ACM SIGGRAPH 2004 Course #30

Visualizing Geospatial Data

Course Organizer:

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Instructors:

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(Chair of the International Cartographic Association's
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Special Interest Group on Graphics (SIGGRAPH) Carto Project Director)

Abstract:
This course reviews concepts and highlights new directions in GeoVisualization. We review four levels of integrating geospatial data and geographic information systems (GIS) with scientific and information visualization (VIS) methods. These include:

- Rudimentary: minimal data sharing between the GIS and Vis systems
- Operational: consistency of geospatial data
- Functional: transparent communication between the GIS and Vis systems
- Merged: one comprehensive toolkit environment

We review how to apply both information and scientific visualization fundamentals to the visual display of geospatial and geoinformatics data. Distributed GeoVisualization systems that allow for collaborative synchronous and asynchronous visual exploration and analysis of geospatial data via the Web, Internet, and large-screen group-enabled displays are discussed. This includes the application of intelligent agent and spatial data mining technologies. Case study examples are shown in real time during the course.

SIGGRAPH 2004 Course #30 Notes

Visualizing Geospatial Data

Introduction:

This course encompasses a half day at SIGGRAPH 2004 and is divided into two components: a) Overview of integrating geospatial data with visualization methods and b) New Directions in Distributed GeoVisualization.

The first component of the course focuses on four levels of integrating geospatial data and geographic information systems (GIS) with scientific and information visualization (VIS) methods. These include: rudimentary: minimal data sharing between the GIS and Vis systems; operational: consistency of geospatial data; functional: transparent communication between the GIS and Vis systems; and Merged: one comprehensive toolkit environment. We provide examples of the four levels of integration. We also introduce how the visual exploration of geospatial and geoinformatics data encompasses methods from both the scientific visualization and information visualization subfields. We then show examples of GeoVRML applications developed for landscape and resource planning, visibility studies and decision making at North Carolina State University.

The second part of the tutorial focuses on distributed geovisualization, including consideration of distribution of visualization operations among components and physical locations and distribution of interaction with the visual tools among users. We review the development of highly interactive geovisualization tools that allow investigators, located at remote sites, to collaborate via the Internet. We discuss the building of user interfaces that support same- and different-place, real time decision making and crisis management using vast geospatial data resources. We highlight appropriate visual display techniques and data mining methods of geospatial data across heterogenous platforms that encompass high end servers, desktop computer, laptops, personal digital assistants, cell phones,and other devices. We then demonstrate GeoVISTA Studio, a Java, component based, open software environment developed at Pennsylvania State University and distributed through SourceForge.

We hope you enjoy participating in this course and reading these notes.

Theresa-Marie Rhyne and Alan MacEachren

Prerequisites & Who should attend this course:

This half day course is intended for scientific researchers, educators, and computer graphics specialists interested in exploring particular issues associated with handling the visual display of cartographic, geospatial and geoinformatics data. Experience in working with geospatial data is helpful as is familiarity with scientific and/or information visualization terminology.

Visualizing Geospatial Data Outline

Introduction/ Course Organization Remarks: Rhyne - 5 minutes

Topic #1: Overview of integrating geospatial data with visualization methods
(Presenter: Theresa-Marie Rhyne - Time Frame: 60 minutes)
Case Study#1: GeoVRML Applications for Landscape Planning & Visibility Studies
(Presenter: Theresa-Marie Rhyne - Time Frame: 30 minutes)

Break

Topic#2: New Directions in Distributed GeoVisualization
(Presenter: Alan MacEachren - Time Frame: 60 minutes)
Case Study#2: The GeoVISTA Studio Project
(Presenter: Alan MacEachren - Time Frame: 30 minutes)

Wrap-Up Discussion: (Rhyne & MacEachren)

Instructors' Biographical Information:

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Dr. Alan M. MacEachren is Professor of Geography and Director of the GeoVISTA Center at Pennsylvania State University. Dr. MacEachren is currently chair of the International Cartographic Association's Commission on Visualization and Virtual Environments. He is also an associate editor of Information Visualization and was a member of the 2001-2003 National Research Council Computer Science and Telecommunications Board Committee on the Intersections Between Geospatial Information and Information Technology (which published their report, IT Roadmap to a Geospatial Future, in spring 2003).

Dr. MacEachren's research foci include: geographic visualization, geocollaboration, interfaces to geospatial information technologies, human spatial cognition as it relates to individual and group use of those technologies, human-centered systems, and user-centered design. Current research is supported by the National Science Foundation, the National Institutes of Health, the National Imagery and Mapping Agency, the Advanced Research and Development Agency, and the U.S. FedStats Task Force. Dr. MacEachren is author of Some Truth with Maps (AAG, 1994) and How Maps Work: Representation, Visualization and Design (Guilford Press, 1995) as well as co-editor of several additional books and journal special issues, including Research Challenges in Geovisualization, a special issue of Cartography and Geographic Information Science, Jan. 2001, Vol. 28, No. 1.

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Theresa-Marie Rhyne is Coordinator of Special Technology Projects in Learning Technology Service at North Carolina State University. In 1996, she founded the ACM SIGGRAPH Carto Project, that explores how viewpoints and techniques from the computer graphics community can be effectively applied to cartographic and spatial data sets. The "Carto Project" is in collaboration with the International Cartographic Association's (ICA) Commission on Visualization and Virtual Environments and the GeoVRML Working Group of the Web 3D Consortium. She has lectured world-wide on geovisualization. From 1990 - 2000, she was a government contractor (initially for Unisys Corporation (1990 - 1992) and then for Lockheed Martin Technical Services (1993 - 2000)) at the United States Environmental Protection Agency's (US EPA) Scientific Visualization Center. She was the founding visualization expert at the Center. In April 2001, she began her work in Learning Technology Service at North Carolina State University. Since that time, she has aided faculty in applying geospatial, geoinformatics and bioinformatics visualization methods.

She served as a Director-at-Large on the ACM SIGGRAPH Executive Committee from 1996 - 2000 and was the ACM SIGGRAPH 1996 Panels Chair. She also has organized and lectured in courses at the annual ACM SIGGRAPH conference from 1994 - 2002. She serves on the Editorial Board of IEEE Computer Graphics & Applications (IEEE CG&A) and is editor of the Visualization Viewpoints department for IEEE CG&A. Theresa-Marie is also a senior member of IEEE. Her specialities include geovisualization, internetworked 3D computer graphics, the application of art techniques to visualization, collaborative-networked visualization, computer graphics education, and, most recently, bioinformatics visualization.

SIGGRAPH 2004 Course #30 Notes

Visualizing Geospatial Data

Topic #1: Overview of Integrating Geospatial Data with Visualization Methods

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Introduction:

This discussion provides an overview of six aspects of integrating geospatial data with visualization methods: (1) the Evolution of GIS and Visualization (Vis); (2) Integrating GIS and Vis (SciVis & InfoVis) Tools; (3) Virtual GIS and World Wide Web (Web) Developments; (4) Time Series Animations; (5) Handheld & Wireless Computing Considerations and (6) Commonplace Visualizations.

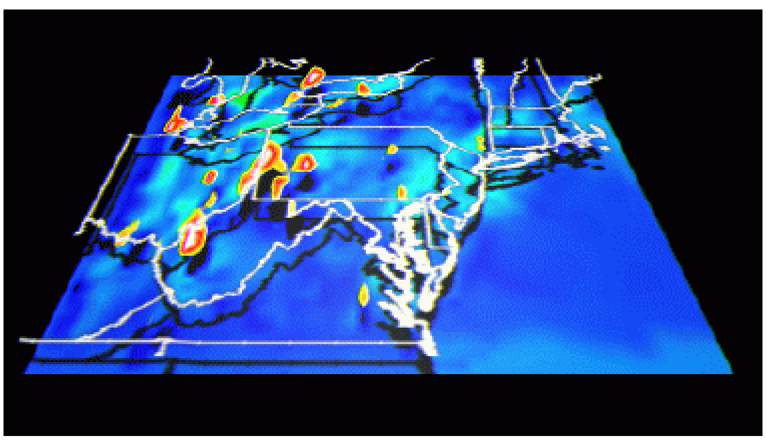


Figure #1: Typical Scientific Visualization of air pollution concentrations. Computational model data is filtered and mapped into geometric primitives. A geographic map is used to provide context for the region under study (the Northeastern part of the United States of America). This visualization was developed from 1990 - 1992 using rudimentary methods of geographic information system (GIS) and visualization (Vis) integration. These course notes will later describe the levels of GIS and Vis integration. Image created by Theresa-Marie Rhyne while working for Unisys Corporation at the United States Environmental Protection Agency (US EPA), using visualization software developed by Lee Westover while at Numerical Design, Ltd. (on a contract with Unisys Corporation in support of the US EPA).

The Evolution of GIS and Visualization (Vis):

A Geographic Information System (GIS) is frequently defined as the combination of a database management system, a set of operations for exploring data, and a graphic display system that are tied to geospatial analysis of data. GIS environments are also cartographic tools that facilitate building maps in real time and examining the impacts of changes to the map interactively.

Scientific visualization (SciVis) converts numerical or symbolic data and information into geometric computer generated images. It is a methodology for interpreting image data entered into a computer as well as data generated from computational models. Generally, SciVis is based on the application of techniques from the convergent fields of: computer graphics; image processing; computer vision; computer-aided design, signal processing, and user interface design. SciVis research and development has focused on issues pertaining to three-dimensional computer graphics rendering, time series animation, and interactive (in real time) displays via computers.

In the late 1980's and early 1990's, both of these disciplines evolved in parallel to each other. Efforts to develop geospatial data standards rarely included how to visualize the data. Computer graphics rendering libraries and standards evolved independently of geospatial data models. This resulted in inefficiencies associated with geovisualization. These include difficulties with registration of geospatial data within SciVis software, cumbersome productions of animation sequences within GIS environments, and perhaps more importantly, the lack of connections between the database and the visualization environment that supports display of geospatial data reliably.

Reference: Theresa Marie Rhyne, William Ivey, Loey Knapp, Peter Kochevar, and Tom Mace, "Visualization and Geographic Information System integration: what are the needs and the requirements, if any??", in Proceedings of the IEEE Computer Society Visualization 94 Conference, October 17 - 21, 1994, Washington, DC, IEEE Computer Society Press, Los Alamitos, California, 1994, pp. 400-403.

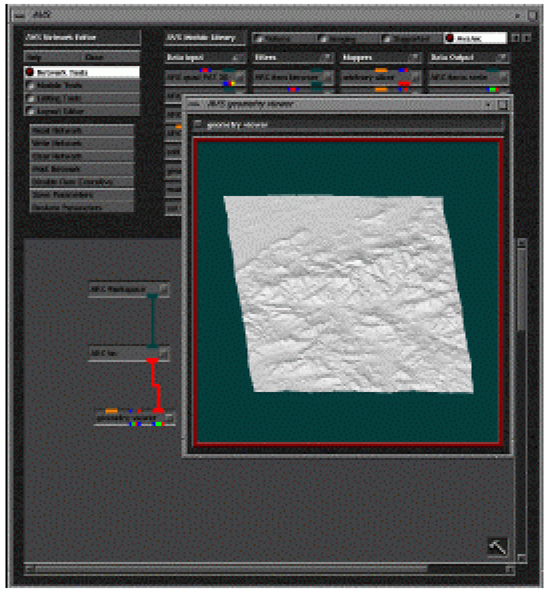


Figure #2: Early attempt at integrating GIS (ArcInfo) environments with SciVis (AVS) tools. We depict here a simple AVS network for importing ARC TIN files. Image produced in 1996 and created by Theresa-Marie Rhyne and Thomas Fowler while working for Lockheed Martin Technical Services at the United States Environmental Protection Agency (US EPA)'s Scientific Visualization Center.

