Virtual and Augmented Reality Interfaces: Empirical Findings and Implications for Spatial Visualization

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Abstract.

This is an exciting and challenging time for researchers of visualization and spatial knowledge integration. We are at a new frontier in geographic visualization research. Recent technological development has produced tools and techniques that change the nature of geographic visualization significantly, especially interfaces, interactions and metaphors. It is essential that the field of geographic visualization understands these technologies, and more importantly, understand their relationship with people and the knowledge that results from interactions with them. New spatial visualization technologies are emerging that fundamentally change the nature of interaction and spatial knowledge acquisition from visualizations. Virtual Environments (VEs) allow users to explore spatial information using a diverse range of visualization artifacts, interaction modalities and control devices. Experiences in such environments can be powerful. However, like all interfaces, every VE provides a unique set of affordances and inherent limitations for visualization and interaction. New interface technologies are emerging that are flexible, portable and more readily combined with everyday practice than existing semi- and fully-immersive VE technologies. Augmented Reality (AR) is an emergent technology which enhances real-world settings with virtual objects. The resulting systems provide compelling visualization and interaction experiences that are easily integrated with day-to-day practice. These characteristics have significant potential as future spatial visualization systems.

This paper presents key issues and challenges in geographic visualization interfaces using virtual environments with a focus on Augmented Reality. The past two years of research has led to the design and implementation of several virtual environments for spatial visualization, including a fully-immersive VE, and several Augmented Reality visualization systems that allow both non-immersion and full immersion. A sequence of user experiments was undertaken to study mental model formation, conceptual change and behavioral interactions with these interface technologies. Empirical and anecdotal findings are presented from the development and testing of these interfaces. The implications and significance of these findings for geographic visualization and cartographic practice are discussed. Future prospects are discussed and research directions are proposed. This work identifies key issues to guide future spatial visualization interface design and development, and to maximize the potential of these new technologies.

Keyword: Visualization, augmented reality, virtual environments.

Introduction

This paper is organized in three main sections. The first discusses contemporary issues and challenges in different kinds of virtual environments. The second section discusses recent and current research by the author, with a focus on establishing a knowledge base for Augmented Reality (AR) visualization interfaces. Findings and expected outcomes of latest endeavors are detailed. The paper concludes with a discussion of the implications of work using these technologies for geographic visualization.

Section1: Issues and Challenges in Geographic Visualization Environments

Rapidly emerging technologies are facilitating new and increasingly sophisticated visualization and interaction possibilities. Unlike GIS, some of these technologies - such as Virtual Environments (VE's) and Augmented Reality (AR) - are only beginning to develop a bond with cartography. They present compelling possibilities for spatial visualization.

Virtual environments (VE's) have received much attention in recent years, and have been formally investigated for at least the past fifteen years. Often popularized by the phrase "Virtual Reality", the term virtual has been employed and misused many times. In the context of this work, virtual environments are some form of three-dimensional environment with which one or more users can interact via computer-supported visual interfaces. These three-dimensional environments may result from the use of real or abstract data (not necessarily three-dimensional to begin with) transformed into three-dimensional structures and objects. Typically, combinations of displays and control devices allow various sensory experiences to occur. These may include desktop or more advanced interfaces. Different interaction modalities may allow exploration of the environment, and may approximate 'experience' in some form.

As VE's have become more accessible, work has begun to emerge from this sub-field focusing on 3D GIS content using desktop PCs as a step towards more advanced visualization interfaces (Slocum et al., 2001). Currently in geography, focus areas of immersion, interactivity, information intensity, and intelligence of objects have been proposed (MacEachren et al. 1999b). It is essential however, for geographers to understand the complex set of systems that contribute to experiences with and in VE's. As with all interfaces, there are advantages and disadvantages to all interface modalities.

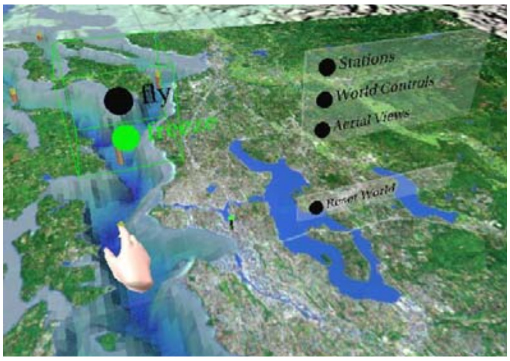
Virtual Environments

Examples of VE's include head-mounted display (HMD)-based immersive environments (Fig 1.3), immersive CAVE environments (one or multiple users, own display), semi-immersive desk environments (with a 'driver' and multiple viewers), and most recently, and new class of VE: Augmented Reality.

