GEOGRAPHIC VISUALIZATION

AS AN EMERGING RESEARCH THEME IN GISCEINCE

A proposal for adoption of this theme by members of the UCGIS community

Presented by

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INTRODUCTION

The human visual system is the most powerful processing system known. By combining technologies such as image processing, computer graphics, animation, simulation, multimedia, and virtual reality, computers can help present information in a new way so that patterns can be found, greater understanding can be developed, and problems can be solved. "Geographic visualization", also referred to as "geovisualization" (GVis), which focuses on visualization as it relates to spatial data, *can be applied to all the stages of problem-solving in geographical analysis, from development of initial hypotheses, through knowledge discovery, analysis, presentation and evaluation. This theme should be a* research priority in GIScience, with a systematic effort to advance our understanding of geographic visualization.

Background

In its 1987 commissioned report to the United States National Science Foundation, the Panel on Graphics, Image Processing, and Workstations defined ***visualization*** as "a method of computing...a tool both for interpreting image data fed into a computer, and for generating images from complex multi-dimensional data sets..." the goal of which is "...to leverage existing scientific methods by providing new insight through visual methods" (McCormick *et al.* 1987: 3). MacEachren *et al.* (1992: 101) expanded that view by arguing that "visualization...is definitely not restricted to a method of computing...it is first and foremost an act of cognition, a human ability to develop mental representations that allow us to identify patterns and create or impose order." Geographic visualization is now considered to encompass not only the development of theory, tools, and methods for the visualization of spatial data, it also involves understanding how the tools and methods are used for hypothesis formulation, pattern identification, knowledge construction, and the facilitation of decision making.

Information visualization is generally considered to involve the use of computers to generate interactive, often animated, representations of multiple variables in multiple linked formats, the goal of which is to develop greater understanding of interactions of components of a system or distribution (Buckley 1997). Often this understanding comes from exploration of the data rather than through problem solving. This generally involves one or a few "expert, highly motivated viewers who are often engaged in ill-defined tasks such as hypothesis formulation" (DiBiase *et al*. 1992: 213). For this paper, our concept of geographic visualization is broader than others may consider as visualization (*i.e.*, computer-dependent methods of data display for small groups of highly-trained individuals who are primarily interested in exploration of very large spatial data sets). For example, we also consider other media (*e.g.*, paper, film, projected displays, holography), other data sets (non-spatial), user groups ranging in size from individuals to crowds, the cognitive process of visualization, and other computer configurations (*e.g.*, mobile computing, wearable computers).

Related Efforts

Our efforts to draft a research agenda for the UCGIS in geographic visualization parallel extensive efforts at the international level. The International Cartographic Association (ICA) formed a Commission on Visualization in 1995; "The Commission's focus is on use of dynamic maps as prompts to thinking (dynamic maps are maps that change in response to user action or to changes in data to which they are linked)" (MacEachren and the ICA Commission on Visualization 1998). Important activities of the group include, in addition to the elaboration of a research agenda, a number of commission meetings to advance work on the research agenda, development of comprehensive bibliographies in each of four major focus areas identified in the research agenda, and special journal issues.

The ICA approach appropriately reflects the cartographic character of the working group, focusing on geographic visualization as an area of research and application that is closely aligned with cartography (*e.g.*, directing attention to the opportunities for cognitive research in visualization, which is largely if not entirely absent from research approaches in other domains of science). A UCGIS research agenda will complement the ICA agenda, providing a slightly different perspective by directing attention to how visualization integrates with other research priorities in GIScience as a whole. The agenda in this paper recognizes the important contribution of the ICA agenda, but it also builds on it to include additional research priorities, presents a number of links to example projects, and focuses on some specific needs that the UCGIS is uniquely positioned to encourage and support. For example, we specifically address the need for collaborative development of this area of research both within the discipline of Geography and between Geography and other domains of science, as well as non-academic sectors (*e.g.*, commercial industry, private organizations, and governmental agencies).