As Information Visualization (InfoVis) evolved and matured in the mid to late 1990's, geographers and cartographers began to actively participate in this new arena of visualization. InfoVis tends to focus on examining visual metaphors of non-inherently spatial data such as text, hierarchies, and statistical elements. Cartographic methods were and continue to be applied to depict non-inherently spatial data.

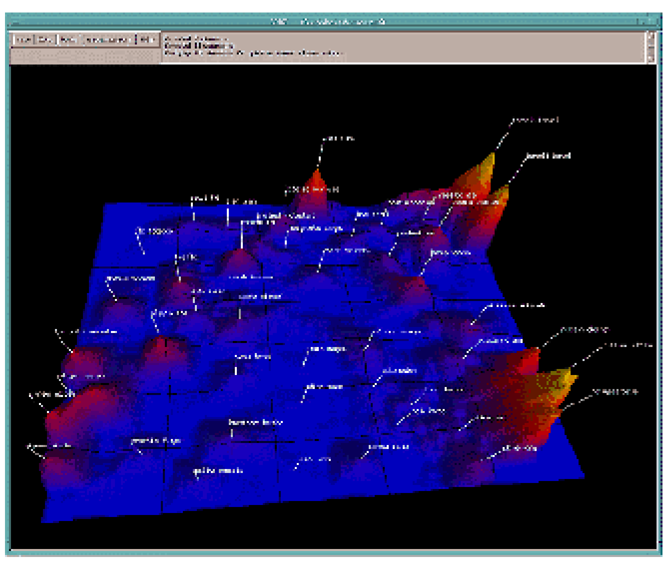


Figure #3a: Information Visualization of topics or themes within a set of documents depicted as a relief map of natural terrain. This visualization concept, entitled

ThemeView, was developed at Pacific Northwest National Laboratory as part of the SPIRE - Spatial Paradigm for Information Retrieval and Exploration - tool, (http://www.pnl.gov/infoviz/spire/spire.html). Image shown courtesy of Pacific Northwest National Laboratory which is managed and operated by the Battelle Memorial Institute on behalf of the United States Department of Energy.

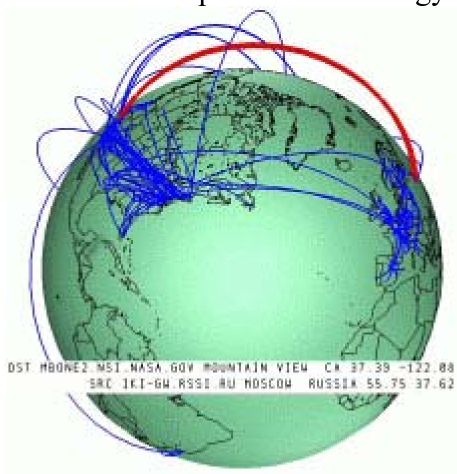


Figure #3b: Information visualization of Multicast Backbone Internet traffic using a 3D globe to represent the data. This visualization is part of the CAIDA toolset for network drawing that was written by Tamara Munzner and Eric Hoffman. See: (http://www-graphics.stanford.edu/papers/mbone/). Image shown courtesy of Tamara Munzner, currently at the Department of Computer Science, University of British Columbia.

At the same time, focus groups were formed to examine specific issues relating to visualizing geospatial data. The International Cartographic Association (ICA) formed the ICA Commission on Visualization in 1995 to address core research issues associated with extending cartographic methods into the visualization arenas. In 1999, the commission was renamed to the ICA Commission on Visualization and Virtual Environments, (http://www.geovista.psu.edu/sites/icavis/). In 1996, the Association for Computer Machinery's Special Interest Group on Graphics (ACM SIGGRAPH)'s Carto Project was formed to examine how viewpoints and techniques from the computer graphics community can be effectively applied to cartographic and spatial data sets, (http://www.siggraph.org/~rhyne/carto/). In 1998, the GeoVRML Working Group of the Web3D Consortium was formed to develop tools and recommended practices for the representation of geographical data using the Virtual Reality Modeling Language, (http://www.geovrml.org/). VRML and GeoVRML will be highlighted in later sections of these course notes. These three groups have collaborated together over the last six or more years to examine methods for visualizing geo-referenced and geospatial data.

In the 2000's, geovisualization has emerged as its own unique subfield with its own research challenges and agenda. Four major aspects of geovisualization include: (a) representation of geospatial information; (b) integration of computational and visual geographic methods; (c) creation of effective interface designs for geovisualization tools; and (d) the study of the usability of geovisualization environments. In January 2001, the International Cartographic Association's Commission on Visualization & Virtual Environments published a geovisualization research agenda in the journal of Cartography and Information Science. These efforts involved collaboration with the ACM SIGGRAPH Carto Project.

Reference: Research Challenges in Geovisualization, Cartography and Geographic Information Science, vol. 28, January 2001, (A. M. MacEachren and M.-J. Kraak, editors), see Guest editors introduction, pp. 3 – 12.

Integrating GIS and Vis (SciVis & InfoVis) Tools:

In the late 1990's and continuing into the 2000's, strides were made to integrate GIS and Vis tools. GIS developers have explored how to incorporate three-dimensional and time series animation capabilities into their software. For example, in the late 1990's, ESRI introduced ArcView 3D Analyst to allow for visualizing surface data and three dimensional modeling. Today, ArcGIS 3D Analyst is integrated into the ArcGIS suite of tools, (http://www.esri.com/software/arcgis/arcgisxtensions/3danalyst/index.html). Meanwhile, SciVis and InfoVis programmers built data readers that support geospatial data formats. As an example, Advanced Visual Systems (AVS), in the late 1990's, developed an AVS-Arc data reader that allowed for direct operational import of ESRI's Arc-Info data into the AVS visualization environment. Today, GIS import and database interaction are incorporated into AVS/Express Professional Edition, (http://www.avs.com/software/soft_t/specs.html#XPV).

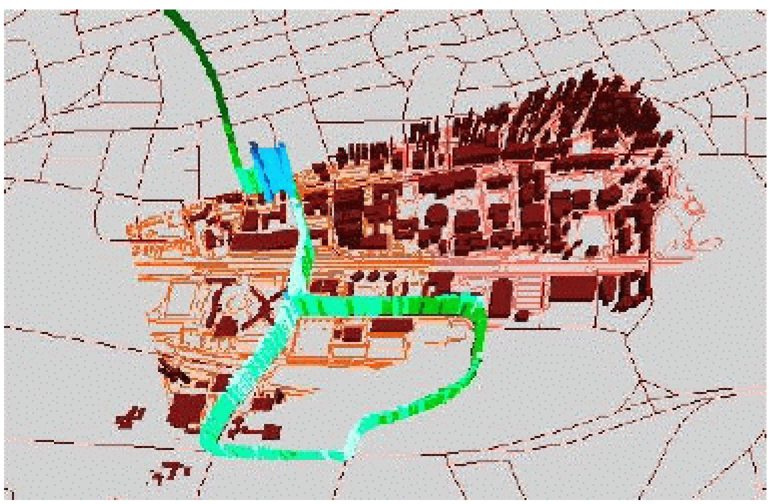


Figure #4: Image of a virtual community with air pollution (Ozone) tracking data, built with ArcView 3D Analyst in 1999. This work was done as part of a "Human Exposure in Urban Environments" project for the United States Environmental Protection Agency (US EPA) - Alan Huber, principal investigator. Image created by Theresa-Marie Rhyne while working for Lockheed Martin Technical Services at the US EPA Scientific Visualization Center.Richard Greene and Dick Dulaney (GIS - Arc/Info & ArcView experts) of the Lockheed Martin Remote Sensing Team, Bettina Brinkley (EPA-ETSD

Intern with a Geography background), and Robert Lin of the Lockheed Martin - US EPA Sci. Vis. Center team provided technical input for the execution of this visualization.

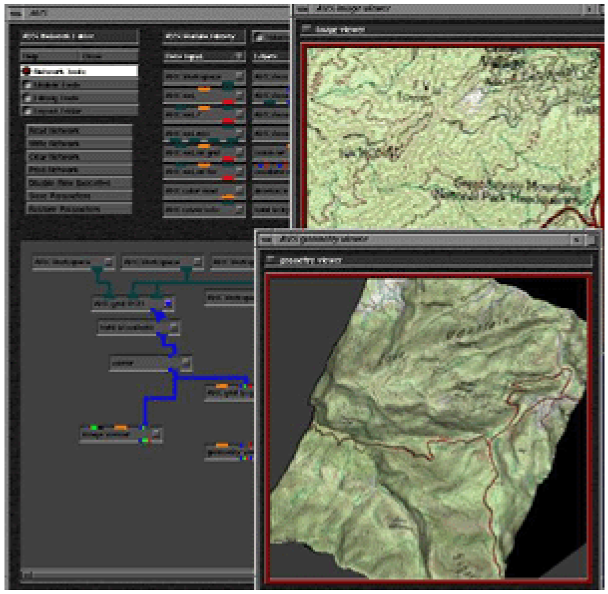


Figure #5: Three-dimensional texture image of a USGS 100K series topographic map shown in the AVS-ARC system with the two dimensional map shown in another background window. Research conducted by Theresa-Marie Rhyne and Thomas Fowler while working for Lockheed Martin Technical Services at the US EPA Scientific Visualization Center in 1995.

In examining such efforts, four levels of GIS and Vis integration can be defined:

- Rudimentary: minimal data sharing between the GIS and Vis systems
- Operational: consistency of geospatial data
- Functional: transparent communication between the GIS and Vis systems
- Merged: one comprehensive toolkit environment

AVS/Express Professional Edition provides rudimentary and operational GIS and Vis integration. Today's version of ArcGIS 3D Analyst provides functional integration between the GIS and Vis components of the ArcGIS environment. Many InfoVis tools, while often incorporating only two dimensional (2) visual displays, have succeeded at approaching merged GIS and Vis integration. In the computer games arena, real-time terrain engines are designed to address rudimentary integration.

Virtual GIS and World Wide Web (Web) Developments:

The introduction of the Virtual Reality Modeling Language (VRML) in 1984 provided for interactive three dimensional (3D) representation of content on the World Wide Web, (http://www.web3d.org/x3d/spec/vrml/VRML1.0/index.html). After three or more years of community effort, VRML 97 was approved by the International Organization for Standardization (ISO) and the IEC (the International Electrotechnical Commission) as an open file format for describing three-dimensional (3D) objects and worlds via the Internet. Information on VRML 97 can be found at: (http://www.web3d.org/x3d/spec/vrml/vrml97/index.htm). During the same time frame of the development of this standard, the VRML Consortium was formed to foster the continued development VRML. The VRML Consortium was charted in early 1997 and changed its name to the Web3D Consortium in December 1998 to address the standardization of multiple technologies associated with 3D on the Internet, (www.web3d.org).

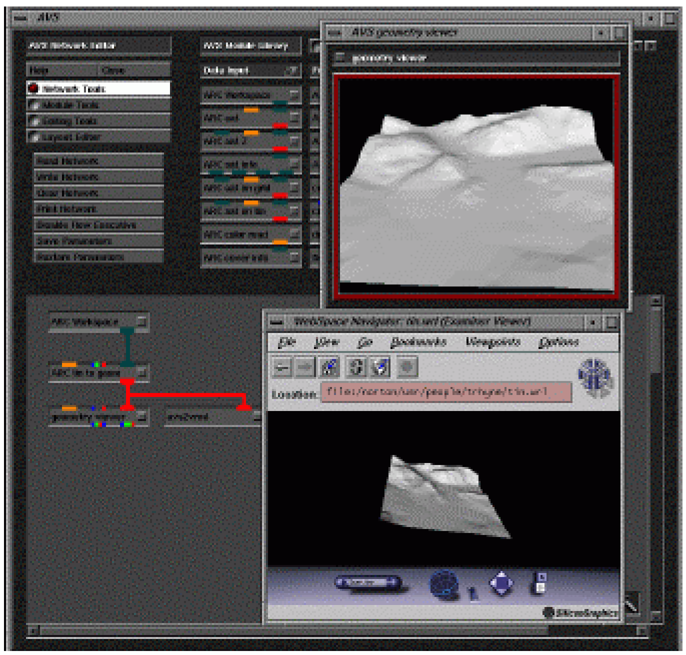


Figure #6: Early example of a VRML 1.0 file created with an (AVS to VRML 1.0) Module. The AVS module was developed by John Evans and Richard Signell at the U.S. Geological Survey. At the U.S. EPA Scientific Visualization Center, we then combined the (AVS to VRML 1.0) module with our AVS-ARC networks. This allowed us to pipe geospatial data directly from a GIS environment into a visualization system and output to the VRML 1.0 format. Research conducted by Theresa-Marie Rhyne and Thomas Fowler while working for Lockheed Martin Technical Services at the US EPA Scientific Visualization Center in mid-1996.