Fig. 1.3

Example of a HMD-based immersive virtual environment

(image to the right is what the user sees inside of Virtual Puget Sound, a University of Washington



Research has demonstrated that VE's can allow users to effectively acquire spatial knowledge (Hunt and Knapp, 1998; Waller, 1999). VE's appear to be effective tools for training, communication, collaboration and education (Winn, 1993; Waller, Hunt and Knapp, 1998; Winn and Jackson, 1999)**.** Several pieces of work have also demonstrated that previous knowledge, experience and interaction are of equal if not greater significance than immersion in virtual environments. (Dede, 1995; Dede et al, 1997; Loftin et al., 1993). These emergent and contextual properties of VE's should remind cartographers and geographers that VE's are not the same as maps. In addition to 3D spatial content, interfaces to these VE's are combinations of displays, control devices, and interaction metaphors.

Through the study of traditional, immersive VE's in multidisciplinary interface research, we have known for some time now that in many respects they represent too much of an abstraction from reality to be a realistic part of it. To unpack this statement, VE's are potentially powerful tools, facilitating unique and powerful experiences, such as the ability to fly anywhere (above ground, or under water in VPS (Fig. 1.3)), inside molecular structures, into the future, to manipulate the world, phenomena, time, and to see abstract or normally invisible phenomena revealed.

Immersive VEs are often a dramatic and engaging visual experience, but they suffer from limitations of expense, accessibility, user disorientation, in addition to enclosing the subject in a computer-generated world that prevents any outside interaction, and rarely provides them with a meaningful or seamless interface with the virtual environment. In the Virtual World the user is immersed in the interface, their natural senses replaced with computer generated sights, sound and touch. The interface is transparent because it is all-encompassing and by default the user's only perceived reality.

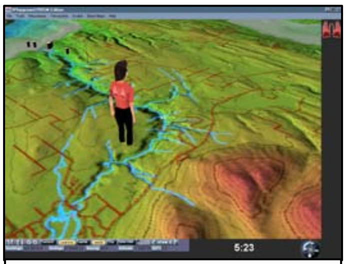


Fig. 1.4a Desktop Interface to a VE

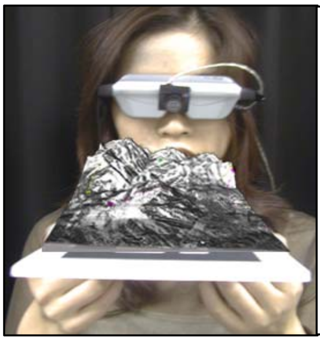


Fig. 1.4b: Augmented Reality

Real person, surroundings and white card. *Virtual* landscape is a VRML model of a USGS DEM. *(This is what you would see if you*

Augmented Reality

AR represents a fundamentally different way of interacting with spatial visualization, that integrates our knowledge of existing VE's with powerful everyday interaction metaphors. AR interfaces 'enhance' reality by mixing real views with virtual objects (Milgram, 1994; Azuma, 1997; Billinghurst and Kato, 1999). In contrast to an immersive VE, AR interfaces subsume the computer into the real world and real objects become digitally enhanced with virtual objects overlaid into views in real time. These interfaces typically allow virtual objects to be attached to real objects that can be touched and manipulated.

AR interfaces are compelling for studying spatial knowledge acquisition, because we are able to: (1) maintain real-world metaphors and spatial metrics (in a room-scale environment with familiar objects of known dimensions) while presenting advanced visualizations; (2) manipulate geographic spatial representations in a ‘manipulable space’ (Montello, 1993) and; (3) manipulate the use of haptic spatial knowledge and its impact on the development of spatial knowledge; (4) manipulate survey, route and landmark knowledge acquisition, depending on the interface modality used. It is believed that AR has significant practical, theoretical and technological potential for geographic visualization.

Section 2: Recent and Current Research

Past Research

Over the past four years, the author has been involved in a range of VE interface projects have yielded a range of findings and experiences about different kinds of VE interfaces for spatial visualization. Examples include simple desktop interfaces for analytical use of 3D GIS visualizations (Hedley et al, 1999) non-immersive desktop interfaces to facilitate collaborative 3D visualization in shared virtual spaces (Hedley and Campbell, 1998), and fully immersive HMD-based VE’s such as *Virtual Puget Sound* (Winn, Windschitl and Hedley, 2001). More recently, AR interfaces have been investigated for collaborative geographic visualization applications (Hedley et al. 2001a; Hedley et al., 2001b), and for non-immersive geographic visualization applications and from spatial cognitive perspectives (Hedley, 2001). This path of research has moved away from traditional fully-immersive VE’s, and is currently focused on revealing the significant aspects of AR interfaces.

Recent Research

Following a period of informal interface testing, a set of prototype AR-ready 3D models were developed to take initial steps towards establishing baseline data upon which to eventually study more sophisticated geographic visualization applications.

