when subjects performed them, however, was conducted to detect differences based on spatial learning from block to block, changes in subject’s strategies for performing tasks, or decreases in ability due to fatigue. Order was found to have a significant effect on both the number of topographic/landform features recalled and subject’s accuracy in locating “choice points.” In both cases the results suggest modification of strategies to more accurately (or easily) accomplish the required tasks, rather than any effect of fatigue or spatial knowledge transfer between test “blocks.”

Finally, as was the case with all of the tasks performed by the subjects in this research, differences in subject’s individual abilities were quite evident. In the analysis of the total number of landmarks recalled, for example, it was quite clear that certain subjects were more capable of recalling larger quantities of information than others. With a low of 18 for one subject, an average of just over three features per “leg” in each “block”, to a high of 5, an average of over eleven features per “leg”,

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individual differences in subjects' ability, willingness to engage in difficult tasks, and
differences in strategy are evident. It is precisely these differences that make
assessments of the effect of treatment, on performance, in a between subject analysis
difficult, based on the methodology employed in this study.
CHAPTER 5

Conclusions

The recent advances in digital computing technologies, including both the hardware and software domains, have presented cartographers with opportunities and challenges of how "best" to represent spatial information for use and analysis. "Until recently... the rendering of GIS results primarily has been restricted to the same set of display techniques used in manual cartography" (Berry, Buckley, and Ulbricht, 1998, p. 47). These techniques, the result of hundreds of years of cartographic experience and decades of cartographic research, have proven appropriate for conventional map products but have yet to demonstrate their efficacy in simulated environments and in modes of acquisition that include movement of the user's point-of-view.

Research investigating the use of various media intended to facilitate the sequential acquisition of spatial information has shown mixed results in the acquisition of landmark and route knowledge. In research utilizing isolated photographs of an environment as the spatial data source (Hershberger, 1975;
Winkel and Sasanoff, 1966), the photographs were found to be inadequate for the accurate acquisition of route sequences or the spatial relationships among landmarks. Likewise, research using sequences of photographs taken at frequent intervals along a route (Allen, Krasik, Siegel, and Herman, 1980; Allen, 1979; Allen, Siegel, and Rosinski, 1978) were found to “… not provide sufficient information to support the learning of relative positions of landmarks” (Goldin and Thorndyke, 1982, p. 458). Other studies, utilizing films of both natural and simulated environments, and computer simulations of both large and small scale space, support the notion that simulated environments can be used for the accurate acquisition of spatial knowledge (Craik, 1977; Craik, 1978; Ciccone, Landee, and Weltman, 1978; Cohen, 1980; Goldin and Thorndyke, 1982). Much as Craik (1977, 1978) compared the effect of media and “environment” on the acquisition of spatial knowledge (color vs. black and white film, and the navigation of real vs. “model” environments), this research has focused on how subjects’ performance in certain tasks is affected by the type of area symbols used as a thematic “drape” during fly-through navigation of a virtual environment. Unlike Craik (1977, 1978) however, no comparison was made between the quantity or quality of spatial knowledge acquired from different sources (e.g., simulated environments vs. maps, “real-world” navigation, written descriptions, films, etc.), leaving questions regarding the appropriate use of these technologies open for future research.
The present research has demonstrated how a variety of experimental tasks can be used to evaluate the effects of differences in visual representation (employing a number of different cartographic techniques), on the acquisition and use of spatial knowledge derived from computer generated environments. As MacEachren (1995, p. 361) has suggested,

GVIS (geographic visualization) has the potential to help us cope with the flood of information that technology increasingly provides, and to stimulate insightful discovery – but only if those creating the GVIS environments understand how visual-cognitive representations interface with the sign systems of cartographic representation. At this point, there are few certain answers about this interface in a dynamic interactive environment, or therefore how to design GVIS environments.

While this research did not address the mechanisms of the interface (e.g. the relationships between the symbols as “signs” and how they confer meaning to information acquired from representational media, as would be the subject of semiotic analysis), this research focused on specific applications of cartographic design and “visual-cognitive” representation, and what, if any, effect they had on experimental task performance. The objective being, to inform the application and development of cartographic principles in the use of simulated environments for data display, as well as, broadening the understanding of spatial knowledge acquisition within virtual environments.

Working at what MacEachren (1995) describes as the level of the core GVIS task of feature recognition, this research employed tasks more frequently associated with research in the areas of spatial knowledge acquisition and
wayfinding, than traditional cartographic research. Utilizing angular and distance estimation tasks, path reproduction tasks, and “point location” tasks similar to those used by Thorndyke and Hayes-Roth (1982), Golledge (1988), Loomis et al (1992), this research acknowledged the link between the processes involved in the acquisition of spatial knowledge in natural and simulated environments. In fact, this research was conducted under the assumption that the processes and strategies used in spatial knowledge acquisition in natural environments are also used for spatial knowledge acquisition in simulated environments. In this research, route reproduction tasks were employed as a means of quantifying the accuracy of subject’s landmark knowledge, including the identification and location of landmarks. For route knowledge, including the identification and sequencing of landmarks along the routes, and the procedures (i.e. turns at “choice points”) associated the movement along those routes was, route reproduction tasks were employed as a means of quantification. Unlike much of the research in spatial knowledge acquisition and wayfinding, however, this research did not focus on the perceptual and cognitive structures and mechanisms involved in spatial learning, rather; this research was conducted with an “applied” cartographic focus.

Recognizing the fact that computer simulations of geographic information are being used for spatial learning (e.g. flight simulation, a variety of military simulations, and in the growing field of GVIS), this research focused on how the
visual representation of geographic data affected the accuracy of subjects’ landmark and route knowledge. While “photo-realistic” virtual environments seem to be the ultimate goal for some (Berry, Buckley, and Ulbricht, 1998, p. 47), the findings of this research suggest that for tasks involving the correct identification and recollection of areal, thematic information, the use of color to distinguish nominal categories is the most effective. For angular perception and recollection tasks, distance estimation, and route learning and recollection the iconicity of the thematic “drape” has no consistent effect.

The term “photo-realistic” suggests that the simulated environment visually exhibits the complexity of the actual location being simulated, as with geospecific texturing methods used in this research. This complexity extends from the purely perceptual, the result of variation among all of the “graphic variables”, to the cognitive, including abilities to recognize and classify visible features into the categories necessary for some spatial tasks. While it might be argued that this visual complexity affords a greater number of visually unique “cues” for use in identifying “choice points”, thus aiding in the learning and recollection of landmarks and routes, this research does not support that position. Additionally, background texture that might be expected to aid in distance estimation tasks (Kleiss, 1995) was not found to be superior to other treatments, even the cartographic-abstract treatment that contained no within-polygon texture. It remains unclear, however, whether this finding reflects a difference in the training and ability of the subjects (geographers vs.
pilots) for performing distance estimation tasks in simulated environments, differences in the environment, rendering quality, or task/methodology differences between this research and the work of Kleiss (1995). Regardless of the underlying reasons, the findings of this research regarding distance estimation tasks do not support the findings of Kleiss (1995).