As noted in the previous section of this writeup, the GeoVRML Working Group of the Web3D Consortium was chartered in February 1998 to facilitate the viewing of geo-referenced data, like maps and 3D terrain models, over the Web via VRML plugins for Web browsers. By 2000, this resulted in the production of a specification and open source code, entitled GeoVRML, for representing and visualizing geographic data using VRML 97, (http://www.geovrml.org/1.0/).

Reference: M. Reddy, L. Iverson, and Y. G. Leclerc (2000). "Under the Hood of GeoVRML 1.0". In Proceedings of The Fifth Web3D/VRML Symposium. Monterey, California. February 21-24, 2000. (http://www.ai.sri.com/~reddy/pubs/pdf/vrml2000.pdf).

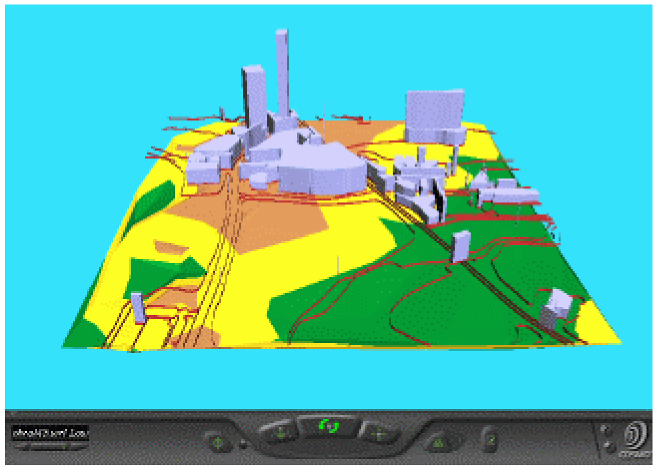


Figure #7: Snapshot of a GeoVRML visualization. The original geovisualization was created with ArcView 3D Analyst in 1998, exported to VRML97 format, and enhanced with GeoVRML techniques in 1999 and 2000. This visualization was developed for the US EPA's Human Exposure in Urban Environments Project - Alan Huber, principal investigator. Image created by Theresa-Marie Rhyne while working for Lockheed Martin Technical Services at the US EPA Scientific Visualization Center.

In 2001, the next generation VRML standard was introduced and entitled Extensible 3D (X3D), (http://www.web3d.org/x3d/spec/ISO-IEC-19775/index.html). X3D was designed to improve upon VRML with new features, advanced application programmer interfaces, additional data encoding formats, stricter conformance, and a component architecture that facilitates a modular approach to supporting the X3D standard. GeoVRML functions were incorporated into the Geospatial profile of X3D with the intent of providing accurate placement and rendering of objects in a 3D Geospatial context. A tutorial on the Geospatial profile of X3D was presented at the Web3D 2004 Symposium (April 2004) by Mike McCann, (http://www.web3d.org/s2004/tutorials.html#Geo).

GeoVRML functions have also been included in OpenGIS Consortium (OGC) discussions regarding Web Services for geospatial data. The OGC is a non-profit member-driven organization aimed at fostering the development of geoprocessing interoperability computing standards, (http://www.opengis.org). Research is currently underway in the OGC regarding missing interoperability functions of three dimensional geovisualization components.

Reference: Angela Altmaier and Thomas H. Kolbe, "Applications and Solutions for Interoperable 3d Geo-Visualization", Proceedings of the Photogrammetric Week 2003 in Stuttgart, Wichmann Verlag (D. Frissch, editor), (http://www.ikg.uni-bonn.de/kolbe/publications/Altmaier_und_Kolbe_PhoWo2003.pdf).

Time Series Animations:

Traditional GIS environments frequently have not incorporated tools for building time series animations. As a result, other tools like Quicktime and Flash are often used to create the animations from the GIS imagery. For example, using ArcGIS 3D Analyst, each frame of a 24 time step sequence can be stored as a JPEG image. Using the Layout editor, metadata elements like notations of each individual time step, a map legend and titles for the animation sequence can be added to each JPEG image. All 24 frames are then be assembled into a Quicktime or Flash movie for viewing on the Web across the Internet. More complex "rich media" presentations that include audio narrations can be developed using streaming media technologies like the Synchronized Multimedia Integration Language (SMIL), (http://www.w3.org/AudioVideo/).

Reference: Ian Johnson and Andres Wilson, "The TimeMap Project: Developing Time-Based GIS Display for Cultural Data", Journal of GIS in Archaeology, Vol. 1, ESRI Inc., Redlands, California, 2002,
(http://www.esri.com/library/journals/archaeology/volume_1/time_based_display.pdf),
Or:
(http://www.timemap.net/documents/publications/2000_j_gis_arch_esri/timemap_article/index.html) .

Reference: Theresa- Marie Rhyne, Web Horizons for Geographic Visualization, Geoinformatics, December 2000, pp. 35-37.

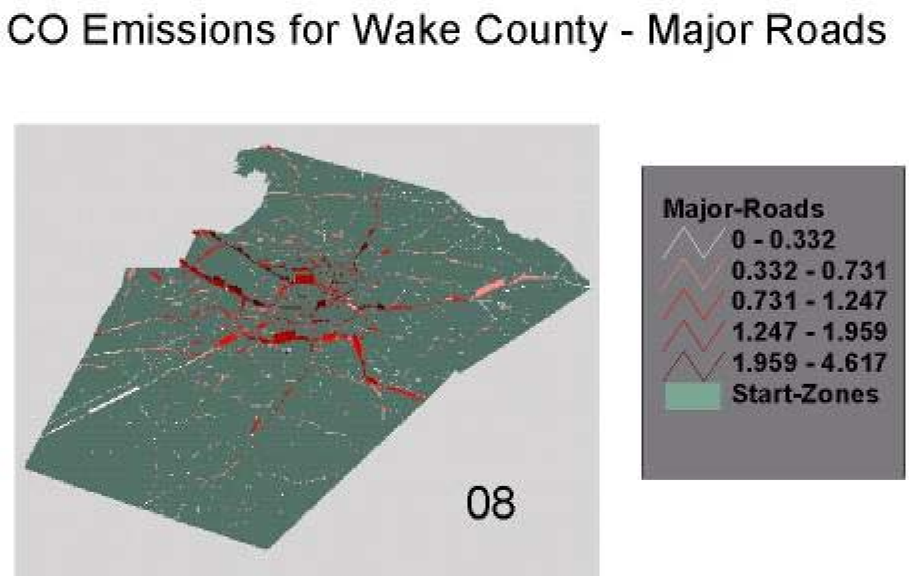


Figure #8: Image from a 24 time step QuickTime movie animation sequence of a Mobile Emissions computational model for the Wake County, North Carolina (USA) area. Each individual frame was created in ArcView 3D Analyst and assembled into a QuickTime movie in 1999 and 2000. This work was done as part of the Mobile Emissions Characterization Visualization Project for the United States Environmental Protection Agency (US EPA) - Sue Kimbrough, principal investigator. Image created by Theresa-Marie Rhyne while working for Lockheed Martin Technical Services at the US EPA Scientific Visualization Center.

Handheld & Wireless Computing Considerations:

Global positioning systems (GPS) are currently available on mobile, handheld platforms such as personal digital assistants (PDAs) and Cellular phones. Other cartography and mapping applications have also been ported to these small screen devices. There has also been success in porting VRML and GeoVRML to handheld devices. Pocket Cortona, from Parallel Graphics, allows for viewing VRML scenes on wireless devices such as the PocketPC, (http://www.parallelgraphics.com/products/cortonace/). As a result, GeoVRML applications can also be ported to wireless handheld devices.

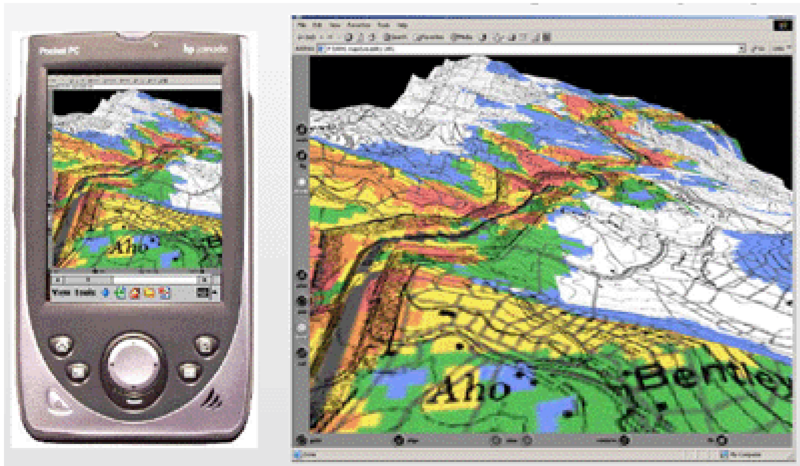


Figure #9: Original visualization by Michael Holmes, Dr. John Fels and James Tomlinson of North Carolina (NC) State University's College of Design. Enhanced GeoVRML Visualization by Theresa-Marie Rhyne, NC State University – Learning Technology Service (circa 2002/2003).

Commonplace Visualizations:

The recent dominance of computer games in the entertainment arena has resulted in significant impacts on the evolution of computer graphics hardware, software, image rendering, and virtual reality. This has also increased the use of commodity graphics boards in high-end scientific applications like visualization. Yielding the realization that scientifically reliable visualizations will likely be eventually performed on computer game consoles as well as wireless PDAs and cell phones. This is also true for geovisualization and the resulting visualization of geospatial data.

Reference: Theresa-Marie Rhyne, "Computer Games and Scientific Visualization", Communications of the Association for Computing Machinery (CACM), Vol. 45, No. 7, July 2002, pp. 40 – 44.

Figure #10: Visualization of a virtual community shown on a mobile cell phone. Image shown courtesy of Lars Bishop and David Holmes of Numerical Design Limited, (http://www.ndl.com).

Computer games developers have long used terrain databases, publicly available from the United States Geological Survey (http://library.usgs.gov/), as starting points for terrain modeling of scenes. Urban Planners have realized the advantages of developing community involvement activities that include interactive elements derived from popular computer games like SimCity (http://simcity.ea.com/) and The Sims (http://thesims.ea.com/). As a result, we are approaching a juncture where the software for creating 3D geovisualizations and Web access to geospatial repositories will be widely available online to the general public. This will result in commonplace interactive visualizations created by general users of desktop computers. We can see these activities starting to take place in arenas such as traffic planning and engineering.

Figure #11: Typcial traffic visualization example. Image shown courtesy of North Carolina Department of Transportation, (image created by Chris Parker). For more information on this project, see: (http://www.ncdot.org/projects/Superstreet/).

It will be the task of geovisiualization professionals to champion the integrity, reliability and usability of online visualization methods for geospatial data. This involves inter and intra disciplinary collaborations with colleagues in computer graphics, cartography, geographic information systems, telecommunications infrastructure, mobile computing, distance education, computer games and many other application disciplines.