The first phase of experiments has been completed. This phase was designed to establish baseline data about the influence of interface characteristics and visualization/model content on individuals’ ability to understand the orientation, structure and dimensions of three-dimensional models of space. These experiments involved abstract model content in non-immersive AR, and focused on the identification of significant aspects of basic interface affordances and visual model content.

Manipulations included: (1) the degree of immersion (immersed or non-immersed AR); (2) the visual characteristics of model content (e.g., textures and color); (3) the spatial characteristics of visualizations (e.g., frequency, size, orientation, complexity); (4) visual and spatial cues for spatial reasoning; and (5) the level of abstraction - from abstract spatial visualizations (data points or simple geometric objects) to naturalistic landscapes (digital elevation models).

Participants completed a series of tasks using a non-immersive AR interface. Participants sat in a chair at a table that is covered in black felt. They wore a liquid-crystal bi-ocular VGA display (1.4b) equipped with a miniature camera attached to the front of the display. Using software developed by the University of Washington’s Human Interface Technology Laboratory the video stream captured by the camera is combined with three-dimensional virtual objects and landscapes. Virtual objects appear when the software recognizes unique patterns of fiducial markers mounted on cards (4.2d). The result is the appearance of virtual objects in views of the real world, when looking though the bi-ocular VGA display. Each virtual object or landscape is spatially registered to a unique fiducial marker pattern. As a result, when you turn or move the card, the virtual object behaves like a real object. If multiple users use the interface, they would see their own unique perspective of the same object.

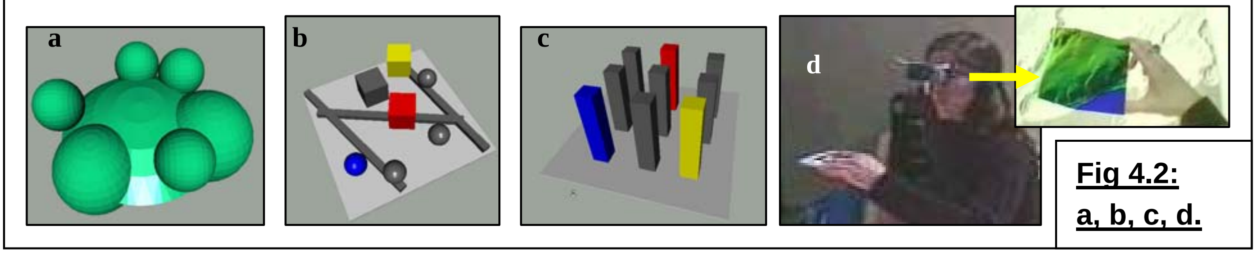


Fig 4.2: a, b, c, d.

Participants are given a pretest to gather background information about training, experience and familiarity with spatial concepts and reasoning, , and experience with interface technologies. Following the pretest, participants are brought to the experimental setting (a single chair at a square table in a laboratory), introduced to the technology and devices they will be using. A five-minute briefing familiarizes participants with the vocabulary to be used and the items referred to. The briefing also describes the interaction and communication protocols of the experiments.

In these experiments, two primary experiments are conducted. The first is an orientation test. A baseline orientation test is conducted. The participant then engages in a two-stage experiment using the AR interface. In the first setting, square cards are used for fiducial markers, and model content includes orthogonal, linear and planar objects. In the second setting, the cards used are circular, and the model content is predominantly composed of curved and spheroid objects (4.2a). Six identical rotation tasks are performed, and require the participant to rotate the virtual objects using the cards (4.2d).

The second experiment again has two treatments. Both use only square cards for fiducial markers. All visualization model content includes one red object, one blue object and one yellow object (4.2b, 4.2c). In both treatments the task is to indicate which of the yellow or blue objects is closer to the red object. Manipulated variables included object size, orientation, structural complexity, arrangement composition and visual occlusion. The major difference between treatments was that in the first treatment, subject were not allowed to touch the card and therefore not move it. They had to remain in their seat and were only allowed to move their head or upper body to change their view.

Report and Observations

20 individuals have participated in formal experiments aimed at establishing basic interface interaction baselines. Participants included computer science, education, geography, architecture, and engineering backgrounds. Notable observations include the strategies used by participants to perform orientation, inter-object distance estimate, and spatial reasoning tasks. There appear to be distinct combinations of visual and spatial cues used by people with different training. Individuals have demonstrated different mental representation and prototyping strategies, that seems to be associated with their background.

During the rotation tasks, there was a distinct decrease in performance of participants when primary spatial referents are removed or reduced. Subjects performed better, more accurately when they had corners, linear features and orthogonal structures in either the interface (table or card) or in the model content itself. In the absence of visual and spatial referents, some individuals used their hands as referents and metrics. This strategy was also seen in the inter-object distance estimate tasks.