Returning to the research questions as stated in the methodology section of the dissertation, it is important to recognize the distinction being made in the wording of the prelude to each of the six questions “Does the level of iconicity, or the symbols used as thematic “drances” in fly-through navigation of simulated environments affect.” By making the distinction between “the level of iconicity” or “the symbols used as thematic drapes”, the number of research questions addressed in this research jumps from six to twelve. The first six relating to the conceptual continuum of the iconic to the arbitrary, the second six relating to the four rendering methods utilized in this research.

In addressing the question of the effect of symbol iconicity on the integration of spatial knowledge acquired during fly-through navigation of simulated environments the results of this research are quite clear. While cartographic symbols can be described in terms of their position on an ordinal scale of “iconicity”, relative position on the continuum is not a predictor of the quantity or quality of spatial knowledge, as tested in this research.
In this research, four methods of rendering thematic data, occupying (arguably) four different positions along the continuum were tested. In the various tests used to establish the acquisition and recall of spatial data from these environments, no pattern of significant differences was found that could be considered related to the ordinal continuum. Rather, the results showed that particular rendering techniques were more affective than others for performing specific tests of spatial knowledge content.

While highly iconic displays, as in the case of photographic drapes, may prove visually compelling, and may lead to subjects becoming "engaged" in the fly-through process, for example, this research has shown that for tasks requiring the identification of thematic classifications the geospecific rendering method is the least effective. For angular estimates, length/distance estimates, and route knowledge acquisition (as tested in choice point accuracy and route accuracy) the geospecific rendering method is not significantly different than any other method tested. For the identification and recollection of thematic data, cartographic techniques, especially the use of contrasting hues to distinguish nominal scale categories is the most effective.

While none of these findings are unexpected, it is hoped that this research has succeeded in meeting the stated objectives of this research, in several ways.
First, through the demonstration of how a variety of tasks, more commonly used in way-finding and spatial knowledge acquisition research can be used as diagnostic tools in cartographic research.

Second, by demonstrating the lack of utility of using the cartographic framework of iconicity/arbitrariness as a predictor of spatial knowledge acquisition.

Third, by offering some findings regarding the effectiveness of particular rendering techniques for spatial knowledge acquisition in novel environments, in a variety of task domains.

And finally, by demonstrating how large-scale simulated environments can be used in more “ecological” approaches to cartographic cognition and spatial knowledge acquisition research.

**Future Research**

There are a number of issues that should receive future attention. First, with the seemingly exponential increase in the cost of achieving more realistic simulations, serious consideration should be given to the benefit/cost relationship between spatial data display techniques and technologies. To this end, there is a need to establish which spatial learning tasks benefit from the properties of virtual reality (VR) display techniques and which of these tasks can be more economically

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performed using other tools such as maps, verbal descriptions, or direct environmental experience.

Another area of needed work, is ongoing research into the impact of "cutting-edge" VR capabilities and technologies on the effectiveness of spatial learning and task performance. The efficacy of "state-of-the-art" hardware including the latest rendering engines, motion-tracked head mounted display units, holographic display devices, and haptic and auditory input and output devices should be investigated. Questions including, how motion-coupled head mounted display devices that allow persons to "look around" much as they would in a natural environment, affect performance, what effect display resolution has on spatial knowledge acquisition, and how peripheral vision affects spatial learning in simulated environments, require investigation.

Research into the impact of data scale, resolution, and precision on spatial knowledge acquisition in simulated environments is needed. As the fly-through mode of data acquisition was examined in this research, it must be recognized that the data needed for other scales of analysis, and modes of acquisition, will differ. While aerial-photography might be adequate for fly-through simulations, what types of data are required for walk-through, or drive-through simulations? Additionally, with the cost of implementing highly detailed simulations, an understanding of the requirements for various task domains and modes of acquisition is essential. While clearly, the highest expression of simulated environments, the artificial imagery (AI)
and special effects used in motion pictures is often justified (if the film makes money), at what cost, and under what circumstances should simulated environments be the tool of choice for cartographers?

With the certainty of increases in data quantity, resolution, and hopefully precision, in the future, and the possibility of new types of data that will enhance our abilities to discover and understand processes and patterns in the world around us come new challenges for representing those data. While the limitations of current technologies control the extent to which we can use simulated/virtual environments as research or learning tools, advances in spectral and hyper-spectral display capabilities, the use of audio and haptic devices as both control and output devices, as well as the potential for the incorporation of smell and taste in simulations, open new vistas to researchers. To take full advantage of what Sutherland (1965) dubbed the “ultimate display”, computer generated environments that “look real, act real, sound real, and feel real”, we must understand more about how humans assimilate information from different media, and from the natural environment. From this knowledge, we can begin to design learning interfaces and environments that will promote insightful learning and discovery. While much can be said for the trial and error approach to development of design principles, it will be through the thoughtful understanding of the process by which people acquire and use spatial knowledge that the promise of visualization using virtual environments will be realized.
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APPENDIX I
San Diego State University
Informed Consent Agreement

The Effects of Symbol Iconicity on the Integration of Spatial Knowledge

Acquired from the Fly-through Navigation of Simulated Environments

You are being asked to participate in a research study. Before you agree to participate, it is important that you read the following information and ask as many questions as necessary to be sure you understand what you will be asked to do.

Investigators:
My name is David Dow. I am a Doctoral Student in the Geography Department, and currently hold a B.S. in Natural Resource Planning from Humboldt State University, and a M.A. in Geography from San Diego State University. My doctoral work has focused the technical areas of geographic information science and cartography, and on the substantive areas of spatial cognition, cartographic cognition and perception, and qualitative methods. This study is being conducted under the supervision of Dr. Richard Wright of the Geography Department.

Purpose of the Study:
The purpose of this research is to study the effect of differences in symbology used in virtual environments on landmark memory, path memory, and distance and direction estimates in fly-through navigation of those environments.

Description of the Study:
You will be asked to fly-through a virtual environment, following a short (5 segment) path around the landscape as accurately as possible, while wearing a head-mounted display device. Your controls during the fly-through will be 2 buttons on a computer keyboard that will control direction of travel only (speed and altitude will be fixed). During the 2-3 minute fly-through you are to pay particular attention to things in the environment that will help you to accurately reproduce your exact path when the path is later removed from the environment. After completing the first fly-through you will remove the head-mounted display and rest for 2 minutes. You will then be asked to put the head-mounted display back on, and will try to reproduce the exact route that you just traveled, however, this time the path will not be visible in the environment (you will work from memory). During this fly-through you will be asked to describe what you are looking at, and what landmarks you are using to navigate accurately. After
completing this path reproduction task you will be asked to perform several memory tasks. First, you will be given a blank piece of paper and pencil on which you will sketch the route you took in your fly-through, including as many landmarks as you remember. This sketching procedure will last 2-3 minutes. Artistic ability doesn’t matter, but I’d like you to show relative locations of landmarks as accurately as possible. As you sketch the environment, I’d like you to verbally describe the features you remember... please try to keep talking. If you stop talking for too long I’ll ask you to “please tell me what you see/remember.” During the sketching task I’ll need to have you remain stationary in front of the paper since I’ll be videotaping the paper and your forearms as you sketch, while recording your verbal description. Next, I’ll give you a paper showing the starting and ending points of the path and empty polygons that you will label with the landuse types you remember. Only label the polygons you feel sure of. Finally, you’ll be asked to estimate the length of the first and last segments of the path, and the angle of the turn between the 1st and 2nd segment and the angle between the 4th and 5th (final) segment of the path. This procedure will be performed a total of 4 times, and will last 45-50 minutes.