Acknowledgements:

We thank Alan Huber and Sue Kimbrough at the United States Environmental Protection Agency (U.S. EPA) for providing projects that tested the early limits of geographic visualization as well as Thomas Fowler for several years of collaborative work at the U.S. EPA Scientific Visualization Center. James Tomlinson, Michael Holmes, and John Fels provided unique geovisualization and geovrml applications from North Carolina State University (NCSU)'s College of Design. Pak Wong, Kristin Cook, and David R. Cook of Battelle Memorial Institute at Pacific Northwest National Laboratory provided input regarding ThemeView and other information visualization techniques. Tamara Munzner, currently at at the Department of Computer Science, University of British Columbia, also provide insight on information visualization and network drawing approaches that apply cartographic methods. Lars Bishop and David Holmes of Numerical Design Limited contributed approaches to the use of geovisualization in computer games applications and on handheld devices. Chris Parker and James H. Dunlop from the North Carolina Department of Transportation provided input on the development of common place visualization for highway and local traffic design. Additional thanks to Alan MacEachren, Pennsylvania State University, for collaborating with me on this "Visiualizing Geospatial Data" course at SIGGRAPH 2004 and to the SIGGRAPH 2004 Courses Committee (Jacquelyn Martino, Chair) for selecting our course proposal.

Summary of References:

Theresa Marie Rhyne, William Ivey, Loey Knapp, Peter Kochevar, and Tom Mace, "Visualization and Geographic Information System integration: what are the needs and the requirements, if any??", in Proceedings of the IEEE Computer Society Visualization 94 Conference, October 17 - 21, 1994, Washington, DC, IEEE Computer Society Press, Los Alamitos, California, 1994, pp. 400-403

Research Challenges in Geovisualization, Cartography and Geographic Information Science, vol. 28, January 2001, (A. M. MacEachren and M.-J. Kraak, editors), see Guest editors introduction, pp. 3 – 12.

M. Reddy, L. Iverson, and Y. G. Leclerc (2000). "Under the Hood of GeoVRML 1.0". In Proceedings of The Fifth Web3D/VRML Symposium. Monterey, California. February 21-24, 2000. (http://www.ai.sri.com/~reddy/pubs/pdf/vrml2000.pdf).

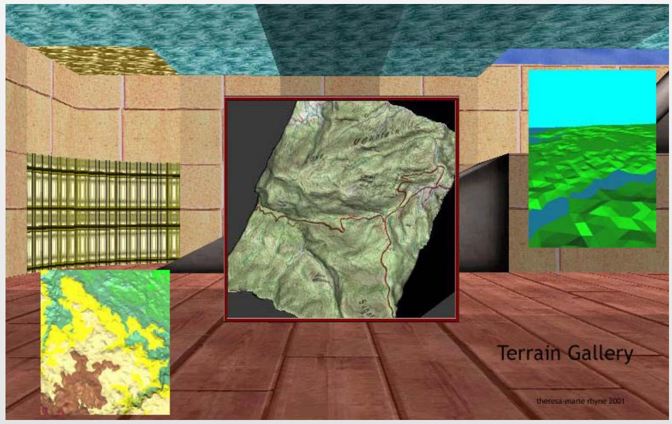
Angela Altmaier and Thomas H. Kolbe, "Applications and Solutions for Interoperable 3d Geo-Visualization", Proceedings of the Photogrammetric Week 2003 in Stuttgart, Wichmann Verlag (D. Frissch, editor), (http://www.ikg.uni-bonn.de/kolbe/publications/Altmaier_und_Kolbe_PhoWo2003.pdf).

Ian Johnson and Andres Wilson, "The TimeMap Project: Developing Time-Based GIS Display for Cultural Data", Journal of GIS in Archaeology, Vol. 1, ESRI Inc., Redlands, California, 2002,
(http://www.esri.com/library/journals/archaeology/volume_1/time_based_display.pdf),
Or
(http://www.timemap.net/documents/publications/2000_j_gis_arch_esri/timemap_article/index.html) .

Theresa- Marie Rhyne, Web Horizons for Geographic Visualization, Geoinformatics, December 2000, pp. 35-37.

Theresa-Marie Rhyne, "Computer Games and Scientific Visualization", Communications of the Association for Computing Machinery (CACM), Vol. 45, No. 7, July 2002, pp. 40 – 44.

Overview of Integrating Geospatial Data with Visualization Methods



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We review six aspects:

- the Evolution of GIS & Visualization
- Integrating GIS & Vis (SciVis & InfoVis) Tools
- Virtual GIS & Web Developments
- Time Series Animations
- Handheld & Wireless Computing Considerations
- Commonplace Visualizations

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Classic Scientific Visualization of an Air Pollution Model with GIS/Mapping Data :

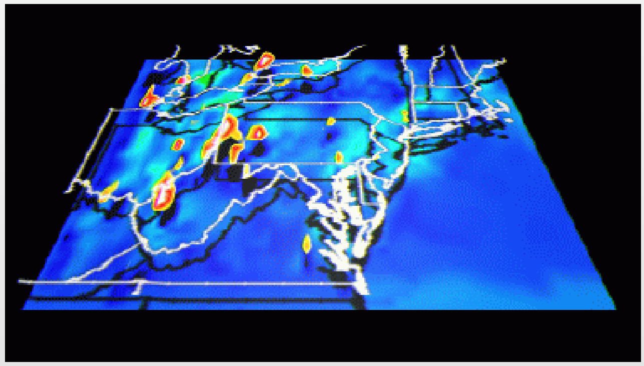

Image created in 1990/1991 at the United States Environmental Protection Agency's Scientific Visualization Center by Theresa-Marie Rhyne while working for Unisys Corporation using software developed by Numerical Design Limited.

Defining a Geographic Information System (GIS):

The combination of

- **a database management system**
- **a set of operations for exploring data**
- **a graphic display system**

Tied to geospatial analysis of data.

Scientific Visualization (SciVis)

converts numerical data into geometric computer generated images:

SciVis Research & Development has focused on

- **3D Computer Graphics Rendering**
- **Time Series Animation**
- **Interactive displays via computers**

In the late 1980's & early 1990's,

GIS & SciVis disciplines evolved in parallel:

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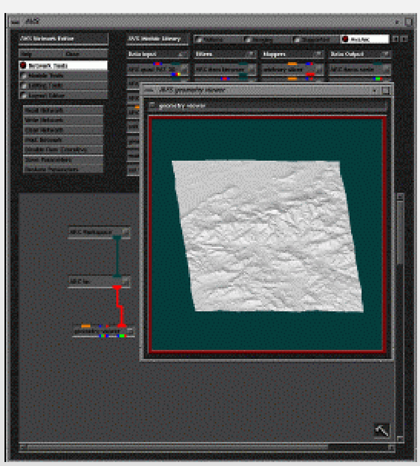
Yielding inefficiences associated with geovisualization:

- Difficulties with registration of geospatial data with SciVis software.
- Cumbersome productions of animation sequences in GIS environments.
- Lack of connections between database and the visualization environment for geospatial data.

Early Attempt to Integrate GIS (ArcInfo) & SciVis (AVS) tools:



A simple AVS network for importing Arc TIN files is shown. Image produced in 1996 by Theresa-Marie Rhyne and Thomas Fowler while working for Lockheed Martin Technical Services as the United States Environmental Protection Agency (US EPA)'s Scientific Visualization Center.

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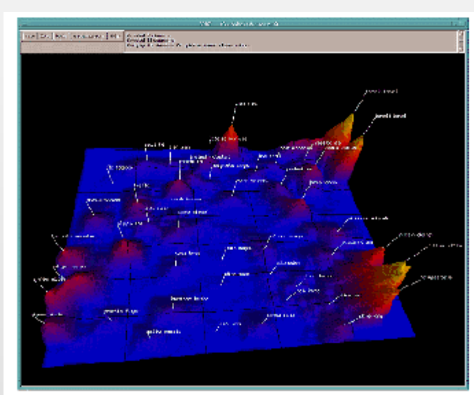
As Information Visualization (InfoVis)

evolved & matured in the mid to late 1990's,

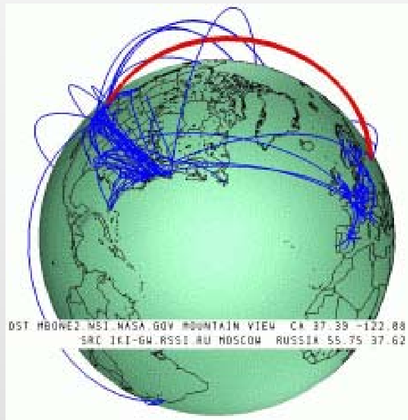
Frequently cartographic methods were applied to non-inherently spatial data.

Information Visualization of topics or themes within a set of documents:



Shown as a relief map of natural terrain, this visualization concept, entitled ThemeView, was developed at Pacific Northwest National Laboratory as part of the SPIRE - Spatial Paradigm for Information Retrieval and Exploration – tool. Image shown courtesy of Pacific Northwest National Laboratory which is managed and operated by the Battelle Memorial Institute on behalf of the United States Department of Energy. (http://www.pnl.gov/infoviz/spire/spire.html

Information Visualization of Multicast Backbone Internet Traffic:



Using a 3D globe to represent the date, this visualization is part of the CAIDA toolset for network drawing that was written by Tamara Munzner and Eric Hoffman. See: (http://www-graphics.stanford.edu/papers/mbone/). Image shown courtesy of Tamara Munzner, currently at the Department of Computer Science, University of British Columbia.

Also in mid & late 1990's focus groups formed:

• International Cartographic Association's (ICA) Commission on Visualization in 1995,

changed to ICA Commission on Visualization & Virtual Environments in 1999.

(http://www.geovista.psu.edu/sites/icavis/)

• ACM SIGGRAPH Carto Project in 1996

(http://www.siggraph.org/~rhyne/carto/)

• GeoVRML Working Group of the Web3D Consortium 1998

(http://www.geovrml.org/)

Over the last six or more years, these focus groups have collaborated together.

Here at SIGGRAPH 2004:

ACM SIGGRAPH Carto BOF

Wendesday, 12:30 – 1:30 PM

Four Levels of GIS and Vis Integration can be defined:

- Rudimentary: minimal data sharing between the GIS and Vis systems.
- Operational: consistency of geospatial data.
- Functional: transparent communication between the GIS and Vis systems.
- Merged: one comprehensive toolkit environment

Example of a GIS with 3D Vis Capabilities:

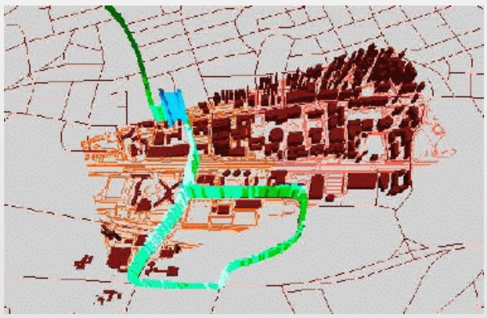


Image of a virtual community with air pollution (Ozone) tracking data, built with ArcView 3D Analyst in 1999. This work was done as part of a "Human Exposure in Urban Environments" project for the United States Environmental Protection Agency (US EPA) - Alan Huber, principal investigator. Image created by Theresa-Marie Rhyne while working for Lockheed Martin Technical Services at the US EPA Scientific Visualization Center.

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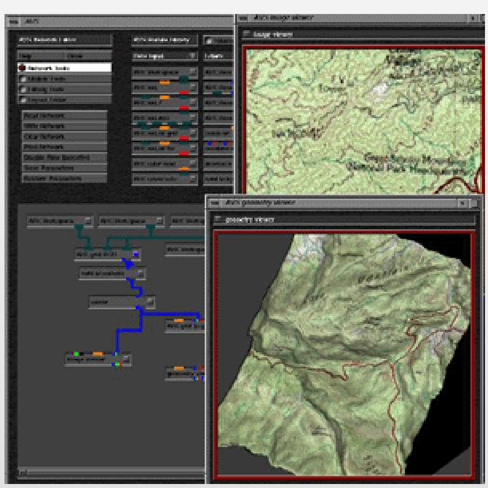
Example of a Vis system that is integrated with a Geospatial database:



Three-dimensional texture image of a USGS 100K series topographic map shown in the AVS-ARC system with the two dimensional map shown in another background window. Research conducted by Theresa-Marie Rhyne and Thomas Fowler while working for Lockheed Martin Technical Services at the US EPA Scientific Visualization Center in 1995.