We recognize that the ICA effort to this point has resulted in extremely comprehensive efforts and supporting literature in scientific journals and on-line owing to the focused work by the commission for a number of years. Duplicating this effort would not only be a waste of time, it is also unlikely that our results would be either vastly different or of superior quality. Therefore, in some sections of this paper, we refer our readers to the work of the ICA and remind the audience of the extensive efforts at the international level on a variety of fronts to advance a research program in geographic visualization. This paper is neither an attempt to synthesize that work nor to provide an explicit complement – rather it is an alternate compilation of research priorities that focus on distinct research opportunities in GVis with respect to the UCGIS.

OBJECTIVES

This paper describes how geographers and other spatial scientists are uniquely positioned to contribute to the advancement of GVis (and visualization in general), and the importance of accepting the challenge to make significant contributions in these areas. We describe current developments of the theory and methods of geographic visualization as a precursor to outlining the future research needs in GVis. We describe how geographic visualization research complements but does not duplicate other UCGIS research priorities. Finally, we describe a number of projects that demonstrate the advancements to date and the promise of future developments in geovisualization research.

THE IMPORTANCE OF VISUALIZATION TO NATIONAL RESEARCH

Although GIScience is a nascent science, it draws heavily upon the rich historical development of cartography, an art and science that evolved around the display and use of spatial data representations for thousands of years. Geographic visualization is closely linked to cartography, and much of the research in GVis is able to exploit the advancements in cartography. Robinson's seminal *The Look of Maps* laid the foundation for the development of cartography as a graphic science. Subsequent works by Bertin (1967) and Macinlay (1986) further defined the basic building blocks used to represent information visually through cartography. More recent contributions by Vasconcellos (1992), Krygier (1994), and MacEachren (1995) extended that representation framework to include touch, sound, and advanced graphics. GVis, however, is not cartography, and we are currently at a point where ***basic research*** on the ***theoretical*** and ***conceptual***, as well as ***methodological*** aspects of geographic visualization is necessary and ***critical***.

While information visualization is being developed in nearly all branches of science, geographers are uniquely positioned to contribute to its further development. A core has emerged, primarily within the discipline of geography, that begins to define the scope of GVis research and its research trends through a unifying set of theoretical concepts and increasing sophisticated methodological advancements. The important early theoretical and conceptual contributions of MacEachren (1994), Taylor (1991), DiBiase (1990), and Buttenfield (1996), among others, provided a framework for GVis research within the spatial sciences that may, to a large extent, be absent in other disciplines. This historical foundation and the recent advancements of geographic visualization in the past decade place geographers and other spatial scientists in a unique and important position to contribute to the national, and indeed international, research agenda in not only GVis, but also information visualization. With the contributions that have and remain to be made from more traditional approaches in cartography, especially in areas such as symbolization, representation, abstraction, and various cognitive aspects of visualization, GVis should maintain a stronghold in the development of scientific computing in the broader scientific and computing communities. We must take up the challenge of setting a GVis research agenda or risk losing the opportunity to make significant contributions from our unique perspective and at the same time help to set the larger research agenda. This paper outlines research directions that will allow us to approach that challenge in a thoughtful and strategic way.

NEEDS

While computational scientists have for a number of years proposed an annually updated set of research priorities for visualization, it is only recently that geographers, specifically cartographers, have defined a set of research priorities for geographic visualization. Although the previous lack of a stated direction may have been acceptable or at least understandable as this area of research matured and developed over the past decade, the time has now come to review the advancements of GVis and assess the research needs for the future, as well as identify links with other research priorities in GIScience. This need is due in part to current and expected demand for GVis capabilities. Not only has the volume of data available increased, the technological capabilities are more advanced. As a result, there are more data to visualize, more ways to visualize them, and more need to understand how visualization works. A thoughtful and directed approach to structuring our understanding of the efforts to, need for, and issues relating to geographic visualization will uniquely position spatial scientists to contribute to the development of visualization in general.

With vast increases in the availability of digital geospatial data, coupled with a need to address ever more complex questions, it becomes increasingly difficult to explore, understand, analyze, and communicate information. Visualization offers new methods to tackle these difficulties in a manner that keeps the expert (geographer) within the problem-solving loop (Gahegan 2000 and 2000a).