What is Experimental in this Study:
None of the procedures or questionnaires in this study are experimental in nature. The only experimental aspect of this study is the gathering of information for the purpose of analysis.

Risks or Discomforts:
Past research using head-mounted displays indicates that some people experience motion sickness when they move around in virtual environments for long periods of time. For that reason each of the virtual experiences will be short in duration. If, at any time during the experiment you begin to experience nausea, eyestrain, or any other discomfort please remove the head-mounted display immediately.

Benefits of the Study:
I don’t anticipate that you’ll receive any direct benefit from participation in this research other than the $15.00 stipend. Your participation is appreciated, and I believe that the results of this research will add to the understanding of the relationship between the methods of presenting spatial data and the acquisition and representation of that data by humans, a relationship at the core of cognitive studies in cartography and GIS.

Confidentiality:
I want to assure you that you will in no way be identified, by name or likeness, through this research. All references to your responses will be identified by an
arbitrarily assigned participant number, and all records of your participation will be confidential. During the fly-through portions of the study the videotape will record only what you see in the head-mounted display. During the sketch mapping portions of the study the camera will record only your voice, forearms, and the sketch you are making. All records of your involvement will be kept in a locked file drawer and your confidentiality will be maintained to the extent allowed by law.

Costs and/or Compensation for Participation:
You will receive a stipend of $15.00 for your participation in this study (approx. 45-50 minutes). You may discontinue participation at any time (for any reason), and you will be compensated in full ($15.00).

Compensation for Injury:
If you need treatment or hospitalization as a result of your participation in this study, the cost will be charged to you. If you have insurance, you may bill your insurance company. You will have to pay any costs not covered by your insurance. San Diego State University will not pay for any care, lost wages, or provide other financial compensation.

Voluntary Nature of Participation:
Participation in this study is voluntary. Your decision about whether or not to participate will not prejudice your future relations with San Diego State University (or any other participating institution). If you decide to participate, you are free to withdraw consent and to discontinue your participation at any time without penalty or loss of benefits to which you are otherwise entitled.

Questions about the Study:
If you have any questions about the research now, please ask. If you have any questions later about the research and/or research-related injuries, you may contact me (David Dow) at (619) 594-0405. If you have any questions regarding your rights as a human subject and participant in this study, you may call the Committee on Protection of Human Subjects at San Diego State University for information. The telephone number of the committee is (619) 594-6622. You may also write to the following address:

The Committee on Protection of Human Subjects
San Diego State University
5500 Campanile Drive
San Diego, CA 92182-1643
**Agreement:**
This consent form has been approved by the Committee on Protection of Human Subjects at San Diego State University as signified by the Committee's stamp. The consent form must be reviewed annually and expires on the date indicated on the stamp.

Your signature below indicates that you have read the information above and have had a chance to ask any questions you have about the study. You agree to be in the study and have been told that you can change your mind and withdraw consent at any time. You have been given a copy of this agreement and have been told that by signing this consent form you are not giving up any of your legal rights.

__________________________  ____________
Signature of Participant      Date

__________________________  ____________
Signature of Investigator     Date
Input.txt

terrain1.wrl
drape1.4096x2048.jpg
0.0 0.0 0.0
0.0 1000.0 0.0
200.0
5000.0
path.txt
sky.jpg
1.0 1.0
1 2

Makefile.txt (code)

WTK_LIB_DIR = /mnt/disk9_ext2/wtk8

# name of the executable
EXENAME=terrain

# system libraries to link in
SYSLIBS=-lm

# compile and link options
OPTS= -o32 -xansi -g -DSGI

# compiler
CC=CC

# any specific -D... for the compile line
DEFS=

INCLS = -I$(WTK_LIB_DIR)/include \
   -I$(WTK_LIB_DIR)/cppwrap/include \
   -I/usr/local/wtkR8/include \
   -I/usr/local/wtkR8/cppwrap/include \

ARCH = sgi
LIBS = -L$(WTK_LIB_DIR)/lib/irix6.x32 \
   -L$(WTK_LIB_DIR)/cppwrap/lib/irix6.x32 \
   -lwtk -lGLW -lGL -lvsiaudiostub -lXm -lXt -lX11 -lm \
   -lvsiaudiostub

# we are going to store our objects we compile here
#OBJDIR=obj.$(ARCH)
OBJDIT=.
# Objects

```
OBJJS = \n  TerrainFly.o WTct32.o

#OBJJS = \n # $(OBJDIR)/ball.o
```

# all rule: creates directory for objects and builds all objects in local directory against libraries.
# notice that the libraries are listed twice to resolve some potential circular references.

```
all: $(OBJDIR) $(EXENAME)
  @echo
  $(CC) $(OPTS) $(OBJJS) $(LIBS) $(LIBS) $(SYSLIBS)
  @mv a.out $(EXENAME)
  @echo;echo "Created executable: $(EXENAME)"
```

# the executable depends on all the objects

```
$(EXENAME): $(OBJJS)
```

# create a directory for the objects if one does not exist

```
$(OBJDIR):
  @echo;echo Objects will be put in: $(OBJDIR)
  @if [ ! -d $(OBJDIR) ]; then mkdir -p $(OBJDIR); fi
```

# compile rule for each source file in local directory

```
$(OBJJS):

TerrainFly.o: TerrainFly.cpp
  @echo
  $(CC) -c $(OPTS) $(DEFS) $(INCLS) TerrainFly.cpp

WTct32.o: WTct32.cpp
  @echo
  $(CC) -c $(OPTS) $(DEFS) $(INCLS) WTct32.cpp
```
#include <stdio.h>
#include <stdlib.h>
#include "wt.h"
#include "mathlib.h"
#include "sensor.h"
#include "sensor2.h"
#include "ct32.h"
#include "serial.h"
#include "wtct32.p"

#include "mathlib.p"
#include "sensor.p"
#include "serial.p"

#define FRONT 100 //move up (z increase)
#define BACK 101 //move down (z decrease)
#define LEFT 102 //move left (x decrease)
#define RIGHT 103 //move right (x increase)