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GeoVRML Developments:

• Introduction of the Virtual Reality Modeling Language (VRML) in 1984.

• VRML97 ISO/IEC Standard released in 1997.

• VRML Consortium chartered in 1997, name changed to Web3D Consortium in 1998.

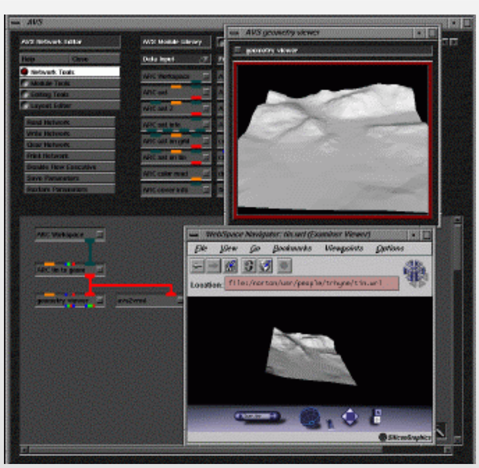
• GeoVRML Working Group of the Web3D Consortium formed in 1998.

• Open Source GeoVRML tools released in 2000.

• GeoVRML integrated with X3D in 2001.

• OpenGIS Consortium examining GeoVRML presently.

Early example of a VRML 1.0 file created with an (AVS to VRML 1.0) Module:



The (AVS to VRML 1.0) module was developed by John Evans and Richard Signell at the U.S. Geological Survey. At the U.S. EPA Scientific Visualization Center, we then combined the module with our AVS-ARC networks. This allowed us to pipe geospatial data directly from a GIS environment into a visualization system and output to the VRML 1.0 format. Research conducted by Theresa-Marie Rhyne and Thomas Fowler while working for Lockheed Martin Technical Services at the US EPA Scientific Visualization Center in mid-1996.

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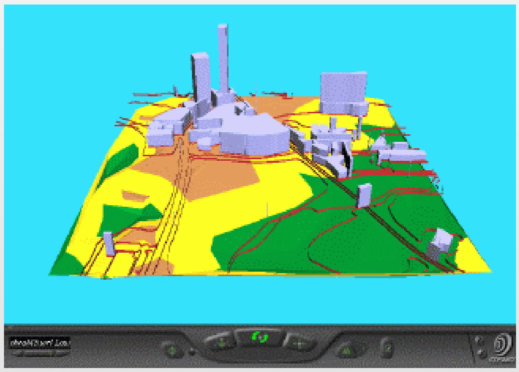
Snapshot of a GeoVRML Visualization:



The original geovisualization was created with ArcView 3D Analyst in 1998, exported to VRML97 format, and enhanced with GeoVRML techniques in 1999 and 2000. This visualization was developed for the US EPA's Human Exposure in Urban Environments Project - Alan Huber, principal investigator. Image created by Theresa-Marie Rhyne while working for Lockheed Martin Technical Services at the US EPA Scientific Visualization Center.

GIS Time Series Animations using brute force:

- Step 1: Build Colormaps
- Step 2: Create Individual Frames
- Step 3: Add Metadata Elements
- Step 4: Join Metadata & Individual Frames
- Step 5: Assemble Quicktime (or whatever) movie

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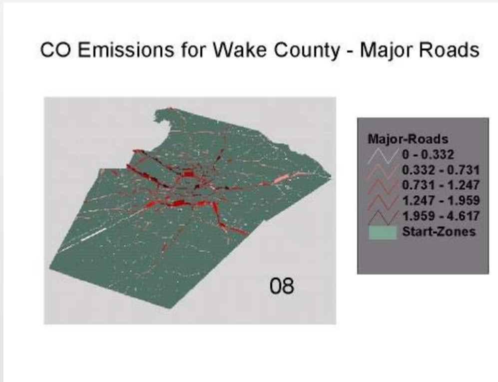
Frame from ArcView 3D Analyst Time Series Animation – in Quicktime format:



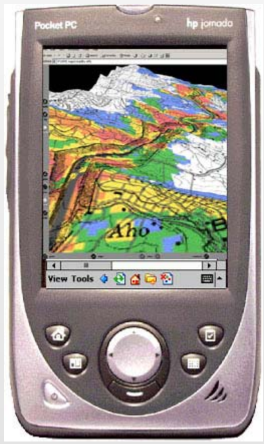
The 24 time step QuickTime movie animation sequence of a Mobile Emissions computational model for the Wake County, North Carolina (USA) area. This work was done as part of the Mobile Emissions Characterization Visualization Project for the United States Environmental Protection Agency (US EPA) - Sue Kimbrough, principal investigator. Image created by Theresa-Marie Rhyne while working for Lockheed Martin Technical Services at the US EPA Scientific Visualization Center.

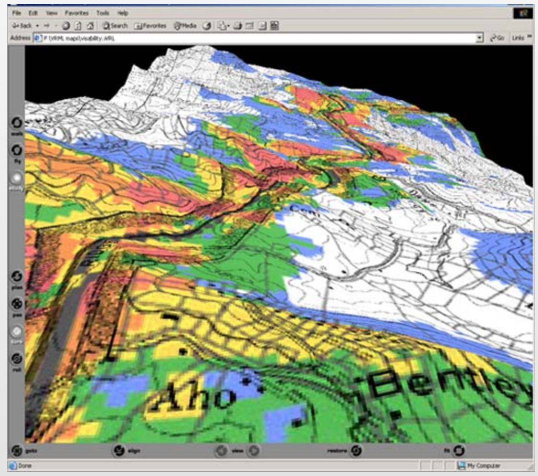
Looking ahead: GeoVisualization on handhelds

- **Assumption: Today's PocketPC is a good indicator of the power of future cell phones.**
- **Assertion: Despite a lack of 3D hardware, good 3D is possible today on PocketPCs.**
- **Virtual Reality Modeling Language (VRML) browser, Pocket Cortona from Parallel Graphics – is already here ! So, we can also consider GeoVRML on handhelds.**

www.parallelgraphics.com/products/cortonace

GeoVRML Visualization of Blue Ridge Parkway targeted for Handheld devices :





Original visualization by Michael Holmes, Dr. John Fels and James Tomlinson of NC State University's College of Design. Enhanced GeoVRML Visualization by Theresa-Marie Rhyne, NC State University – Learning Technology Service (circa 2002/2003).

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Commonplace 3D Visualizations used to enhance cell phone as a:

Web browser Email client

SMS communicator

Pocket game device

MP3 player

Video player

Camera GPS unit

Fax machine Pager

Wireless learning device

… and more….

Visualization of a virtual community shown on a mobile cell phone. Image shown courtesy of Lars Bishop and David Holmes of Numerical Design Limited, (http://www.ndl.com).

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The Future: the wide acceptance of geovisualization techniques for problems like traffic visualization

Typcial traffic visualization example. Image shown courtesy of North Carolina Department of Transportation, (image created by Chris Parker). For more information on this project, see: (http://www.ncdot.org/projects/Superstreet/).

Comments, Questions, Discussion, or additional geovisualizations?

Image by Theresa-Marie Rhyne, 2003

Special Thanks to:

Thomas Folwer, GIS Wizard.

Alan Huber and Sue Kimbrough, United States Environmental Protection Agency (US EPA).

Pak Wong, Kristin Cook, and David R. Cook of Battelle Memorial Institute at Pacific Nortwest National Laboratory

Tamara Munzner, University of British Columbia

Jay Tomlinson, NC State University College of Design.

Lars Bishop & David Holmes, Numerical Design Limited.

Chris Parker & James H. Dunlop, NC Department of Transportation.

Alan MacEachren, Pennsylvania State University

Martin Reddy, Pixar

Jacquelyn Martino, Chair & the SIGGRAPH 2004 Courses Committee

And many other colleagues and co-workers around the world who continue to be inspirations.

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SIGGRAPH 2004 Course #30 Notes

Visualizing Geospatial Data

Topic #2: New Directions in Distributed Geovisualization

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Chair, International Cartographic Association Commission on
Visualization & Virtual Environments

Introduction:

The potential for interdisciplinary research and development to result in a fundamental advance in the availability and use of geospatial information was highlighted in a recent National Research Council Report – *IT Roadmap to a Geospatial Future*[1] (Muntz et al., 2003). The interdisciplinary challenges outlined in this report were one impetus for organizing this course – to stimulate more cross-disciplinary sharing of ideas. To put my portion of the course into context, I begin with a sketch of the historical cartographic roots that my own perspectives build on.

Cartography has a tradition of visually representing the world that spans centuries. More recent is a cartographic tradition of abstract representation of selected (often non-visual) aspects of that world (called *thematic* mapping); these efforts can be traced to the middle of the 19th century (MacEachren, 1979; Robinson, 1982). The move from depicting the visual world as accurately as possible to a complementary focus on developing abstract visual representations designed to focus attention and prompt insights about specific phenomena in the world has been termed a *revolution in cartographic thought and practice* (Robinson, 1976). It seems likely that, a few decades hence, historians of cartography will look back on current developments in the *visualization of geospatial data* as another revolution for the field.

Since the mid-19th century, there have been two primary threads in cartographic research and practice: (1) a focus on capturing information about and representing the physical world (with increasing degrees of accuracy and through an increasing variety of delivery devices) and (2) a focus on developing innovative strategies for visual abstraction and

[1] This report is available electronically from: http://www7.nationalacademies.org/cstb/pub_geospatialfuture.html

information analysis that take advantage of the power of human visual to see order in complex scenes.

As detailed by Theresa-Marie Rhyne in Topic #1 (Overview of Integrating Geospatial Data with Visualization Methods), efforts have been underway since the late 1980s to link developments in computer graphics (and their application to advances in visualization) with developments in geographic information science (GIScience[2]) focusing on the collection, encoding, transformation, display, and analysis of geospatial information. These efforts to integrate developments have resulted in advances within both of the threads of cartographic research and practice mentioned above – with a strong connection between the first thread and scientific visualization (SciVis) and a similarly strong connection between the second thread and information visualization (InfoVis). See sidebars on *spatialization* for examples of Cartography-InfoVis interaction.

In the first part of the course, Theresa-Marie has provided a comprehensive overview of the first of these cross-disciplinary connections (between cartography and SciVis), with details on evolution of the ideas and applications and looks to the future. She also introduced the second set of cross-disciplinary connections (between cartography and InfoVis), with discussion of use of visual metaphors for understanding non-inherently spatial data.

In my part of the course, I will cite developments in both domains, but will emphasize the second set of connections. Specifically, I will focus on efforts to develop innovative methods for information abstraction and representation along with related methods for interacting with the information through those representations. In doing so, I will highlight some of the links between geovisualization and InfoVis.The primary focus of this part of the course, however, is not on either thread through cartographic research and practice identified above, nor on the specific links of geovisualization to SciVis or InfoVis. The focus is on new directions in *distributed geovisualization* that are enabled by progress in these and related fields. As part of the approach presented, I will also consider some of HCI issues (perceptual, cognitive, usability) that are important to consider if we are to take full advantage of advances in these complementary fields.

Distributed geovisualization[3]

Geospatial data visualization poses many challenges[4]. These include very large data volumes (e.g., satellite generated data from the Earth Observatory System produces more

---

[2] GIScience is an interdisciplinary field of research and practice that integrates perspectives on geographic information and technologies. The University Consortium for Geographic Information Science (UCGIS) lists the following contributing disciplines: cartography, cognitive science, computer science, engineering and land surveying, environmental sciences, geodetic science, geography, landscape architecture, law and public policy, remote sensing and photogrammetry, and statistics. For more information, see: http://www.ucgis.org/aboutucgis/history.htm

[3] Some of the ideas presented in this section were introduced in a recent *Computer Graphics & Applications* "Viewpoints" paper. That paper is included as a supplement to these course notes, courtesy of the IEEE.