PRIORITY RESEARCH AREAS

In this section, we suggest a number of research priorities that should be recognized in a geographic visualization research agenda. Although there are a large number and a wide variety of issues relevant to the advancement of research in geographic visualization, the ones presented here reflect those that are closest to the core of GVis rather than those that might be more easily categorized under one of the other UCGIS research themes. For example, while scale is integral to map-based visualization and there are clear research needs that lie at the intersection of these two themes (such as the support of scale dependent displays and the use of visualization for understanding how patterns and processes relate between scales), the UCGIS research theme on scale captures many of the issues that are also relevant in GVis. On the other hand, there are some research priorities of such great importance to GVis that they could not be left for possible but not certain inclusion in other themes. For example, cognitive issues that underlie the design and use of geographic visualization tools are central to the unique approach that geographers offer to visualization research and therefore deserve special attention despite the existence of a "Cognition of geographic information" research theme.

The research priorities are prefaced by the presentation of two issues that are time-invariant and should be addressed immediately and continuously. The research priorities are not ranked; the order in which they are presented should not be construed to imply relative importance, amount of previous attention to the problem, potential difficulties in solving the problems, or other factors relating to various facets of the research challenges. The research priorities are categorized into three classes that roughly reflect the immediacy of the need for research: short- (2-3 years), medium- (3-5 years), and long-term (10 years and beyond). At the same time, we recognize that advancements, particularly those related to computation, could shift the relative importance of the research priorities over time. Limited space does not allow all related research to be cited; however, we enthusiastically refer readers to a set of comprehensive bibliographies compiled by the ICA Commission on Visualization and Virtual Environments in which various references relating to many of these research priorities are cited (these bibliographies are described in detail in the section below entitled "Example Research Projects").

Time-invariant Issues

Collaboration with Others

Large-extent, multivariate, spatial or spatio-temporal data sets present scientists and researchers with special challenges for displaying the data in some form that is intelligible and insightful. Advancements in the past decade in the development of concepts, theory, and methods of geographic visualization have earned GVis recognition as a viable and valuable tool for the exploration of these large data sets. However, the development of GVis methods and techniques is often uncoupled from the practice of data exploration within a specific scientific domain, as computer scientists, statisticians, and/or GIS/cartographic scientists work in isolation from the domain experts. Although technologically advanced, the techniques developed may not address the specific requirements of the domain scientists, or the complexity or novelty of the methods may be confusing, distracting, or even frightening to the domain experts. Too often, the result is the slow (or lack of) adoption of the visualization methods by the targeted scientific community. A research agenda in GVis should, therefore, foster communication and collaboration between developers and the practitioners.

Another need would be for groups of experts, each from different perspectives, to work together. The pressing need here is to understand Earth's complex physical and social systems from an integrated perspective, necessarily involving a shared understanding across many traditional domains in geoscience/geography. Collaborative visualization might be used to facilitate this need (Brodlie *et al*. 1998).

In addition to collaborating with other academics, researchers in GVis stand to benefit greatly from interaction with non-traditional collaborators. For example, some of the most impressive advancements in visualization have come from outside the academy. The entertainment industry has contributed to the advancement of computer animation for film, abstract and schematic graphic representations in cartoons, virtual reality and immersive environments for recreation, and game animation for video and other media. Additionally, commercial industries have developed methods for creative and innovative visualization in areas such as car navigation systems, animated and interactive graphics design for the Web, and voice-activated methods for hands-free wearable computation. Collaboration between GIScientists, domain scientists, computational scientists, and non-scientists offers potential promise for rapid innovative advancements in geographic visualization.

Emerging Technologies

In addition to paying attention to who is working in the visualization arena, GIScientists should be aware of emerging technologies and their potential impact on the advancement of GVis. Some emerging technologies that will influence geographic visualization to varying degrees are identified below.