#define MOUSE3D 1 // the device to control the viewing direction
#define FAKESPACEBOOM 2 // the boom to control the orientation
#define CT32HEADTRACKER 3 // the ct32 headtracker to control the orientation

void ViewpointTerrainFollowing(WTp3 p);

static float xmin, ymin, zmin, xmax, ymax, zmax; // the bounding box of the terrain
static WTM4 m4; // the accumulated transformation matrix for the terrain geometry
static WTnode *terrainNode; // the terrain node subtree
static WTnode *root; // the root node of the scene graph
static int terrainFollowing=0; // 1==yes; otherwise no

static WTSensor *mouse3D=NULL; // 3d mouse for testing
static WTsensor *boom=NULL;  //pointer for fake space boom
static WTsensor *ct32HeadTracker=NULL;  //pointer for ct32 head tracker

static char terrainName[128];  //file name of the wrl terrain model
static char drapeName[128];  //file name of the texture file
static WTp3 startViewPoint;  //viewpoint start point
direction
static float step;  //speed
static float height;  //the default elevation of the viewpoint over the terrain
static char pathName[128];  //file name for the outputting the viewpoint path and viewpoint direction
static FILE *fpPath;  //file pointer for the output viewpoint path file

static char backgroundName[128];  //file name of the background texture
static float maxU;  //max U texture coordinate of the background geometry
static float maxV;  //max V texture coordinate of the background geometry

//modification start
//static int direction=LEFT;  //viewpoint move direction
static float direction=180.f;  //viewpoint move direction
static float directionAngStep=5.f;  //left arrow down direction += 5.f;

//right arrow down direction -=5.f;  //you may change this value
//modification end

static int flying=FALSE;  //flying tag

static int port=1;  //the port to which the 3d device is connected
static int device=MOUSE3D;  //the device to control the orientation of the viewpoint
static int changeViewingDirection=FALSE;  //TRUE------change viewing direction according to the 3d device when flying;
viewing direction when flying

//if the projection of point vp in the XZ plane is within the the
poly's projection return 1
// otherwise return 0
//m4---the transformation matrix for the poly
//vp---a 3D point to be tested
int XzplaneProjectionInsidePoly(WTgeometry *geom, WTpoly *poly,
    WTm4 m4, WTp3 vp)
{
    WTp3 *p;
    float xmin, zmin, xmax, zmax;

    xmin=10000000.;
    zmin=10000000.;
    xmax = -1000000.;
    zmax = -1000000.;

    int num=WTpoly_numvertices(poly);
    p=(WTp3 *) malloc(num*sizeof(WTp3));
    for (int i=0; i<num; i++) {
        WTvertex* v=WTpoly_getvertex(poly,i);
        WTgeometry_getvertexposition(geom,v,p[i]);
        WTp3_multm4(p[i], m4, p[i]);

        if (p[i][0]<xmin) xmin=p[i][0];
        if (p[i][2]<zmin) zmin=p[i][2];
        if (p[i][0]>xmax) xmax=p[i][0];
        if (p[i][2]>zmax) zmax=p[i][2];
    }

        return(0);
    //it may need more calculations to decide if the point's
    //projection is inside the poly,
    //but we just stop here and asssume it is inside the poly.
    else
        return(1);
}

//m4---the transformation matrix for the geometry
//vp---the viewpoint position
// geom - the geometry of the terrain
//
// ip - the intersection point to be found
int LineGeometryIntersection(WTp3 vp, WTgeometry* geom, WTm4 m4, WTq q, WTp3 ip)
{
    WTp3 cg;
    WTp3 norm;

    WTpoly* poly = WTgeometry_getpolys(geom);
    while (poly != NULL) {
        if (XzplaneProjectionInsidePoly(geom, poly, m4, vp) == 1)
        {
            // to find the intersection point of the poly
            and a vertical line (parallel to y axis) passing vp
            // v = WTpoly_getvertex(poly, 0);
            // WTgeometry_getvertexposition(geom, v, p);
            // WTp4_multm4(p, m4, p);

            WTpoly_getcg(poly, cg);
            WTp3_multm4(cg, m4, cg);

            WTpoly_getnormal(poly, norm);
            WTp3_rotate(norm, q, norm);

            ip[0] = cg[0];
            ip[1] = cg[1];
            ip[2] = cg[2];

            if(fabs(norm[1]) >= 0.000001) {
                ip[1] = cg[1] - (norm[0] * (vp[0] -
            }
            return(1);
        }
        poly = WTpoly_next(poly);
    }
    return(0);
}

// to get the elevation of the viewpoint
void GetViewpointElevation(float *realHeight)
{
    WTp3 vp;
    WTm4 m4;
    WTq q;
    WTp3 ip;

    // 1. get the viewpoint position vp
WTviewpoint*
view=WTwindow_getviewpoint(WTuniverse_getwindows());
WTviewpoint_getposition(view,vp);
//printf("vp==f f f\n",vp[0],vp[1],vp[2]);

//2. get the geometry of the terrain
//3. find the intersection point between a vertical
line(paralle to y axis) passing vp and the terrain---->ip;
//4. height=vp[1]-ip[1];

int numChildren=WTreeNode_numchildren(terrainNode);
for (int i=0;i<numChildren;i++) {
   WTreeNode* node=WTreeNode_getchild(terrainNode,i);
   if (WTreeNode_gettype(node)==WTreeNode_GEOMETRY) {
      WTreeNodePath* np=WTreeNodePath_new(node,root,0);
      WTreeNodePath_gettransform(np,m4);
      WTreeNodePath_getorientation(np,q);
      WTreeNodePath_delete(np);

      WTreeNodeGeometry* geom=WTreeNodeGeometry_getgeometry(node);
      if (LineGeometryIntersection(vp,geom,m4,q,ip)==1) {
         *realHeight=fabs(vp[1]-ip[1]);
         break;
      }
   }
}

//input
//height----the fixed elevation of the viewpoint(global variable)
//vp--------the current viewpoint position
//pos--------the translation along xz direction.
//
//output:
//pos--------the translation along xz directions and the adjustment
along y direction.
//
void ViewpointTerrainFollowing(WTp3 pos)
{
   WTp3 vp;
   //the viewpoint
   WTp4 m4;
   WTp3 q;
   WTp3 ip;

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// the intersection point

WTviewpoint* view=WTwindow_getviewport(WTuniverse_getwindows());
WTviewpoint_getposition(view, vp);

vp[0] += pos[0];
// vp[1] += pos[1];
vp[2] += pos[2];

int numChildren=WTnode_numchildren(terrainNode);
for (int i=0; i<numChildren; i++) {
    WTnode* node=WTnode_getchild(terrainNode, i);
    if (WTnode_gettype(node)==WTNODE_GEOMETRY) {

        WTnodepath* np=WTnodepath_new(node, root, 0);
        WTnodepath_gettransform(np, m4);
        WTnodepath_getorientation(np, q);

        WTgeometry* geom=WTnode_getgeometry(node);
        if (LineGeometryIntersection(vp, geom, m4, q, ip)==1) {
            pos[1]=fabs(vp[1]-ip[1])-height;
            break;
        }

        WTnodepath_delete(np);
    }
}

float fu(WTp3 pos)
{
    WTp3 p;

