VIRTUAL ENVIRONMENTS FOR GEOGRAPHIC VISUALIZATION: POTENTIAL AND CHALLENGES

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ABSTRACT

Virtual environment (VE) technologies have considerable potential to extend the power of information visualization methods, and those of scientific visualization more broadly. Our specific focus here is on VE technologies as a medium for geographic visualization and on some of the challenges that must be addressed if the potential of VE is to be realized in this context.

Keywords: virtual reality, scientific visualization, maps, interactivity, collaboration

1 INTRODUCTION

The application of virtual environment technology as a medium for geographic visualization (geovisualization) poses several specific challenges not shared by all forms of visualization implemented within virtual environments. A working hypothesis behind much of the research in visualization in scientific computing (ViSC) over the past decade is that the most successful visual representation methods will be ones that take the fullest advantage of human sensory and cognitive systems developed for interacting with the real world. As a result, emphasis in ViSC has been on 3D dynamic displays and realism applied to the representation of objects, particularly objects that have visible form in the real world (e.g., the human body, aircraft wings, thunderstorms). Extension of these methods for use with VE technology requires only modest changes conceptually (although there are technical challenges). In contrast to ViSC, emphasis in geovisualization research over the same time span has been on integrating and extending cartographic, image analysis, and exploratory data analysis methods. These methods emphasize 2D and 2.5D display and highly abstract data representations within a geographic frame that is often represented less abstractly (DiBiase et al. 1992, Fisher 1994, MacEachren et al. 1998a, Mitas, Brown, and Mitasova 1997). As a result, the application of VE technologies to geovisualization lags behind that of ViSC more generally and poses special challenges associated with the kinds of information depicted, methods developed over several decades for depicting that information, and the problems to which the information is applied.

The VE technologies considered here range from relatively ubiquitous web-based tools, particularly use of the Virtual Reality Modeling Language (VRML), through high-end systems such as immersive workbenches, CAVEs, or Power Walls. In relation to web-based VE, the focus has been on creating 3D navigable "worlds" displayed on standard computer monitors (often accessed through web browsers).* Like early VE applications more generally, GeoVRML efforts have focused on depicting the experiential environment (e.g., Rhyne, 1996; Fairbairn and Parsley 1997; Dykes, Moore, and Wood 1999). An emphasis on the experiential environment is also evident in initial application of non-desktop VE for geospatial information representation -- to facilitate tasks such as urban planning (Verbree et al. 1999), natural resources management (Bishop and Karadaglis 1994), or learning an environment prior to a military action in that environment (Darken, Allard, and Achille 1998). There have, however, been a few efforts to explore abstract (non-visible) geospatial data using immersive VE. Examples include the Virtual Chesapeake Bay, that supports exploration of a coupled physical/biological model of currents, wind, salinity, temperature, and other variables (Wheless, et al., 1996) and implementation (within a CAVE) of analysis methods for exploring georeferenced statistical data on the livability of US cities (Cook, et al., 1997).

In this short paper we draw upon our own experiences with geovisualization methods implemented in both desktop and non-desktop VE, as a base from which to define and pursue key research issues associated with geospatial VE (GeoVE). We begin with a discussion of the factors that can contribute, individually or in combination, to a virtual experience. Then, we use examples from our recent work to consider three issues: spatial iconicity of visual representation within GeoVE, interaction methods for exploring spatiotemporal data in GeoVE, and development of GeoVE to support same time–different place collaboration.

2 FACTORS IN VIRTUALITY

Part of our long term goal is to investigate, directly, the hypothesis that virtual displays have advantages over 2D/2.5D (traditional cartographic) displays for exploring complex multidimensional geospatial data. In this context,

Part of this work was carried out within the Apoala Project, supported by: the U.S. Environmental Protection Agency (grant # R825195-01-0 – Donna J. Peuquet and Alan M. MacEachren, Co-PIs, www.geog.psu.edu/apoala). Support of the Penn State Center for Academic Computing is also appreciated. Correspondence should be directed to the first author at: alan@geog.psu.edu or 302 Walker, Dept. of Geography, Penn State University, University Park, PA 16802

a GeoVE can be used to depict more than the visible characteristics of geographic environments–to produce geospatial virtual "super environments" in which users can not only see what would be visible in the real world, but also experience the normally invisible and control what is usually beyond human control. Testing a hypothesis that GeoVEs have advantages over traditional geospatial display environments is not a simple problem, since the display environments do not divide cleanly into categories of virtual and non-virtual. A key step in the process, then, is to delineate the factors that make a GeoVE virtual.