- Computer hardware and software continues to increase in capability and decrease in cost; we are still obeying Moore's law -- double in performance in 18 months. Advancements relating the GVis include improvements to graphics hardware and the ability to maximize the advantages of fast bus architecture.
- Alternative display media are being explored to overcome the limitations of CRT displays. This is of critical concern in visualization since the low resolution and limited extent of these media exert unavoidable controls on the quality of graphic displays. Alternatives being explored include scalable display wall systems for large-format display, high-resolution wall displays for clearer projector-based displays, and multiprojector displays for multiple views (Funkhouser and Li 2000).
- Internet capabilities and limitations will continue to drive visualization as many tools are now being developed for the Web to take advantage of the capabilities of networked communication.
- Personal Digital Assistants (PDAs) currently provide low resolution, affordable, mobile displays with limited data storage and data processing capabilities. These devices continue to become more advanced, offering more communication and display capabilities.
- Immersive environments, such as computer-assisted virtual environments (CAVEs), walls, workbenches, will continue to be developed and have an impact on GVis. The realism of immersive environments continues to increase and the potentials for substitution for realism with abstraction are yet to be fully explored.
- Mobile computing will release users from desk-bound influence on not only when and where we can access displays, but also how we access them. Wireless area networks (WANs) support untethered computing over potentially limitless ranges.
- Real-time displays of spatial location are made possible through the integration of GPS and visualization and directly influence navigation capabilities.
- Advancements in navigation tools will create further demands for innovative displays that allow users to quickly and easily orient themselves in frequently unknown spaces.
- Hands free computing that takes advantage of voice recognition and interactivity will enable additional navigation solutions.
- Wearable computers, such as head mounted displays are being used to augment the real landscape with abstract information that is spatially aligned in superimposed real/virtual displays
- New data coding schemes, such as XML (extensible Markup Language), GML (the geographic XML implementation), SMIL (Synchonized Multimedia Integrated Language), and SVG (Scalable Vector Graphics), will improve the functionality of New Media.

Short-term Visualization Research Challenges

Interactivity -- Interactivity can be viewed as either internal (*e.g.*, the user alters the map display) or external in the sense that the interface provides linkages to resources outside the immediate display (*e.g.*, linked databases, hyperlinked web sites) (Andrienko and Andrienko 1999). Interactivity is key in the ability to “mine a data set” effectively, and there is a serious need the development of tools that allow users more interaction with both the data and the displays.

Cognitive issues -- Research in cognition includes a number of pressing research needs, including greater understanding of the impact of visualization on knowledge discovery, extending representations for visualization to include qualitative, intangible, multisensory, and conceptual data, and the development of evaluation methods to test the effectiveness of visualization tools.

Computer interface design -- It has been suggested that the interface is in fact the visualization since, at least for computer-based visualization, the user only interacts with the data through the interface, and the interface defines the ways that the users can interact with the data. Multimodal and natural interfaces attempt to mimic the way humans interact with one another and appear particularly promising for the visual-spatial data (Oviatt 1997, Oviatt and Cohen 2000). The development of new interface metaphors is also related to this research theme.

Media issues -- The format in which the visual displays are developed or presented (*e.g.*, paper, screen, projective displays, virtual environments) can influence the effectiveness of visualization. Research is needed on the impact of visualization in and by new media formats, including geospatial virtual environments (GeoVE), immersive environments, computer assisted virtual environments (CAVEs), augmented reality, and head-mounted displays (HMDs).

Multi-user/collaborative visualization -- An emerging area of research in GVis is collaborative visualization for multiple users. This involves the development of "environments that facilitate the use of manipulable visual displays for exploration of ideas and/or decision making by two or more individuals (perhaps located at a distance)" (MacEachren and Kraak 2000). Tools for collaborative visualization of georeferenced information have considerable potential for use in contexts such as urban planning, environmental management, and scientific interpretation of models of climate or other environmental processes.

Differences between users -- Various characteristics of users, including expertise, sex, age, culture and language, and sensory limitations, have the potential to greatly affect the effectiveness of tools (Gilmartin and Patton 1984, McGuinness 1994, Nyerges 1993). The effects of individual and group differences such as these are not clearly understood and require further research (Nyerges *et al*. 1998).

Visual design issues -- Issues include the ability to incorporate a number of capabilities into visualization, including dimensionality (spatial, symbolic, temporal), dynamism, animation, and, as mentioned above, interaction. Further research is also needed in the representation of non-spatial data in spatial formats, such as spatialization, or the process of converting abstract non-numerical information into a viewable spatial framework (Kuhn 1997, Skupin and Buttenfield 1996 and 1997, Couclelis 1998, Fabrikant and Buttenfield 1997, and Fabrikant 2000).