    WTp3_multm4(pos, m4, p);

    float u=(p[0]-xmin)/(xmax-xmin);
    // if (u<0.0)
    //    printf("u==%f\n", u);
    // else if (u>1.0)
    //    printf("u==%f\n", u);
    return(u);
}

float fv(WTp3 pos)
{
WTP3 p;

WTP3_multm4(pos,m4,p);

float v=(p[2]-zmin)/(zmax-zmin);
//if (v<=0.0)
// printf("v=%f\n",v);
//else if (v>=1.0)
// printf("v=%f\n",v);
return(v);

}

void PrintOutViewpoint()
{
    WTP3 vp;

    WTVIEWPOINT*
    view=WTVIEWPOINT_GETVIEWPOINT(WTuniverse_getwindows());
    WTVIEWPOINT_GETPOSITION(view,vp);
    //printf("viewpoint===%f %f %f\n",vp[0],vp[1],vp[2]);
}

void ActionFn()
{
    short ch;
    WTP3 pos;
    WTQ q;
    //float height;
    WTVIEWPOINT *view;

    static float xLastAng,yLastAng,zLastAng;
    static int firstAng=TRUE;

    ch=WTKKEYBOARD_GETKEY();

    view=WTVIEWPOINT_GETVIEWPOINT(WTuniverse_getwindows());

    //get the 3d mouse data
    //WTBARPON_RAWDATA *raw;
    //raw=(WTBARPON_RAWDATA *) WTSensor_getrawdata(mouse3D);
    //printf("position===%f %f %f\n",raw->p[0],raw->p[1],raw->p[2]);
    //printf("euler angle in degrees===%f %f %f\n",raw->w[0],raw->w[1],raw->w[2]);

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//printf("mem**************=%d\n",WTtexture_getmemory());

//printf("ch=%d\n",ch);
//printf("Framerate====%f\n",WTuniverse_framerate());

WTviewpoint_getorientation(WTwindow_getviewpoint(WTuniverse_getwindows()),q);

switch (ch) {
    case 'g':
        //disable the terrain following feature
        terrainFollowing=0;
        break;
    case 'f':
    case 'F':
        //enable the terrain following feature
        terrainFollowing=1;
        break;
    case 'c':
    case 'C':
        changeViewingDirection=TRUE;
        break;
    case 'x':
    case 'X':
        changeViewingDirection=FALSE;
        break;
    case 's':
    case 'S':
        //start flying in the current direction
        flying=TRUE;
        break;
    case 'e':
    case 'E':
        //end flying session
        flying=FALSE;
        break;

    //modification start
    case WTKEY_RIGHTARROW:
        //set the flying direction to x+ direction
        //direction=RIGHT;

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direction -= directionAngStep;
{
    // change your viewing direction once your driving
    // direction changes
    WTP3 p, minusp;

    WTviewpoint_getposition(view, p);
    minusp[0] = -p[0];
    minusp[1] = -p[1];

    WTviewpoint_translate(view, minusp, WTFRAME_WORLD);
    // WTviewpoint_rotate(view, X, (raw->w[0] - xLastAng)*PI/180., WTFRAME_WORLD);
    WTviewpoint_rotate(view, Y, - directionAngStep*PI/180., WTFRAME_WORLD);
    // WTviewpoint_rotate(view, Z, (raw->w[2] - zLastAng)*PI/180., WTFRAME_WORLD);
    WTviewpoint_translate(view, p, WTFRAME_WORLD);
}

break;

case WTKEY_LEFTARROW:
    // set the flying direction to x- direction
    // direction=LEFT;
    direction += directionAngStep;
{
    WTP3 p, minusp;

    WTviewpoint_getposition(view, p);
    minusp[0] = -p[0];
    minusp[1] = -p[1];

    WTviewpoint_translate(view, minusp, WTFRAME_WORLD);
    // WTviewpoint_rotate(view, X, (raw->w[0] - xLastAng)*PI/180., WTFRAME_WORLD);
    WTviewpoint_rotate(view, Y, directionAngStep*PI/180., WTFRAME_WORLD);
    // WTviewpoint_rotate(view, Z, (raw->w[2] - zLastAng)*PI/180., WTFRAME_WORLD);
    WTviewpoint_translate(view, p, WTFRAME_WORLD);
}

break;

case WTKEY_UPARROW:
    // set the flying direction to z+ direction
    // direction=FRONT;
    break;

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case WTKEY_DOWNARROW:
    // set the flying direction to the z- direction
    // direction=BACK;
    break;
    // modification end

case 'd':
case 'D':
    // decrease height
    pos[0]=0.;
    pos[1]=step;
    pos[2]=0.;

    WTVIewpoint_translate(WTwindow_getviewport(WTuniverse_getwindows()),pos,WTFRAME_WORLD);
    height -= step;
    PrintOutViewport();
    
    printf("aaaa \n");
    break;

case 'i':
case 'I':
    // increase height
    pos[0]=0.;
    pos[1]=-step;
    pos[2]=0.;

    WTVIewpoint_translate(WTwindow_getviewport(WTuniverse_getwindows()),pos,WTFRAME_WORLD);
    height += step;
    PrintOutViewport();
    break;

case 'l':
    // take a screen snapshot
    { int x,y,width,height;

        WTwindow_getposition(WTuniverse_getwindows(),&x,&y,&width,&height);
        printf("x== %d y==%d w==%d h==%d \n",x,y,width,height);
        WTVIewpoint_saveimage(WTuniverse_getwindows(),0,0,
            width,height,"snap1.tga");
    }
    break;
case '2':
    // take a screen snapshot
    {
        int x,y,width,height;

        WTWindow_getposition(WTuniverse_getwindows(),&x,&y,&width,&height);
        printf("x== %d y==%d w==%d h==%d\n",x,y,width,height);
        WTWindow_saveimage(WTuniverse_getwindows(),0,0,
                          width,height,"snap2.tga");
    }

    break;

    case '<':
    case '>':
        // increase speed
        step += 50.;
        printf("step==%f\n",step);
        break;
    case '.':
    case ',':
        // decrease speed
        step -= 50.;
        printf("step=%f\n",step);
        break;

    default:
        // printf("default\n");
        break;
}

if (flying==TRUE) {

    // modification start
    /* switch (direction) {
    case LEFT:
        pos[0]= -step;
        pos[1]= 0.;
        pos[2]= 0.;
        break;
    case RIGHT:
        pos[0]= step;
        pos[1]= 0.;
        pos[2]= 0.;
        break;
    */

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case FRONT:
    pos[0] = 0.;
pos[1] = 0.;
pos[2] = step;
break;

case BACK:
    pos[0] = 0.;
pos[1] = 0.;
break;

} /*
{
    float ang;
    ang=direction*3.14159f/180.f;
pos[0] = step*sin(ang);
pos[1] = 0.f;
pos[2] = step*cos(ang);
}
//modification end

if (terrainFollowing==1) {
    ViewpointTerrainFollowing(pos);
    //printf("pos YYY=%f\n",pos[1]);
}