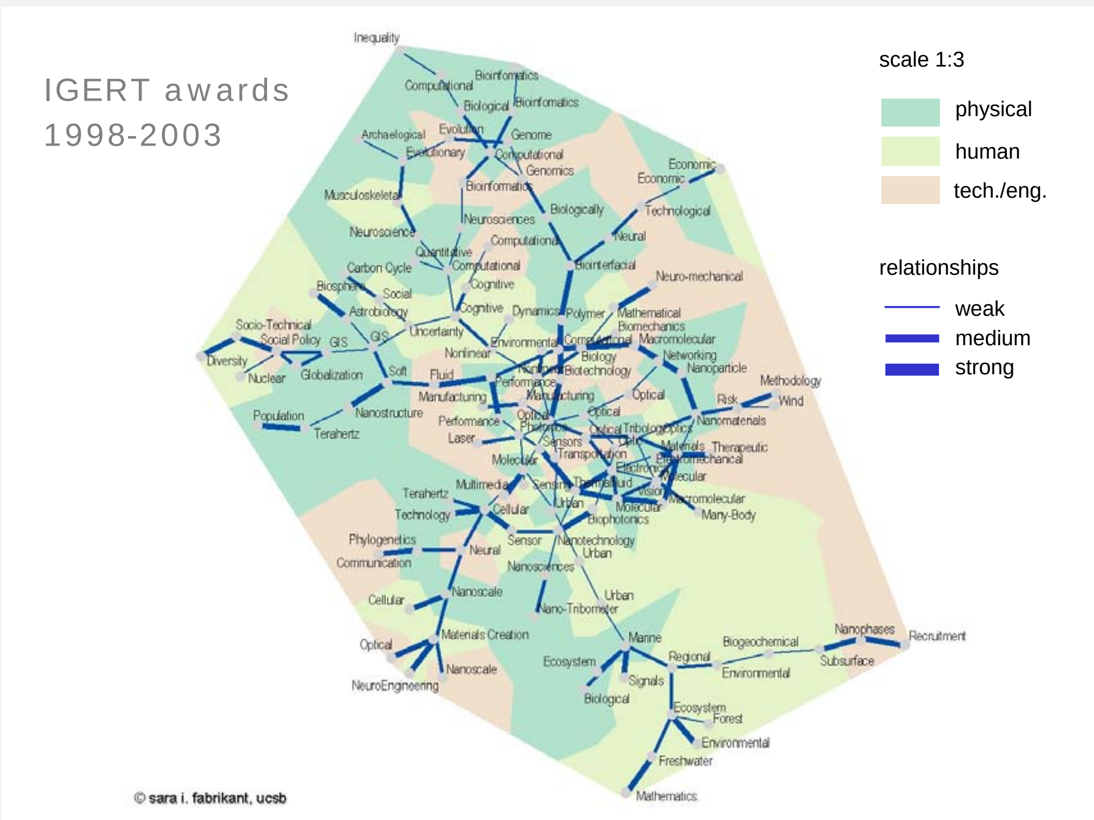
[4] For recent detailed discussion of the computer and information science challenges posed by geospatial data, see: (Muntz et al., 2003)

Spatialization – integrating cartographic and InfoVis perspectives on information landscapes

Dr. Sara Fabrikant (Geography, UCSB) and colleagues have been exploring the potential of map and landscape metaphors for depicting non-spatial information, with particular attention to understanding the assumptions about absolute and relative distance that typical users apply to interpreting these displays.

The figure below spatializes the relationships among all NSF Interdisciplinary Grants for Education, Research, and Training (IGERT). The representation is based on a computational analysis of published abstracts for the grants. Relative locations of nodes in the figure below are meaningful, absolute location/orientation is not. The closer two nodes are in space, the more similar the content of the abstracts are. Pathfinder Network Scaling of a distance matrix generates links between the nodes. Strength of relationship is based on PFNet scaling.

Constructing semantic regions: Intramax cluster analysis is carried out on the distance matrix. 2 and 3 cluster solutions are suggested in data space. This corresponds to semantic levels of details or map scale. The levels are hierarchically nested. At a scale 1:3 (three cluster level, shown here), the grants divide into those focused on the physical sciences, those focused on human science, and those focused on IT/engineering. Voronoi tesselation is calculated around each node, Voronoi boundaries are dissolved based on cluster membership, and remaining regions are color coded.



Example and figure courtesy of Sara Fabrikant

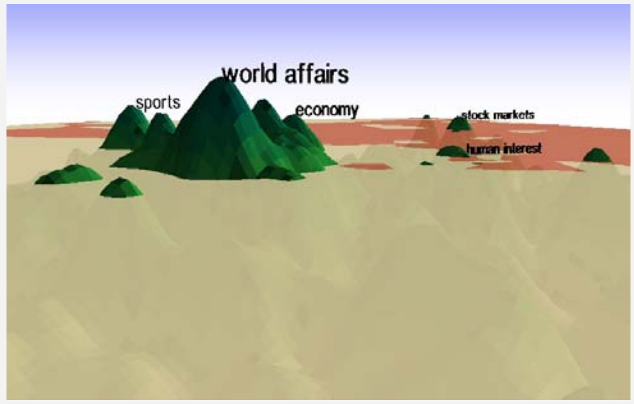
For details on empirical studies focused on human use of spatializations, see:

Fabrikant, S. I. 2001, Evaluating the Usability of the Scale Metaphor for Querying Semantic Information Spaces. Spatial Information Theory: Foundations of Geographic Information Science. Conference on Spatial Information Theory (COSIT '01), Lecture Notes in Computer Science 2205, Santa Barbara, CA, pp. 156-171.

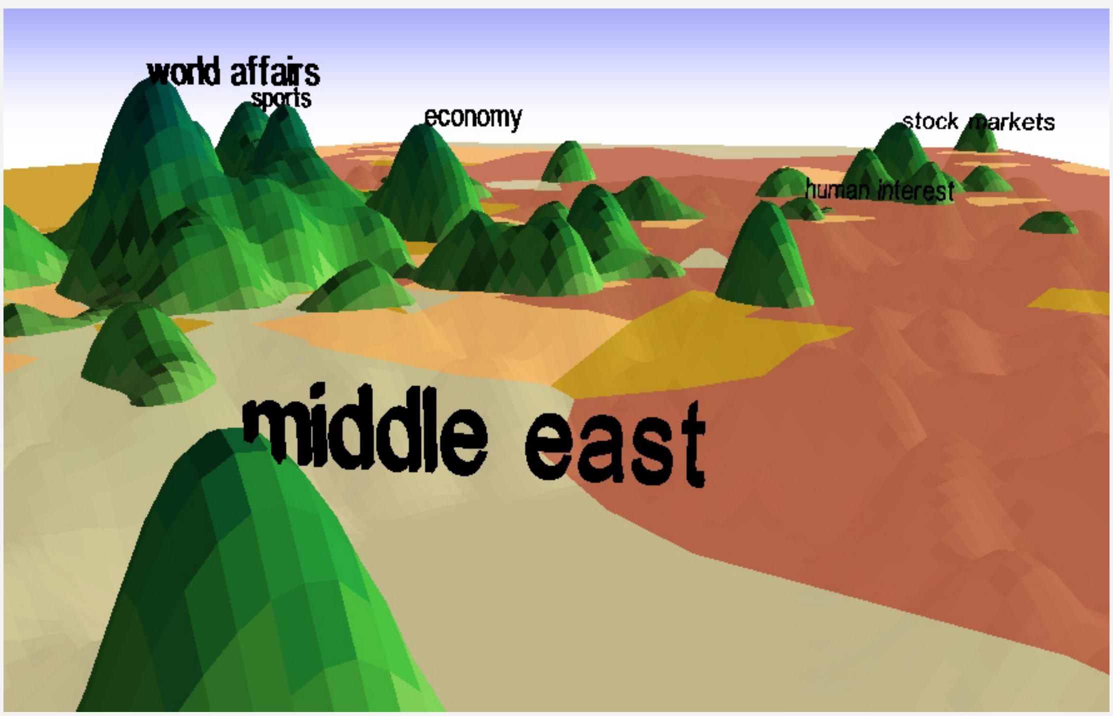
Fabrikant, S. I. & Skupin, A. in press, Cognitively Plausible Information Visualization. In J. Dykes & A. M. MacEachren & M.-J. Kraak (Eds.), Exploring Geovisualization.

Spatialization–2: integrating cartographic and InfoVis perspectives on information landscapes

The Figures here show two perspective views of semantic relationships among Reuters news stories, spatialized in 3D. Dense document clusters pile up to news mountains. The higher the peak, the denser the document cluster, thus the more focused the information in that region. This landscape can be queried interactively through a spatial metaphor. A query filter has been applied to only depict the highest information peaks. At scale 1:2 (two cluster levels shown here), world affairs, economy and sports emerge as dominant information landmarks.



The altitude of the query filter can be moved interactively to reveal more detail in the information landscape. For example, a user has brushed the data space (cluster dendrogram shown in the lower right corner of the Figure below), and decided to investigate the information landscape at larger cartographic scale (e.g. 1:4, four clusters shown below). As the user moves into higher levels of detail in the cluster dendrogram, the lower altitude of the query filter reveals more detail in the landscape.



For details on theoretical aspects of 2D and 3D spatialization, including HCI issues, see:

Fabrikant , S. I. and Buttenfield, B. P. (2001). Formalizing Semantic Spaces for Information Access. Annals of the Association of American Geographers, 91: 263-280.

Fabrikant , S. I. (2000). Spatialized Browsing in Large Data Archives. Transactions in GIS,4(1): 65-78.

than a terabyte per day of geospatial data) and very diverse users and applications (e.g., ranging from environmental and health scientists, through urban or transportation planners, intelligence analysts and crisis managers, to members of the general public). The data containing geospatial referencing are also diverse, including: remotely sensed images of surface and subsurface features, demographic and health data, telephone and credit card transactions, field samples collected with GPS, transportation and utility databases, and many others. To meet the diverse demands of geospatial data users, geovisualization methods and tools must be able to support this diversity.

Supporting data, user, and application diversity requires strategies for taking advantage of distributed resources and expertise as well as strategies for acquiring information where and when it is needed. One component of an approach to meet this challenge is development of methods and tools that support *distributed geovisualization*. The concept of distributed geovisualization is defined here broadly to include three complementary forms of "distribution" that are enabling flexible and effective visual access to relevant geospatial information when, where, and by whom it is needed:

1) distribution of resources to support geovisualization (e.g., software, data, knowledge linked at run time),

2) distribution of geovisualization tasks, and knowledge applied to those tasks, among individuals (thus collaborative geovisualization), and

3) distribution of the site for geovisualization across space (thus different-place collaboration and mobile access to geovisualization tools).

Each of these forms of distribution is discussed and illustrated below. Selected references provide additional information and some of the concepts are elaborated upon in accompanying reprints/preprints from recent publications.

Geovisualization and Distributed Resources

There are many kinds of distributed resources. Resources can include software programs or components, data, and knowledge about particular kinds of data (or about how to analyze these data). Here, resources are considered "distributed" if they are accessed only as needed at run time (whether or not they reside on the same computer or are physically separated, perhaps on different continents). Thus, distributed geovisualization can take the form of a desktop application, a web mapping service, or a GRID application that takes advantage of mechanisms to support distributed data and knowledge as well as distributed software for visualization. For examples of Grid-based distributed applications (including those for geovisualization), see: http://www.geongrid.org/

Since this is a course on geovisualization, my focus will be on approaches to support distributed components through which geovisualization software methods and tools can be created. I will emphasize GeoVISTA *Studio*, an environment for which I share in the development. Related methods and tools will, however, also be discussed.