Here, we propose a preliminary taxonomy of meta factors that (together or separately) contribute to the *virtuality* of a GeoVE, factors that these environments can share with real environments. This categorization divides the factors into four groups associated with: immersion, interactivity, information intensity, and intelligence of display objects. The first three of these are adapted from Heim (1998) who proposed immersion, interactivity, and information intensity as the "three I's of VR." Our perspective on interactivity is broader than that suggested by Heim and we have added a fourth "I" to the list. Each category of factor in virtuality is detailed below, briefly.

2.1 Immersion

Immersion describes the sensation of "being in" the environment. Being in a real world environment involves use of all our senses. Thus, it seems clear that there will be degrees of immersion in a virtual environment that, in part, are a function of which senses are stimulated in ways similar to that experienced in the real world and, in part, are a function of the fidelity of that stimulation. A key research problem here is to identify the specific display environment characteristics that lead to a sensation of immersion (in a geographic scale space) and the relative impact that use of each has for understanding geospatial phenomena and their interrelationships (at and across geographic scales).

2.2 Interactivity

Interactivity, from Heim's (1998) perspective, refers to enabling a participant in a virtual experience to change their viewpoint on the environment (e.g., through body and head movements and corresponding head-tracking) and to change the relative position of their body (or body parts – hands) in relation to that of other objects (e.g., making it possible to interact with a virtual object by picking it up and rotating it in the hand). To this, we add kinds of interaction that allow a participant to manipulate the characteristics of environment components (e.g., the color of objects or which objects are visible -- interactions that, in the real world, might be accomplished by physically painting a house, turning on a light switch, or donning night vision or augmented reality goggles).

2.3 Information intensity

Information intensity refers to the detail with which objects and features of the GeoVE are represented. The virtualness of an environment will be enhanced if its objects have sufficient detail to appear like real world objects and features. This does not necessarily mean that the objects and the features must look like real world objects. What is required is a level of detail that corresponds to what we expect of real world objects at particular distances. Additionally, increasing proximity to an object should allow a user to see increasing detail, as it does in the real world (up to the focal length of human vision). Just as it is possible to use a magnifying lens in the real world to see even more detail, the virtualness of a GeoVE will be enhanced if zooming to scales beyond those of normal vision continues to provide additional detail (using virtual microscopes and telescopes).

2.4 Intelligence of objects

Intelligence of display objects refers to the extent to which components of the environment exhibit context sensitive "behaviors" that can be characterized as exhibiting "intelligence." The experiential world is not populated exclusively by inanimate objects that lack intelligence, as most displays have been. Achieving realism in a virtual environment, then, will be enhanced if display objects exhibit behaviors that correspond to those of animate objects in the world. Particularly when the objects represent (potential) collaborators in a task, rational behaviors appropriate to the situation will be expected.

3 DATA EXPLORATION IN GeoVE

Here, we draw upon our recent experiences with the application of both non-immersive and immersive interactive three-dimensional display technologies to exploration and analysis of geospatial information. A particular focus of that work is to develop methods for exploratory analysis of spatiotemporal climate data. Our experiences include work on desktop GeoVE applications (using Tcl/TK-IBM/DX, Tcl/Tk-VTK and Java-VRML) and work on ImmersaDesk (IDesk) applications (using Cave5D/6D and Java 3D). From this base, we address three issues: (1) spatial iconicity of representation in GeoVE and the associated balance of realism and abstraction with which different information components are depicted; (2) approaches to interaction for geovisualization within GeoVE; and (3) the development of GeoVE for facilitating collaboration among individuals (locally and remotely).

3.1 Spatial iconicity of representation

One characteristic shared by the GeoVEs we have developed is that each involves use of 3D display and thus has the potential to depict the three geographic dimensions of real spaces *iconically*, with each dimension of the display space depicting a geographic dimension. As we define them, however, a GeoVE does not require that this one-to-one iconic match be applied. More abstract representation is often useful for understanding complex multivariate geospatial information. Here we distinguish three categories of "spatial iconicity" for GeoVE: iconic, semi-iconic, and abstract.