WTviewpoint_translate(WTwindow_getviewport(WTuniverse_getwindows()),pos,WTFRAME_WORLD);
//PrintOutViewpoint();
GetViewpointElevation(&height);
//printf("height*****=%f\n",height);

//WTviewpoint_translate(WTwindow_getviewport(WTuniverse_getwindows()),pos,WTFRAME_LOCAL);
//printf("left \n");

//rotate the viewing direction according to the 3D device
if (changeViewingDirection) {
    if (device==MOUSE3D) {
        WTbaron_rawdata *raw;
        raw=(WTbaron_rawdata *)
WTsensor_getrawdata(mouse3D);
        //printf("position=-%f %f %f\n",raw->p[0],raw->p[1],raw->p[2]);
//printf("euler angle in degrees==%f %f
\n",raw->w[0],raw->w[1],raw->w[2]);

if (firstAng) {
    firstAng=FALSE;
    xLastAng=raw->w[0];
    yLastAng=raw->w[1];
    zLastAng=raw->w[2];
}
else {
    WTp3 p, minusp;
    WTviewpoint_getposition(view, p);
    minusp[0] = -p[0];
    minusp[1] = -p[1];

    WTviewpoint_translate(view, minusp, WTFRAME_WORLD);
    WTviewpoint_rotate(view, X, (raw->w[0]-xLastAng)*PI/180., WTFRAME_WORLD);
    WTviewpoint_rotate(view, Y, (raw->w[1]-yLastAng)*PI/180., WTFRAME_WORLD);
    WTviewpoint_rotate(view, Z, (raw->w[2]-zLastAng)*PI/180., WTFRAME_WORLD);

    WTviewpoint_translate(view, p, WTFRAME_WORLD);
    xLastAng=raw->w[0];
    yLastAng=raw->w[1];
    zLastAng=raw->w[2];
}
else if (device==FAKESPACEBOOM) {
    WTboom_rawdata *raw;
    raw=(WTboom_rawdata *)
    WTsensotor_getrawdata(boom);
    //printf("%d %d %d %d %d\n",raw->angles[0],raw->angles[1],raw->angles[2],angles[3],angles[4],angles[5]);

    if (firstAng) {
        xLastAng=raw->angles[0];
        yLastAng=raw->angles[1];
        zLastAng=raw->angles[2];
        firstAng=FALSE;
    }
    else {
        WTp3 p, minusp;
        W
float deltax, deltay, deltaz;

WTviewpoint_getposition(view, p);
minusp[0] = -p[0];
minusp[1] = -p[1];

WTviewpoint_translate(view, minusp, WTFRAME_WORLD);

deltax = raw->angles[0] - xLastAng;
deltay = raw->angles[1] - yLastAng;
deltaz = raw->angles[2] - zLastAng;

// printf("delta==== %f %f %f\n",
deltax, deltay, deltaz);

WTviewpoint_rotate(view, Y, deltay * PI/180., WTFRAME_WORLD);

WTviewpoint_rotate(view, X, deltay * PI/180., WTFRAME_WORLD);

WTviewpoint_rotate(view, Z, deltaz * PI/180., WTFRAME_WORLD);

WTviewpoint_translate(view, p, WTFRAME_WORLD);

xLastAng = raw->angles[0];
yLastAng = raw->angles[1];
zLastAng = raw->angles[2];

}

} else if (device == CT32HEADTRACKER) {

WTct32_update(ct32HeadTracker);

/* WTct32_rawdata *raw;

raw = (WTct32_rawdata *)
WTsensor_getrawdata(ct32HeadTracker);
// printf("euler angle in degrees==%f %f %f\n", raw->w[0], raw->w[1], raw->w[2]);

if (firstAng) {

firstAng = FALSE;

xLastAng = raw->w[0];
yLastAng = raw->w[1];

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zLastAng=raw->w[2];

} else {
    WTp3 p, minusp;
    WTviewpoint_getposition(view, p);
    minusp[0] = -p[0];
    minusp[1] = -p[1];

    WTviewpoint_translate(view, minusp, WTFRAME_WORLD);
    WTviewpoint_rotate(view, X, (raw->w[0]-xLastAng)*PI/180., WTFRAME_WORLD);
    WTviewpoint_rotate(view, Y, (raw->w[1]-yLastAng)*PI/180., WTFRAME_WORLD);
    WTviewpoint_rotate(view, Z, (raw->w[2]-zLastAng)*PI/180., WTFRAME_WORLD);

    WTviewpoint_translate(view, p, WTFRAME_WORLD);
    xLastAng=raw->w[0];
    yLastAng=raw->w[1];
    zLastAng=raw->w[2];
}

}  
  
} 

  
  //write the viewpoint and viewing direction to the path file
  {
    WTp3 viewPos, viewDir;

    WTviewpoint_getposition(WTwindow_getviewport(WTuniverse_getwindows()), viewPos);
    fprintf(fpPath, "%f %f %f\n", viewPos[0], viewPos[1], viewPos[2]);

    WTviewpoint_getdirection(WTwindow_getviewport(WTuniverse_getwindows()), viewDir);
    fprintf(fpPath, "%f %f %f\n", viewDir[0], viewDir[1], viewDir[2]);
  }
  
} else {
    //flying not true; change the viewing direction according to the 3d device

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if (device==MOUSE3D) {
    WTbaron_rawdata *raw;
    raw=(WTbaron_rawdata *)
WTsensor_getrawdata(mouse3D);
    //printf("position=%f %f %f\n",raw->p[0],raw->p[1],raw->p[2]);
    //printf(" euler angle in degrees=%f %f %f\n",raw->w[0],raw->w[1],raw->w[2]);
    if (firstAng) {
        xLastAng=raw->w[0];
        yLastAng=raw->w[1];
        zLastAng=raw->w[2];
        firstAng=FALSE;
    } else {
        WTp3 p,minusp;
        float deltax,deltay,deltaz;

        WTviewpoint_getposition(view,p);
        minusp[0]= -p[0];
        minusp[1]= -p[1];

        WTviewpoint_translate(view,minusp,WTFRAME_WORLD);
        deltax=raw->w[0]-xLastAng;
        deltax=raw->w[1]-yLastAng;
        deltax=raw->w[2]-zLastAng;
        //printf("delta===== %f %f %f\n",deltax,deltay,deltaz);
        WTviewpoint_rotate(view,Y,deltay*PI/180.,WTFRAME_WORLD);
        WTviewpoint_rotate(view,X,deltax*PI/180.,WTFRAME_WORLD);
        WTviewpoint_rotate(view,Z,deltaz*PI/180.,WTFRAME_WORLD);
        WTviewpoint_translate(view,p,WTFRAME_WORLD);
        xLastAng=raw->w[0];
        yLastAng=raw->w[1];
        zLastAng=raw->w[2];
    }
}
else if (device==FAKESPACEBOOM) {
    WTboom_rawdata *raw;
    raw=(WTboom_rawdata *)
    WTsensor_getrawdata(boom);
    //printf("%d %d %d %d %d\n",raw->angles[0],raw->angles[1],raw->angles[2],raw->angles[3],raw->angles[4],raw->angles[5]);

    if (firstAng) {
        xLastAng=raw->angles[0];
        yLastAng=raw->angles[1];
        zLastAng=raw->angles[2];
        firstAng=FALSE;
    }
    else {
        WTP3 p,minusp;
        float deltax,deltay,deltaz;