Non-conventional graphics -- Rather than using the computer to replicate traditional methods of data display, the computational power of computers needs to be further exploited to develop heretofore previously unconcieved of methods for displaying spatial information. Additionally, further development of non-conventional techniques, such as morphing (the transformation of the geometry of one image to that of another), superimposition (overlaying images with varying degrees of transparency), and multiple viewpoints, is required.

Medium-term Visualization Research Challenges

Multisensory GeoVE -- To further our understanding of the capabilities that can be developed for virtual and immersive environments, research is needed in the how visualization can be adapted for the other senses to complement or enhance methods that have been designed for visual communication. Geographic virtual environments should be developed to make use of all the human senses, requiring related research in tactile (sensations on the skin surface), haptic (relating to pressure and resistance), kinematic (relating to motion), olfactory, and other sensations. Of these, mapping for the visually impaired is perhaps the most advanced at this point (see, for example, and Jacobsen 1998, Kitchin *et al*. 1998, and Olsen and Brewer 1997).

Effectiveness of visualization -- There is need for further research into perceptual and cognitive aspects of communication, and we need to understand more about what affects the effectiveness of communication through visualization in particular (Buckley 1998). Visualization offers the means to combine and interactively change many of the visual properties of a display, and also new techniques to show ever-increasing amounts of data, yet research into the effectiveness of visualization has not kept pace.

Sensory limitations and variations -- Related to the above theme is the effect that sensory limitations may have on the effectiveness of visualization tools and techniques. For example, limitations in or lack of the ability to see color can negate otherwise sound graphic design decisions in visual displays. As visualization begins to take advantage of other senses, the effects of limitations in those senses will also have to be considered.

Abstracting away from reality -- The interplay between realism and abstraction needs to be further explored. Augmented reality, for example, couples these two to create new perspectives of previously unseen displays. The challenge is to automatically create a sketch to convey a desired action more effectively than can a real picture. Much research has been directed toward realism, and indeed, more is required. "At the same time, realism is in some sense easier, as we can draw on the quantitative tools of physics and mathematics. When we want to create an abstraction that somehow conveys key ideas while suppressing irrelevant detail, we need to draw on the less-quantified tools of perceptual psychology and cognitive psychology, and the vast knowledge of cartographers and animators" (Foley 2000). This is likely to vary with the application. We need to be able to determine what the right amount of realism for visualization to be maximally effective. For example, imagine an "abstraction" control, interactively varying the realism of the scene.

Displaying more data -- There has already been some work by the visual data mining community to further the developments that allow massive datasets to be combined on a computer screen using averaging, aliasing, and other methods (Keim and Kriegel 1996, Keim 1996). As the volume of spatial data available continues to grow, the need for methods for displaying much of it, perhaps simultaneously, will increase.

Displaying more pixels -- We need to look for ways to use solutions that will provide desk-sized and wall-sized work areas with sufficient pixels to maintain the image quality we have become accustomed to on our desktop monitors. Although faster graphics engines are being developed, we continue to display information on less than two square feet of display area with one to three million pixels that subtend perhaps 25 degrees at normal viewing distance. Or we use a projection system and magnify each pixel onto a large screen that, when viewed from a distance, is the same 25-degree field of view. The human eye, however, has a field of view of more than a 180-degrees.

Displaying fewer pixels -- At the same time that we advocate higher-resolution and larger display surfaces, we are increasingly working with smaller, lower-resolution displays found in personal digital assistants (PDAs), cell phones, car navigation systems, and other information appliances. "Consider PDAs and intelligent communicators on the palm-top, information appliances on the counter-top, automotive navigation systems on the dash-top, and messaging watches on the wrist-top. Making the best use of a limited number of pixels is in many ways more challenging than working with millions of pixels" (Foley 2000).

User interfaces for 3-D creativity -- Rather than doing creative work with traditional tools and then transferring the results into a computer graphics system for further work, we need to develop tools that allow the same subtle freedom as traditional tools in terms of greater expressiveness, more rapid development of prototypes, and sensory feedback. The challenge is to build interfaces and devices that allow the creative process of compiling a display to be developed with the computer as well.