3.1.1 Spatially iconic GeoVEs

A spatially iconic GeoVE is defined as one using the three dimensions of the display environment to represent the three dimensions of physical space (figure 1). A spatially iconic GeoVE, takes advantage of human perception and cognition, as developed to deal with the experiential world. Real world metaphors should be easily adopted for taking action in these GeoVEs, such as "digging" to the center of the earth and "flying" across local to global scale distances.

Taking advantage of the naturalness of a space-to-space mapping between real world and display does not require that GeoVEs be representationally iconic (replicate reality) in all respects. Realism can be a distraction. An air photo, for example, represents visual aspects of the world realistically, but does not function as well as a more abstract map for navigation. Similarly, an ultra-realistic virtual environment (by itself) may not function well as a tool to explore geospatial information. Thus, the same rules of abstraction and generalization relied upon for successful cartographic representation in two dimensions may apply in three. For example, although a realistic virtual 3D display of a tornado might be visually compelling, insight is more likely when wind direction, speed, and temperature are represented through abstract visual symbology.

Important research questions here (beyond consideration of effective metaphors, discussed in more detail below) include determining the appropriate level of abstraction with which to depict visible and non-visible features within a spatially iconic GeoVE and investigating the impact of user manipulation of this abstraction level on understanding.

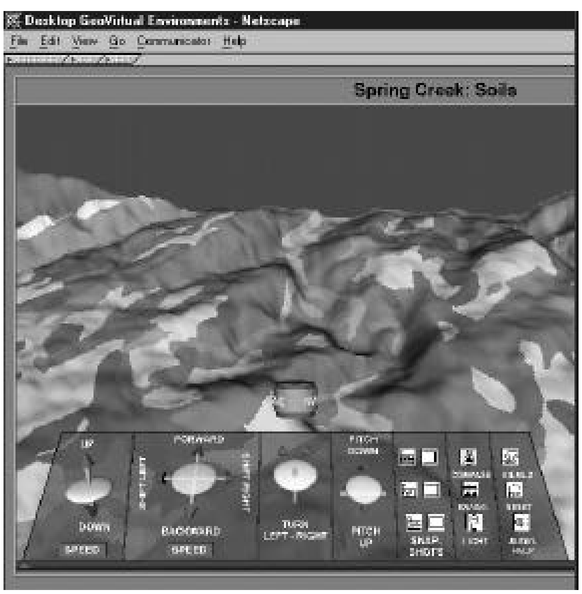

Figure 1 GeoVRML application in which display space represents geographic space iconically and color (in the original screen display) represents soil categories abstractly. See Fuhrmann and MacEachren, 1998 for more detail on the interface to this environment.

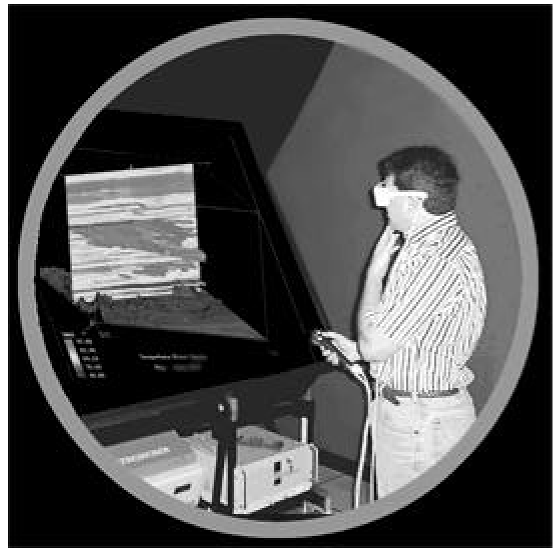

Figure 2 A space-time cube being analyzed in an ImmersaDesk environment. The x- and y-dimensions of the display space represent latitude and longitude of geographic space. The lower portion of the z-dimension of the display shows the vertical geographic dimension, while the remainder of the z-dimension is used to depict time (a three-month period). The vertical slice depicts temperature along a transect in space through the full time period, see:
www.geovista.psu.edu/publications/ica99/

3.1.2 Spatially semi-iconic VEs

Although the direct mapping of geographic dimensions to the three virtual space dimensions may be intuitive, different insights can be gained by using one or more of the VE axes to depict a non-geographic variable (e.g., income). For space-time data, use of the third dimension to represent time has a long history as a useful representation form (Parkes, et al, 1980; Szego, 1987; Samtaney et al. 1994). These “space-time cubes” can be populated with data depictions and colored (or glyphed) to represent the presence or magnitude of some additional variable. Use of "isosurfacing" in space-time can help to extract spatiotemporal features not apparent in representations that separate time from space. Many of the representations we have developed within the Apoala project (www.geovista.psu.edu/apoala) have utilized this representation form successfully, in both immersive and non-immersive GeoVEs (figure 2).