        WTviewpoint_getposition(view,p);
        minusp[0] = -p[0];
        minusp[1] = -p[1];

        WTviewpoint_translate(view,minusp,WTFRAME_WORLD);

        deltax=raw->angles[0]-xLastAng;
        deltay=raw->angles[1]-yLastAng;
        deltaz=raw->angles[2]-zLastAng;

        //printf("delta==== %f %f %f\n",
        deltax,deltay,deltaz);

        WTviewpoint_rotate(view,Y,deltay*PI/180.,WTFRAME_WORLD);
        WTviewpoint_rotate(view,X,deltax*PI/180.,WTFRAME_WORLD);
        WTviewpoint_rotate(view,Z,deltaz*PI/180.,WTFRAME_WORLD);

        WTviewpoint_translate(view,p,WTFRAME_WORLD);

        xLastAng=raw->angles[0];
        yLastAng=raw->angles[1];
        zLastAng=raw->angles[2];
    }
}
else if (device==CT32HEADTRACKER) {
    /*WTct32_rawdata *raw;

    raw=(WTct32_rawdata *)
    WTsensor_getrawdata(ct32HeadTracker);
    //printf("euler angle in degrees=%f %f
%f\n",raw->w[0],raw->w[1],raw->w[2]);

    if (firstAng) {
        firstAng=FALSE;

        xLastAng=raw->w[0];
        yLastAng=raw->w[1];
        zLastAng=raw->w[2];
    }
    else {
        WTP3 p,minusp;

        WTviewpoint_getposition(view,p);
        minusp[0]= -p[0];
        minusp[1]= -p[1];

        WTviewpoint_translate(view,minusp,WTFRAME_WORLD);
        WTviewpoint_rotate(view,X,(raw->w[0]-
        xLastAng)*PI/180.,WTFRAME_WORLD);
        WTviewpoint_rotate(view,Y,(raw->w[1]-
        yLastAng)*PI/180.,WTFRAME_WORLD);
        WTviewpoint_rotate(view,Z,(raw->w[2]-
        zLastAng)*PI/180.,WTFRAME_WORLD);

        WTviewpoint_translate(view,p,WTFRAME_WORLD);

        xLastAng=raw->w[0];
        yLastAng=raw->w[1];
        zLastAng=raw->w[2];
    }*/
    WTct32_update(ct32HeadTracker);
}

//WTviewpoint_setorientation(WTwindow_getviewport(WTuniver-
se_getwindows()),q);
}
// for testing
WTnode* CreateNode(WTnode *parent, float xmin, float ymin, float zmin, float xmax, float ymax, float zmax)
{
    WTp3 p;

    WTgeometry* geom=WTgeometry_begin();

    p[0]=xmin;
    p[1]=ymin;
    p[2]=zmin;
    WTgeometry_newvertex(geom,p);
    p[0]=xmax;
    p[1]=ymin;
    p[2]=zmin;
    WTgeometry_newvertex(geom,p);
    p[0]=xmax;
    p[1]=ymax;
    p[2]=zmin;
    WTgeometry_newvertex(geom,p);
    p[0]=xmax;
    p[1]=ymax;
    p[2]=zmax;
    WTgeometry_newvertex(geom,p);
    p[0]=xmin;
    p[1]=ymax;
    p[2]=zmax;
    WTgeometry_newvertex(geom,p);

    WTpoly* poly=WTgeometry_beginpoly(geom);
    WTpoly_addvertex(poly,0);
    WTpoly_addvertex(poly,1);
    WTpoly_addvertex(poly,2);
    WTpoly_addvertex(poly,3);
    WTpoly_close(poly);
    WTpoly_setbothsides(poly,TRUE);
    WTgeometry_close(geom);
    WTgeometry_setrgb(geom,128,128,128);

    WTnode* node=WTgeometrynode_new(parent,geom);
    return(node);
}

// 1. create a rectangle just below the terrain (ymax...) and larger in x and z direction than
// the terrain
// 2. attach it to the root node
// 3. apply a sky texture upon it
void CreateBackgroundNode()
{
    WTp3 p;
    float factor=2.0;
float u[4], v[4];

WTgeometry* geom = WTgeometry_begin();

p[0] = xmin * factor;
p[1] = ymax;
p[2] = zmin * factor;
WTgeometry_newvertex(geom, p);
p[0] = xmax * factor;
p[1] = ymax;
p[2] = zmax * factor;
WTgeometry_newvertex(geom, p);
p[0] = xmin * factor;
p[1] = ymax;
p[2] = zmax * factor;
WTgeometry_newvertex(geom, p);
p[0] = xmin * factor;
p[1] = ymax;
p[2] = zmax * factor;
WTgeometry_newvertex(geom, p);

WTpoly* poly = WTgeometry_beginpoly(geom);
WTpoly_addvertex(poly, 0);
WTpoly_addvertex(poly, 1);
WTpoly_addvertex(poly, 2);
WTpoly_addvertex(poly, 3);
WTpoly_close(poly);
WTpoly_setbothsides(poly, TRUE);
WTgeometry_close(geom);
WTgeometry_setrgb(geom, 50, 60, 234);

WTnode* node = WTgeometrynode_new(root, geom);

u[0] = 0.0;
v[0] = 0.0;

u[1] = maxU;
v[1] = 0.0;

u[2] = maxU;
v[2] = maxV;

u[3] = 0.0;
v[3] = maxV;

WTpoly_settextureuv(poly, backgroundName, u, v, FALSE, FALSE);

}
void main(int argc, char *argv[]) {
    WTsensor *sensor; /* the Mouse */
    WTviewpoint *view; /* the Viewpoint */
    float radius;
    WTp3 viewPos, viewDir;
    WTgeometry *geom;
    WTnode *axisx, *axisy, *axisz;
    WTp3 pos;

    // read in the initial parameters and
    // assume the parameters are in "input.txt"
    FILE* fp = fopen("input.txt","r");
    if (fp == NULL) {
        printf("initial file input.txt does not exist!\n");
        exit(0);
    }
    fscanf(fp,"%s", terrainName);
    fscanf(fp,"%s", drapeName);
    fscanf(fp,"%f %f %f", &startViewpoint[0],&startViewpoint[1],&startViewpoint[2]);
    fscanf(fp,"%f %f %f", &startViewDirection[0],&startViewDirection[1],&startViewDirection[2]);
    fscanf(fp,"%f", &step);
    fscanf(fp,"%f", &height);
    fscanf(fp,"%s", pathName);
    fscanf(fp,"%s", backgroundName);
    fscanf(fp,"%f %f", &maxU, &maxV);
    fscanf(fp,"%i %i", &device, &port);
    fclose(fp);