Modular visualization software

Most of the distributed geovisualization methods and applications to be discussed here rely on modular, component-oriented software from which custom applications can be assembled and reassembled as needed while pursuing a data analysis task. Modular approaches to software for visualization have been common for many years (Brodlie, in press). Early examples include AVS (Rhyne, 1994a), IRIS Explorer (Wood et al., 1996), and IBM DX (Abram & Treinish, 1995), all of which allow users to link distinct program modules together through a visual programming environment. Thus users of modular software can construct an application without knowledge of a formal programming language.

Traditional modular visualization environments have often been applied to visualization of geospatial information (e.g., (Gahegan, 1998; Rhyne, 1998; Treinish, 2002)). Modular, component-based visualization tools are popular in science due to their extensibility. They also have a variety of limitations, several of which were identified by Wright and colleagues (Wright et al., 1996), including reliance on unidirectional data flow pipelines (which restricts queries initiated by direct manipulation of the visual display about data held at an earlier stage of the process) and limits on preserving previous states of an iterative process (something particularly important for enabling “what-if” strategies of exploration important for science and policy applications).

Another limitation of these traditional modular toolkits is that they relied on proprietary architectures. This brings two constraints.

1) The first constraint is the general constraint of all closed-source tools; developers and users are unable to add any features that the software development environment is not inherently designed to support. For example, all of the environments listed above use a different custom data structure designed for visualization performance. While each is able to achieve impressive performance, none is able to easily implement geospatial data models that meet OpenGIS Consortium (http://www.opengis.org/) standards for interoperability of geospatial data. The goals of these standards are products that services that “enable users to freely exchange and apply spatial information, applications and services across networks, different platforms and products.” The Federal Government’s GeoSpatial OneStop Program, for example, requires that software developed to support the program meet these standards.

2) The second constraint is that even when such environments are converted to open environments (e.g., IBM DX, http://www.opendx.org/), users and developers remain restricted to use of modules written with these software tools. Thus, extensions are only possible if designed and implemented within the application building environments provided.

Two recent projects focused on the general strategy of modular, component-based visualization attempt to address some of the issues above: the *Snap-together-visualization* environment (North & Shneiderman, 2000) and GeoVISTA *Studio* (Gahegan et al., 2002). Both projects have produced cross-platform environments, written in Java (with free distribution of source code), and both are designed to support application building in which components being integrated into an application are not required to be constructed with the idea of integration in mind.

The Snap web site provides a clear overview of goals. *Snap is a web based interface for creating customized, coordinated, multiple-view visualizations. Snap provides users with the ability to coordinate visualizations in ways unforeseen by the original developers. Users build a multiple-view visualization by combining existing visualization components and connecting them to a relational database. Then they specify coordinations between visualizations for selecting, navigating, or re-querying*. (http://infovis.cs.vt.edu/snap/). A sidebar on *Snap-Together-Visualization* provides more details.

GeoVISTA *Studio*[5]

GeoVISTA *Studio* (subsequently called *Studio*) is an open source, component-based software development environment distributed through SorceForge: http://geovistastudio.sourceforge.net/. *Studio* provides a visual programming interface through which users can quickly build applications from available JavaBeans® (that are distributed with *Studio* or acquired from other sources). *Studio's* visual programming environment allows an analyst to package assembled functionality into a working program (in the form of a cross-platform, JavaBeans® component, an applet, or an application). Studio supports development of non-geographic as well as geographic applications (e.g., InfoVis tools).

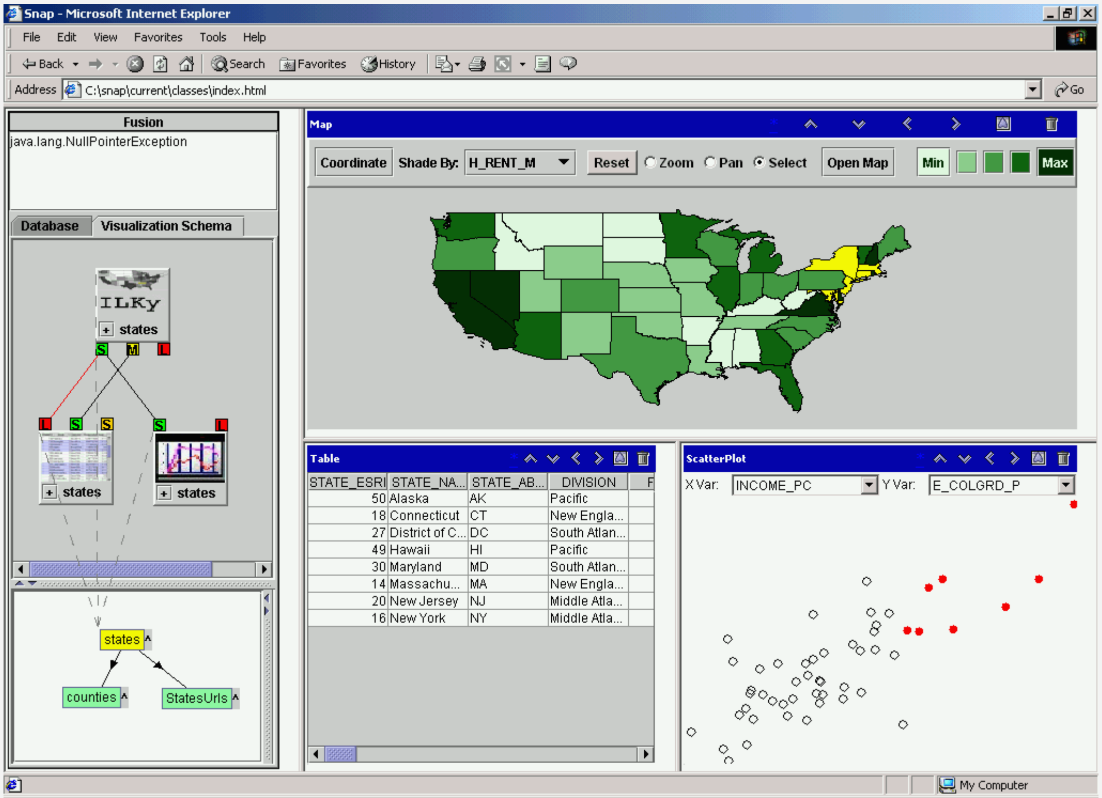
To support the OpenGIS data interoperability needs mentioned above, *Studio* developers have begun to adapt and extend the GeoTools geospatial data access and visualization methods for use with other *Studio* components. GeoTools is a complementary Open Source Java library for developing OpenGIS (http://www.opengis.org/) solutions to geospatial data access, analysis, and presentation tasks (http://www.geotools.org).

The view below shows a *Studio* design window (left) where applications are built and the resulting application views (right) that depict three integrated components: a choropleth map (of mean mercury emission by county in the U.S.), a Java implementation of the ColorBrewer color scheme selection tool (see below for explanation), and an excentric labelling tool (a component distributed by Fekete and Plaisant, see: http://www.cs.umd.edu/hcil/excentric/).

A major difference from most past visual programming environments for building visual analysis tools is that the modules a user links together, in the program's *design box*, are true "components" – units that can be deployed independently and combined with third party applications. Thus, components developed by our research team to work within *Studio* can also function independently. These components can be used in other JavaBean® applications or by third parties; and components developed by others can be used within *Studio* (as long as they meet the JavaBeans® Application Programming

[5] This section draws upon a conference paper initially presented at the 2001 NSF Digital Government Conference (MacEachren et al., 2001b), and an extended abstract for a demonstration of Studio at the 2004 NSF Digital Government Conference (Dai et al., 2004). Both are reproduced in full as part of the course notes.

Snap-Together Visualization



Example and figure courtesy of Chris North

Chris North and colleagues have developed an innovative approach to creating flexible coordinated views onto datasets. Multiple coordinated views can enable information visualization users to rapidly explore complex data and uncover patterns and relationships. Building such coordinated views when needed is a challenging task for most users. *Snap-Together Visualization* allows users to construct customized, coordinate multiple views that fit their needs. Users of Snap query their relational database and load results into desired views (e.g., maps, graphs, tables). Then they specify the kinds of coordination supported between views (for selecting, navigating, or re-querying).

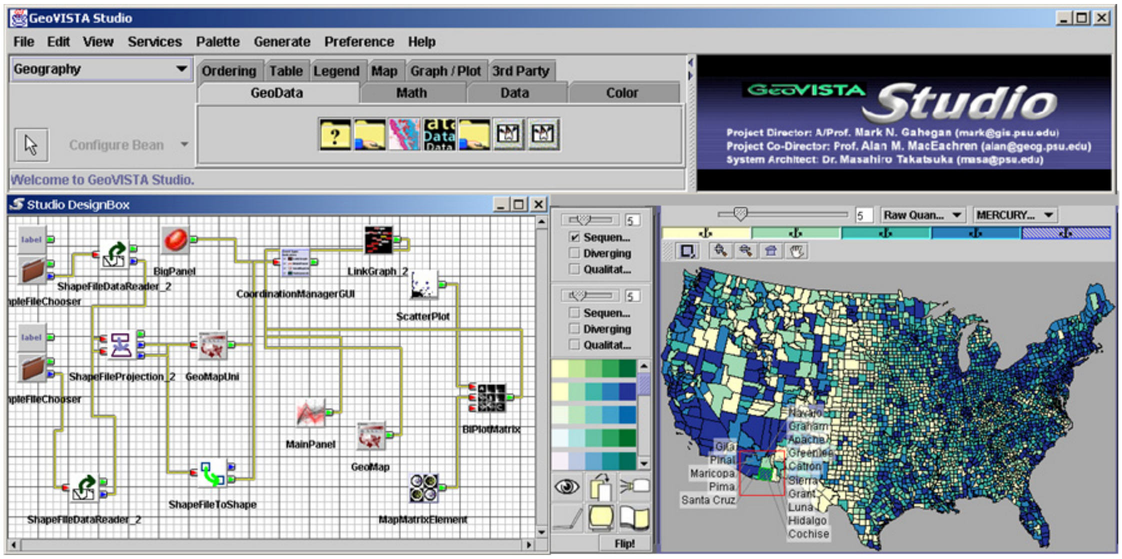
In rapidly evolving data-intensive environments (for example, environmental informatics), database schemas are constantly changing. Visualization tools developed for a particular database are, thus, often obsolete by the time they are implemented. North and colleagues introduce the concept of a *visualization schema* (analogous to relational database schemas) as a way to address the problem. Visualization schemas enable rapid design of custom visualizations for any given database without programming. Visualization schemas complement relational data schemas and, thus, providing an integrated and coordinated approach to the design of data and the design of data visualization.

The figure above depicts a geovisualization application in Snap (which uses Geotools for the map component). The view at the left shows the Snap Visualization Schema concept with is the visual analogy to data schemas. Views are dynamically linked by user. Linking concepts are at the higher task level (e.g. selection, navigation), rather than at low-level data or API levels used in typical data-flow tools.

Details are described in:

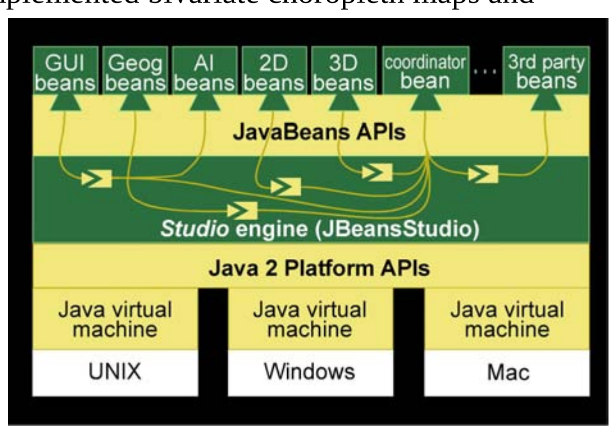
North, C., Conklin, N., & Saini, V. 2002, Visualization schemas for flexible information visualization. *Proceedings, IEEE Symposium on Information Visualization*, Boston, 28-29 Oct. 2002, pp. 15- 22.