Long-term Visualization Research Challenges

Imaginative information visualization -- There is endless opportunity for creativity in discovering new ways to present information. Advancements in this area will lie at the interface of computer graphics and graphic design. "Computer graphics empowers so many techniques concerning time variation and 3-D and interactive navigation that knowledge of and enhancement of these computer graphics techniques is an inherent, essential part of the creative challenge, awaiting integration with graphic designers' awareness of aesthetics and perceptual issues" (Foley 2000).

Automated creation of information and information visualizations -- The underlying challenge is to automatically create informative and aesthetic visualizations that help the user understand the underlying data being presented. This requires that the user express what information is being sought and that an automated assistant then synthesize a visualization that conveys that information. The challenge is to have a system where the user state the problem, "Please show me the relationships between landscape conditions and in-stream habitats ... " and suddenly have an aesthetically pleasing and effective graphic created based on domain knowledge and graphic design knowledge. Work in this area has already been advanced to some level by Senay and Ignatius (1998) and Gahegan and O'Brien (1997).

Unified graphics -- Geometry-based graphics contains points, lines, curves, planes, surfaces, and solid models. Image-based graphics contains image maps (also called bit maps), texture maps, environment maps, range maps, volume graphics (such as 3-D image maps), video, lumigraphs, and light fields, all representing point samples in 2-D, 3-D, or 4-D. There is a need to unify geometry-based graphics, image-based graphics, and time-based graphics. Additionally, sound, touch, and even taste and smell all need to be integrated.

THE UCGIS APPROACH

"Geographic information science" is accepted by the UCGIS as an umbrella term to capture the fundamental problems surrounding the effective capture, interpretation, storage, analysis, and communication of geographic information. While various applications of geographic visualization can be incorporated into all of these facets of GIScience, GVis is primarily a form of both ***spatial data analysis*** and ***communication***. It can also be applied to all stages of geographic problem solving and potentially to all types of geographic problems. Therefore, it is possible to find linkages between geographic visualization and all of the other UCGIS research priority areas. However, there is a distinct core to GVis and research issues that are related to it that are not engulfed in the other themes.

The key objectives of a UCGIS research initiative in visualization should be to:

- channel efforts to develop inventive and effective methods of geographic visualization;
- support the application of geovisualization methods to the significant problems in GIScience;
- foster cooperation between researchers in geovisualization and other areas of GIScience;
- promote geovisualization research in academia with respect to relevant efforts in private, industry, and government arenas;
- support methods to disseminate advancements in geovisualization to the wider scientific community; and
- investigate how visualization can be applied successfully to all the stages of problem solving in geographical analysis, from development of initial hypotheses, through knowledge discovery, analysis, presentation and evaluation.

EXAMPLE RESEARCH PROJECTS

The ICA Commission on Visualization has expended a huge effort in the compilation of bibliographies referencing work in the four focus areas that they have developed for their research agenda: (1) representation, (2) interface design and interaction, (3) integration of visualization with databases, data mining, spatial analysis, and geocomputation, and (4) cognitive issues in visualization (MacEachren and the ICA Commission on Visualization 1998). Although different categories could be used to compile sources of information about relevant research and advancements in geographic visualization, it is likely that most of the works would be cited in one or more of the ICA working bibliographies. The bibliographies are available on-line at the following web addresses:

- Representation (Team leader: Marc Armstrong) -- http://www.geovista.psu.edu/icavis/biblios/representation.html
- Interface design & interaction (Team leader: Bill Cartwright) -- http://www.geovista.psu.edu/icavis/biblios/interface.html
- Integration of Visualization with databases, data mining, spatial analysis, and geocomputation (Team leader: Mark Gahegan) -- http://www.geovista.psu.edu/icavis/biblios/dataMining.html
- Cognitive issues in visualization (Team leader: Terry Slocum) – http://www.geovista.psu.edu/icavis/biblios/cognitive.html

We enthusiastically refer our readers to these resources as they detail more historic and recent research in geographic visualization than we can present herein. Rather than duplicating the ICA effort, we instead focus on a number of ongoing research projects that we consider to be contributing significantly to the advancement of geographic visualization.