    // open a file for writing the viewpoint path
    fpPath = fopen(pathName,"w");
    if (fpPath == NULL) {
        printf("cannot open path file for writing\n");
        exit(0);
    }

    WUniverse_new(WTDISPLAY_DEFAULT, WTWINDOW_DEFAULT);
    root = WUniverse_getrootnodes();
    WThandle_open();
}

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// Load light from terrain.light
// if (!WTlightnode_load(root,"terrain.light")) {
//   printf("light file not found\n");
// }

// to open the device
if (device==MOUSE3D) {
  if (port==1)
    mouse3D=WTbaron_new(SERIAL1);
  else  mouse3D=WTbaron_new(SERIAL2);
  if (mouse3D==NULL) {
    printf("\n\n opening 3d mouse not successful\n");
  } else printf("3d mouse open successful\n");
}
else if (device==FAKESPACEBOOM) {
  if (port==1)
    boom=WTboom_new(SERIAL1);
  else  boom=WTboom_new(SERIAL2);
  if (boom==NULL)
    printf("\n\n opening Boom not successful\n");
  else printf("Boom open successful\n");
}
else if (device==CT32HEADTRACKER) {
  if (port==1)
    ct32HeadTracker=WTct32_new(SERIAL1);
  else  ct32HeadTracker=WTct32_new(SERIAL2);
  if (ct32HeadTracker==NULL)
    printf("\n\n opening CT32 Head Tracker not successful\n");
  else printf("CT32 Head Tracker open successful\n");
}

//WTuniverse_setrendering(WTRENDER_SMOOTH);
//WTuniverse_setrendering(WTRENDER_WIREFRAME);

/*
 // to make a world coordinate system.
 //
 geom = WTgeometry_newblock( 600.0f, 3.0f, 3.0f, TRUE);
 WTgeometry_setrgb(geom,255,0,0);
pos[0] = 300.0f;
pos[1] = 0.0f;
pos[2] = 0.0f;
WTgeometry_translate( geom, pos);
axisx = WTgeometrynode_new(root, geom);
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WTnode_setname(axisx, "X");

//y
gem = WTgeometry_newblock( 3.0f, 600.0f, 3.0f, TRUE);
WTgeometry_setrgb(geom,0,255,0);
pos[0] = 0.0f;
pos[1] = 300.;
pos[2] = 0.0f;
WTgeometry_translate( geom, pos);
axisy = WTgeometrynode_new( root, geom);
WTnode_setname(axisy, "Y");

//z
gem = WTgeometry_newblock( 3.0f, 3.0f, 600.0f, TRUE);
WTgeometry_setrgb(geom,0,0,255);
pos[0] = 0.0f;
pos[1] = 0.;
pos[2] = 300.0f;
WTgeometry_translate( geom, pos);
axisz = WTgeometrynode_new( root, geom);
WTnode_setname(axisz, "Z");
*/

//l. load the terrain model
terrainNode=WTnode_load(root,terrainName,1.);

radius=WTnode_getradius(root);
printf("radius==%.f\n\n\n",radius);
//sensor = WTMouse_new();
//view = WUniverse_getviewpoints();
//WViewpoint_addsensor(view, sensor);

view = WUniverse_getviewpoints();

//to set the viewpoint and viewdirection
//viewPos[0]=0.;
//viewPos[1]= -5000.;
//viewPos[2]= 0.;
WViewpoint_setposition(view,startViewpoint);

//viewDir[0]=0.;
//viewDir[1]= 1000.;
//viewDir[2]= 400.;

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// find the real elevation and then adjust the y component of the viewpoint
float realHeight;
GetViewpointElevation(&realHeight);
printf("real height==%f\n\n",realHeight);

startViewpoint[1] += realHeight-height;
// reset the viewpoint
WTviewpoint_setposition(view,startViewpoint);

printf("dir==%f %f %f\n\n",startViewDirection[0],startViewDirection[1],startViewDirection[2]);
WTviewpoint_setdirection(view,startViewDirection);

WTviewpoint_getposition(view,viewPos);
printf("vp==%f %f %f\n\n",viewPos[0],viewPos[1],viewPos[2]);

WTviewpoint_getdirection(view,viewDir);
printf("dir==%f %f %f\n\n",viewDir[0],viewDir[1],viewDir[2]);

// 2. apply the texture

// a. get bounding box
WTp3 ext;

WTnode_getmidpoint(terrainNode,pos);
WTnode_getextents(terrainNode,ext);

printf("pos==%f %f %f\n\n",pos[0],pos[1],pos[2]);
printf("ext==%f %f %f\n\n",ext[0],ext[1],ext[2]);

xmin=pos[0]-ext[0];
xmax=pos[0]+ext[0];

ymin=pos[1]-ext[1];
ymax=pos[1]+ext[1];

zmin=pos[2]-ext[2];
zmax=pos[2]+ext[2];

printf("\n\n xmin xmin ymin zmin==%f %f %f %f\n",xmin,ymin,zmin);
printf(" xmax,ymax,zmax==%f %f %f %f\n",xmax,ymax,zmax);

/* WTnode_remove(terrainNode);

terrainNode=CreateNode(root,xmin,ymin,zmin,xmax,ymax,zmax);
WTnodepath* np=WTnodepath_new(terrainNode, root, 0);
WTnodepath_gettransform(np, m4);

geom=WTnode_getgeometry(terrainNode);
WTgeometry_settextureuv(geom, "drapel.1024x512.jpg", fu, fv, TRUE, FALSE);

/*

//b. get the geometry node and call
WTgeometry_settextureuv()
int numChildren=WTnode_numchildren(terrainNode);
for (int i=0;i<numChildren;i++) {
    WNode* node=WTnode_getchild(terrainNode,i);
    if (WTnode_gettype(node)==WTNODE_GEOMETRY) {
        WTnodepath* np=WTnodepath_new(node, root, 0);
        WTnodepath_gettransform(np, m4);
        WTgeometry* geom=WTnode_getgeometry(node);
        WTgeometry_settextureuv(geom, drapeName, fu, fv, FALSE, FALSE);
        //WTgeometry_settextureuv(geom, "drapel.1024x512.jpg", fu, fv, FALSE, FALSE);
        WTnodepath_delete(np);
    }
}

//2.5 create a sky background
//CreateBackgroundNode();

//WTnode_remove(terrainNode);

WTuniverse_setactions(ActionFn);
WTnode_print(root);

WTuniverse_ready();
WTuniverse_go(); /* Starts simulation */
WTuniverse_delete(); /* All done */

WTkeyboard_close();

fclose(fpPath);
## Total, Absolute Error in Angular Estimates (degrees)

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180
"Scale Corrected" Error in Distance/Length Estimates (meters)

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"Scale Correction" Values

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(number in italics represents largest error - meters - and is used as "SCA")

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