3.1.3 Spatially abstract GeoVEs

Geographic information scientists are naturally inclined to preserve the spatiality of a virtual display, but information designers and visualization specialists across many disciplines have long understood the power of spatialization (the remapping of non-spatial quantities into the display space). Scatter plots, time series plots, parallel coordinate plots, and box plots are only a few of many different representations where some abstract non-spatial variable is transformed into space (on the page or screen) in order to facilitate the understanding of that variable in relation to others. Interactive GeoVEs for geographic information visualization are likely to be most effective if the (re)assignment of space (or time or attributes) to each (or all) of the dimensions of the environment is a fundamental functionality of the system (i.e., is under user control). For these abstract depictions to be effective in prompting geographic insight, it is important to link them to other representations that are spatially more iconic, with dynamic links that support "brushing" and similar operations (MacEachren, et al, 1999).

3.2 Metaphors and interactors for data access and exploration

The abstract nature of information technology creates a need for metaphors in graphical user interfaces, so that users can conceptualise and understand software without having to master its technical workings. Graphical user interface metaphors map familiar source concepts into abstract, computational target domains (Kuhn 1995). They have become a key idea in designing and assessing human-computer interaction (Kuhn 1996). The main role of metaphors is to afford ways of interacting and to help the user in mastering complex tasks. Interface metaphors are a conceptual, not only a presentational device. They act as 'sense makers' - an indispensable function for any user interface (Kuhn 1995). In one recent project, we implemented and have begun to test several metaphors for navigation and orientation in desktop GeoVE (Fuhrmann and MacEachren, 1999; see also figure 1).

An idea that comes quickly to mind, when working with an immersive GeoVE, is: "Let’s throw away my keyboard and mouse and interact directly with the representation to change its characteristics." To a limited extent, this is possible with our IDesk implementation (see figure 2). Head tracking updates the view in response to user movements and a laser-pointer "wand" allows the user to point to objects in 3D and control their position.

While direct manipulation of 3D objects sounds appealing, there is little empirical evidence to help determine when (or if) a user interface for 3D+ environments should include 3D controls rather than 2D, or a combination of both. Considerable attention has been directed to design of 2D graphical user interfaces for two-dimensional computer environments generally (del Galdo and Nielsen 1996; Shneiderman 1992; Wood 1998), for 2D desktop mapping/GIS (Medyckyj-Scott and Hearnshaw 1993; Nyerges et al. 1995), and for 2D geovisualization (Edsall and Peuquet 1997; Howard 1998). As geovisualization displays extend to 3-, 4-, or n-dimensions (by taking advantage of VE technologies), we need to consider, directly, the relative advantages of 3D versus 2D controls for aspects of 3D GeoVEs.

A key step in designing such interaction tools (and in research directed toward better designs) is to categorize potential uses of a GeoVE. Shneiderman (1992) distinguishes four primary applications in design, generally: life-critical systems; industrial and commercial uses; office, home and entertainment applications; and exploratory, creative, and collaborative systems. Possible GeoVE examples of each are: visual simulation tools that support flood and related disaster scenario testing; real-time visualization of a telephone network to identify faults, bottlenecks, and fraud; interactive maps used for business geographics; and exploratory visualization used to study human dimensions of global environmental change. Our focus has been on Shneidermans's fourth category, exploratory and collaborative use of a GeoVE.

A primary focus of our exploratory geovisualization research is the development of methods for analyzing spatiotemporal data visually. Thus, change over time is a key issue in our work and it has been a research focus over the past decade (MacEachren and DiBiase, 1991; MacEachren, 1995; Harrower, et al, 1999). In several projects, we have directed specific attention to developing interface methods (grounded in logical metaphors) for posing temporal queries and for displaying and manipulating temporal aspects of a visual analysis (Edsall and Peuquet, 1997; Edsall, et al., 1997). In particular, we have focused on design of interactors that support two complimentary conceptualizations of time, as linear and cyclic (figure 4).