POSSIBLE SHOWCASE DEMONSTRATIONS

There are numerous excellent examples of showcase cartographic visualization projects; most of them are already featured on the web and therefore available for demonstration. Prime examples are described below. Web site links are provided so that the reader can embark on a virtual tour of projects around the globe that are advancing the visualization of geospatial data.

Time-Series Animation Techniques for Visualizing Urban Growth, U.S. Geological Survey, USA -- Acevedo and Masuoka, working with USGS's Urba Dynamics research program, have created a series of variants on animation

sequences that show the historical growth of the Baltimore-Washington built-up area. They argue that before creating an animation, various issues which will affect the appearance of the animation should be considered, including the number of original data frames to use, the optimal animation display speed, the number of intermediate frames to create between the known frames, and the output media on which the animations will be displayed. Three-dimensional perspective animations were created by draping each image over digital elevation data prior to importing the frames to a movie file.
http://www.geom.unimelb.edu.au/envis/automap/Acevedo/ACEVEDO.HTM

TerraVision™ II, SRI International, USA -- At SRI, a research group has pioneered the development of TerraVision, a distributed, interactive terrain visualization system which allows users to navigate, in real time, through a 3-D graphical representation of a real landscape created from elevation data and aerial images of that landscape. TerraVision is optimized to browse very large datasets, in the order of terabytes, distributed over multiple servers across the Web. Data are supported in 3-D VRML and GeoVRML. The software is web-enabled via a browser plug-in, and it is available as shareware. A visual demonstration of the system was used to advance the Digital Earth concept at the White House. http://www.tvgeo.com/overview.shtml

Floating Ring: A New Tool for Visualizing Distortion in Map Projections, Santa Cruz Laboratory for Visualization and Graphics, UC Santa Cruz, USA -- At the University of California, Santa Cruz, research has produced an interactive tool for the visual exploration of the distortion associated with map projections. Called "the floating ring", the method involves a software tool that allows the specification of the size and coloration of a ring on the globe that is shown, with its distortions in 3-D on the map. Executables for several different platforms are available in an on-line paper that includes examples of the images and the types of interaction supported.
http://www.cse.ucsc.edu/research/slvg/map.html

GeoVISTA Studio, Department of Geography, Penn State University, USA -- GeoVISTA Studio is an open software development environment developed within the GeoVISTA center at Penn State. The main aim of the studio is to provide a programming-free environment within which to conduct both geocomputation and geographic visualization http://www.geovista.psu.edu/publications/geocomp2000/FinalStudioPaper.pdf). Studio employs a visual programming interface, allowing users to quickly build their own applications using a workflow or dataflow paradigm. http://www.geovista.psu.edu/products/studio/index.htm

The following are described on the ICA "Projects" homepage http://www.geovista.psu.edu/icavis/projects.html).

GeoVISTA Center - Geographic Visualization - Science, Technology & Applications Center, Department of Geography, Penn State University, USA -- The Center is devoted to fundamental and applied scientific research on the visualization of georeferenced information, development of geographic visualization (GVis) technologies, and the application of both in science, industry, decision making, and education. The Center directs particular attention to research that links GVis with other components of geographic information science thus to the integration of many perspectives on geographic representation. http://www.geovista.psu.edu/

Commission collaboration with the Association for Computing Machinery Special Interest Group on Graphics (ACM-SIGGRAPH) -- In June 1996, a cross-organizational collaboration between the activities of the Association for Computing Machinery's Special Interest Group on Graphics (ACM SIGGRAPH) and the International Cartographic Association's (ICA) Commission on Visualization began. The "Carto Project" explores how viewpoints and techniques from the computer graphics and cartographic communities can be effectively integrated in the context of computer graphics applied to spatial data sets. http://www.geovista.psu.edu/icavis/icavis/vis-acm.html

Reliability Visualization (RVIS), Department of Geography, Penn State University, USA -- This project focuses on development of exploratory spatial data analysis methods for depicting data and data reliability associated with changes in the health of the Chesapeake Bay. In addition, attention is given to design of interactive interfaces that make implementation of these methods possible. http://www.geog.psu.edu/Howard/HowardHTML/RVIS.html