Participants often looked for unique landmark objects to use as spatial referents. In the absence of unique features, some resorted to the ‘body as referent’ tactic once more. An interesting strategy observed in one case was a subject who studied a faceted surface of an otherwise nondescript object. After considering the pattern structure of the facets, he calculated the required rotation by mentally prototyping the resulting pattern structure of the facets. Another participant demonstrated confident, rapid and accurate three-dimensional mental manipulation ability in the rotation task. The reasons for this were not immediately apparent from observation alone. It turns out that the first individual was an experienced spatial analyst/GIS user, while the latter individual was an architect.

In the inter-object distance estimate tasks, the differences between treatment were less dramatic than those differences between the rotation treatments. However, the inter-treatment difference of ability to touch/move/rotate the card (and therefore the model) provoked a valuable behavioral response on the part of subjects. When constrained to viewing the model without touching or rotating it, it was informative to see what individuals wanted to be able to view or do in order to understand the content and structural arrangement of each model. The most popular strategy appeared to be an overhead view. This makes a great deal of sense considering it was an inter-location distance exercise. The next most popular strategy was a table-level, sideways strafing motion, back and forth. By watching the relative motion of objects and surfaces during this behavior, it appeared that individuals were attempting to fill in some of the gaps in their spatial model by seeing how the visual characteristics changed with personal movement.

The basic experiments described here are an essential first step in identifying interface and visualization features that may be significant in this new interface setting. To the author’s knowledge, this is one of the first formal empirical studies of augmented reality as a spatial visualization tool.

Current Work

The 20-participant study described in the previous section was a prototype system designed to inform more advanced AR visualization interfaces. Since then a more sophisticated research design has been developed. 120 participants will engage in experiments using desktop interfaces and non-immersive AR interfaces to 3D geographic visualizations. This work is currently in progress. Participants use more advanced AR interfaces to solve spatial decision-making tasks.

It is hoped that this new experimental phase – which will be completed later this year – will establish a baseline data and the foundation of a knowledge base based on cumulative experience and experimental work to this point. It is also hoped that in turn this will help to inform research colleagues of the challenges and positive possibilities of these new technologies.

Section 3: Implications for Spatial Visualization

Geographic visualization is in a period of technological, and practical transition. These dynamic times bring many different tools and concepts into the research arena. As a result of the information technology developments in recent years, cartography (or cartography-like practices, see MacEachren 1995, p.4) and spatial visualization span a far broader range of technological, representational and practical implementations than they have in the past. As geographers and cartographers, we must ask ourselves:

- Do traditional cartographic techniques translate to these new technologies?
- Are we moving into an era of visualization interfaces that are more transparent or intuitive than conventional cartographic interfaces?
- Do new visualization techniques match traditional forms of spatial visualization training, or do they engage different faculties of individuals? Are interactions different?
- How are metaphors of interaction and representation changing?
- Do these factors impact the meaning of visualizations and the information they present?

It is clear that integrated basic research is needed in this area. A key question that is driving this research is: does AR provide enhanced cognitive access to 3D geographic visualizations than other existing and emergent visualization interfaces? The ability to make sense of a 3D model, through viewing and manipulation is potentially powerful. The initial baseline experiments described in this paper indicate that this is likely to be an important avenue of research to pursue, in light of participants’ behavioral reaction to the removal and manipulation of spatial and visual referents.

Summary and Future Prospects

These technologies may fundamentally change the way in which we present spatial visualizations. More importantly, they will change how we extract and exchange spatial knowledge with them. The reason that AR is chosen as one of the key technologies for this research is our ability to manipulate the mode of spatial knowledge acquisition, using AR as a manipulable space to provide access to representations of geographical space. In addition to spatial cognitive advantages to using this technology, an opportunity exists to formally test and develop theory surrounding AR for spatial visualization as the technology and application domain evolve. Doing so will allow us to identify the areas in which the greatest contributions may be made, and to inform the research community of the results.

The immediate phase of empirical research to establish interface and visualization baseline data is the foundation for exploring the dimensions of mental model formation using augmented reality (AR) environments. As more data is gathered and integrated into the knowledge base, more sophisticated visualizations will be used, and modular experiments will be implemented to explore specific spatial knowledge acquisition mechanisms.

Further down the road, following the experimental sequence using individuals and augmented reality, two further experimental sequences are planned. The first is a version of the AR environments developed by the HIT Lab and ATR Labs. An enhancement to the AR setting described in this paper, the user has the choice of holding the landscape/model in their hands non-immersively, or they may fly into the virtual environment, and explore it in exactly the same way as an immersive virtual environment (the real world disappears during the transition). This was demonstrated as the ‘Magic Book’ at SIGGRAPH 2000. This should provide some exciting opportunities to manipulate survey versus route knowledge acquisition while maintaining exact consistency of virtual environment content. The second future experimental sequence will study collaborative augmented reality environments that integrates the preceding phases into an advanced development of the collaborative AR work described in Hedley et al. (2001).

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