Figure 3 Examples of cyclical (left) and linear (right) temporal legends. The cyclical legend suggests a clock metaphor (with its repeating cycles) while the linear legend suggests an unending time line.

We are beginning to experiment with the adaptation of these interaction forms for use in immersive GeoVEs. A possible metaphor we are investigating is that of a coil (figure 5). Viewed end-on, this coil is seen as a time wheel with which cyclic components of time can be explored. Viewed from the side, the coil presents time in a primarily linear way, directing focus to spans of time. Viewed obliquely, the interactor may support analysis leading to an integration of cyclic and linear perspectives on time.

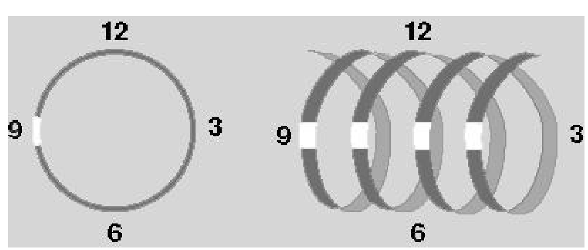

Figure 4 An example of a cyclical legend using a coil metaphor. At left it is shown end-on and at right it is viewed obliquely making both the linear and cyclic perspective apparent.

3.3 Collaboration among individuals

The size of displays used in non-desktop GeoVEs and the increasing bandwidth of network connections used by all GeoVEs are making it possible to extend geovisualization from its current focus on facilitating *individual* information analysis toward new environments that support *group* research, learning, and decision-making. In a series of projects, we have begun to explore the potential of immersive and desktop VE technology, combined with high speed networking, to facilitate collaboration among scientists at remote locations as they explore complex spatiotemportal data. Here, we describe (briefly) a demonstration project in which we implemented an immersive GeoVE to enable same-time collaboration among researchers in different places. The demonstration was part of an "Internet2 Day" on the Penn State Campus in November, 1998, an activity designed to illustrate the potential of high speed Internet connections for supporting science and education. Environmental and computer scientists at Old Dominion University (who developed the Cave6D software used), worked with us to conduct this demonstration. The specific virtual technology used in this collaboration was a pair of IDesks. An IDesk uses a large format screen, 3D projection, and head tracking of the "driver" to provide users with a sense of being "in" the environment and allows small groups to use the system at the same time.

The data used in the Penn State component of the demonstration are extracted from a much larger climate data set for the Susquehanna River Basin of Pennsylvania, New York, and Maryland – specifically daily maximum temperature and precipitation extending from May through July, 1972. The primary visualization method implemented is dynamic manipulation of slices through a remapping of real world time onto one of the spatial axes of our display space (to produce what we call a space-time cube, see figure 2 and section 3.1.2 above). Among the features that the resulting dynamic environment highlights are the relationship of temperature to both topography and precipitation. With the latter, one of the more dramatic relationships is substantially reduced temperature across the basin following Hurricane Agnes, as the huge quantities of water dumped on the region slowly evaporated. IDesks at each location were used to share experiences in exploring data spaces created by each group (for further details, see: www.geovista.psu.edu/i2.htm; MacEachren et al. 1998b).

Fundamental research questions raised in this work include: (1) how to represent each participant's frame of reference in a manner that allows participants to switch between their own and other visual perspectives without becoming disoriented, (2) how to share different conceptual perspectives on the problem context (e.g., that of a climatologist and a land use planner), and (3) how to manage multiuser interaction with a highly interactive scene.

4 CONCLUSIONS

We have introduced the concept of GeoVirutal Environments and discussed the potential of such environments for geovisualization. Achieving this potential will require meeting a set of challenges. Key among these challenges are: (1) determining the appropriate balance of realism and abstraction for different geospatial application domains, different users, and different tasks; (2) developing new, innovative, methods for interaction with the spatial, temporal, and attribute components of geospatal information, separately and together; (3) developing approaches that take advantage of VE's potential to facilitate both same time–same place and same time–different place collaboration in research, learning, and decision-making that involves geospatial data.

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* This work has been facilitated by interdisciplinary and international collaboration between the International Cartographic Assoc. Commission on Visualization (www.geovista.psu.edu/ica) and the ACM SIGGRAPH Carto Project led by Theresa-Marie Rhyne (www.geovista.psu.edu/icavis/vis-acm.html). This collaboration prompted creation of the GeoVRML working group of the Web3D Consortium (www.ai.sri.com/geovrml/).