Argus Project, Department of Geography, Leicester University, UK -- The remit for Project Argus is to promote Visualization in the Spatial Sciences. The project members have identified a matrix of visualization techniques that can be applied to a series of data types. The application of technique to data type is being demonstrated by combining diverse data sets with existing visualization software, and developing new software. The data, software and images and movies created from them constitute a Visualization Toolkit, which will provide a number of tools for visualizing spatial data for research and/or teaching purposes. http://www.mimas.ac.uk/argus/

Using Java to interact with geo-referenced VRML Department of Geography, Leicester University, UK -- Virtual reality technology is providing earth scientists and cartographers with new, exciting and interactive ways to model the world and real-life phenomena. One of the most important functions of traditional cartography is providing information about location: where the user is, where an object is located and what is at a location. This is equally, if not more, important for navigating virtual worlds and referencing information from the real world. http://www.geog.le.ac.uk/mek/usingjava.html

MANET - Extensions to Interactive Statistical Graphics for Missing Data Department of Mathematics, Universität Augsberg, Germany -- MANET is an object-oriented program designed for interactive graphical analysis of statistical data. Mainly, MANET focuses on missing values through use of interactive highlighting - how to tell something about the quality of a data set, if not knowing how many values (or which combinations) are relevant? http://www.geovista.psu.edu/icavis/projects.html

U.S. EPA Scientific Visualization Center (SVC), USA -- Information visualization is an important tool for environmental research. By representing numerical data in a visual format, information visualization allows environmental scientists and analysts to better understand the results of their research and to effectively convey those results to others. This site provides an overview of the many visualization research and application activities currently underway at the U.S. EPA. http://www.epa.gov/vislab/svc/index.html

Examining Dynamically Linked Geographic Visualization, GeoVISTA Center, Department of Geography, Penn State University, USA -- At the United States Environmental Protection Agency (US EPA), efforts are underway to integrate the agency's geographic information systems (GIS), scientific visualization (SciVis) and World Wide Web (WWW) suite of tools for comprehensive environmental decision support. One result of these efforts is the EPA Spatial Data Library System (ESDLS), which is currently accessible via the WWW. http://www.geovista.psu.edu/NoSuchPage.htm

The Apoala Project, GeoVISTA Center, Department of Geography, Penn State University, USA -- Environmental risk assessments and decision support for ecosystem management requires the integration and analysis of large volumes of data derived from both models and direct measurement of the environment. The objective of the research being initiated is to design, implement, and assess a high performance computing prototype that can cope with spatio-temporal data and multiscale analysis, specifically, a prototype Temporal Geographic Information system with integrated multivariate spatio-temporal visualization capabilities. http://www.geovista.psu.edu/grants/apoala/tour1.htm

The ArcView/XGobi/XploRe Environment: Spatial Data Analysis in a Linked Software Environment, Iowa State University, Iowa, USA -- The ArcView/XGobi/XploRe software environment closely couples three independent software packages: ArcView, a Geographic Information System (GIS), XGobi, a dynamic statistical graphics program, and XploRe, a statistical computing environment. Attribute data from point, polygon, and linear themes that are maintained within ArcView can be passed into XGobi and/or XploRe for a complete statistical analysis. One of the main features of the ArcView/XGobi/XploRe environment is linked brushing among the three software packages. Examples for the use of the ArcView/XGobi/XploRe environment include forest health data, precipitation data, and satellite imagery. http://www.public.iastate.edu/~arcview-xgobi/

CONCLUSIONS

Visualization engages, at a deeper level, the cognitive systems of the geographer. It also has the ability to present data in new ways, offering alternative perspectives, to stimulate the exploration of new hypotheses. It may be that the greatest contribution of visualization to the process of scientific thinking is liberating the brain from the fundamental activity of information retrieval and manipulation required to produce an image, thereby allowing the brain to devote its time and energy to higher levels of analysis and synthesis (Friedhoff and Benzon 1989, McCormick *et al.* 1987). To promote further advancements in geographic visualization, we need to coordinate and share perspectives among different communities of scientists and on-scientists. Finally, visualization can look cool – the appeal of a pleasing, intriguing, creative, or innovative display should not be underestimated. Visual appeal is captivating; it draws the eye and engages the brain. For some problems in Geographic Information Science, that may be the first step toward their solution!

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