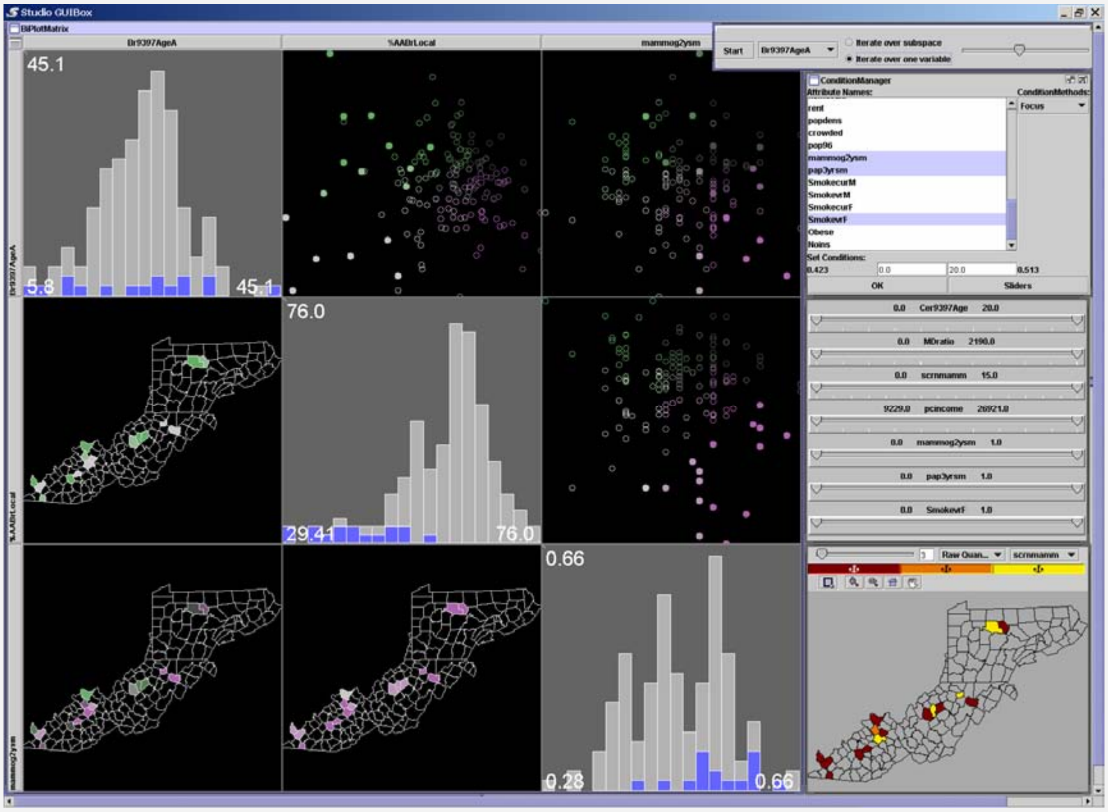
North, C. & Shneiderman, B. 2000, Snap-together visualization: can users construct and operate coordinated visualizations? *International Journal of Human-Computer Studies,* **53**(5), 715-739.



Interface (API) standards). This flexibility is enabled through the "builder" (a component-oriented application construction system), which connects components together at runtime, without the need for recompilation, linking or any other form of 'preparation'. By using Java's 'introspection' function, the builder obtains a syntactic description of all the services (methods) that a bean provides, and can expose these methods for linking to other beans. Thus it is not necessary to have source code available before a bean can be assimilated into the *Studio* environment, nor any prior knowledge of its methods. The figure below depicts the system architecture.

A primary goal behind *Studio* is to support the fusing of diverse visual and analytical capabilities into custom analysis tools that enable a multi-perspective ('mixed initiative' (Amant & Cohen, 1998) approach to knowledge construction and dissemination (Gahegan et al., 2002; Takatsuka & Gahegan, 2002). *Studio* has been leveraged recently to support rapid development of new visual and computational analytical methods through its facilities for integrating independently developed components. Some of that recent work has focused on a Multiform Bivariate Matrix tool (MacEachren et al., 2003a) and dynamically connected LinkGraph. The Matrix tool (see first figure next page) generalizes the well-know data exploration method, a scatterplot matrix, to support any bivariate representation forms (we have implemented bivariate choropleth maps and space-filling visualizations – see sidebar on *Multiform Bivariate Matrix* for more details. The LinkGraph tool (see second figure next page) uses a minimum spanning tree to define relative position of geographic places (e.g., counties) in attribute space. In the application show, Clinton County, PA was selected on the map and the LinkGraph finds all counties in a 3-state section of Appalachia that are similar in demographic-health space to Clinton





Multiform Bivariate Matrix

The Matrix and linked bivariate map in this figure shows the relationship between four variables for counties in Pennsylvania, West Virginia, and Kentucky that are part of the Appalachia Cancer Network (in the Matrix: age-adjusted breast cancer mortality rate/100,000, % of cancer diagnoses at local stage in the body, and % of women age 54-65 who have had mammograms in the past 2 years; in the univariate map: number of screening mammography facilities/1000 population). In general, an increase in cancer screen leads to more early detection (thus a positive relationship with % local stage diagnosis – the lower right scatterplot). There is, however, a group of counties with a high % of women having had a mammogram in the past three year but low % early detection. Using the tools capability to do multiple additive selections these counties have been selected in the scatterplot and highlighted in all scatterplots and maps.

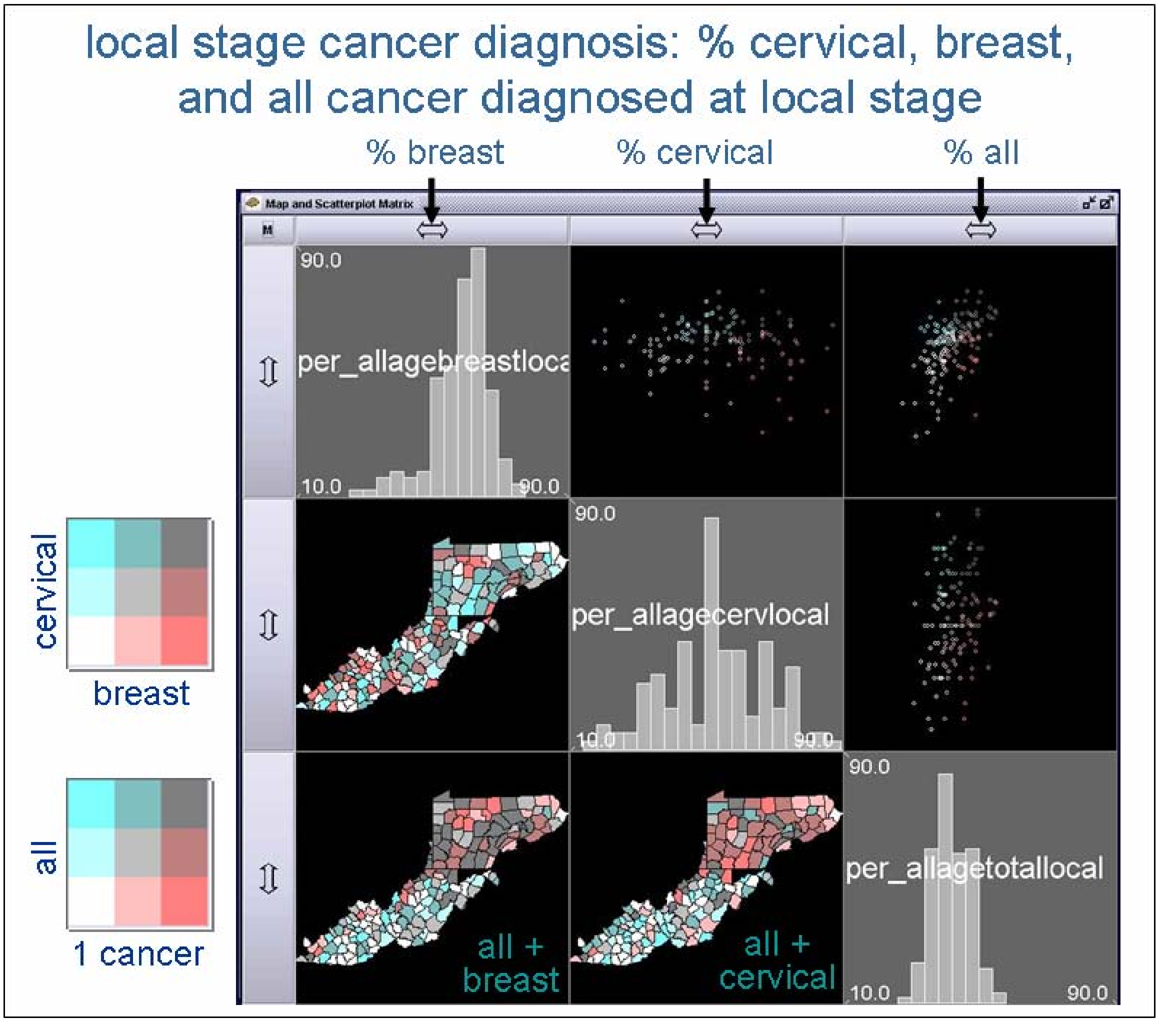
The linked univariate map of screening facility accessibility (lower right) shows that this pattern occurs mostly in counties where accessibility to screening is low (the dark red counties). A possible explanation for the observed pattern is that, although women in these counties have been screened recently, lack of screening facilities may have limited their past screening, leading to detection of cancer at later stages.

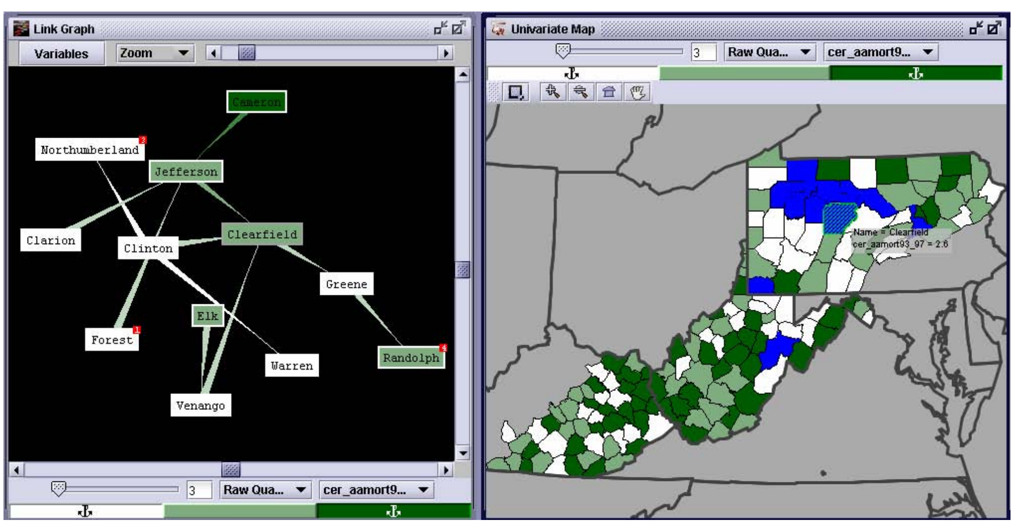
Further details about the Multiform Matrix and its variants are found in:

Dai, X. & Hardisty, F. 2002, Conditioned and Manipulable Matrix for Visual Exploration. *Proceedings of the National Conference for Digital Government Research*, Los Angeles, CA, May 20-22, 2002, pp. 489-492.

MacEachren, A., Dai, X., Hardisty, F., Guo, D., & Lengerich, G. 2003, Exploring High-D Spaces with Multiform Matricies and Small Multiples. *Proceedings of the International Symposium on Information Visualization*, Seattle, WA, Oct. 19-21, 2003, pp. 31-38.

County in PA (and highlights these on both the map and graph – note that most are contiguous in space to Clinton County).

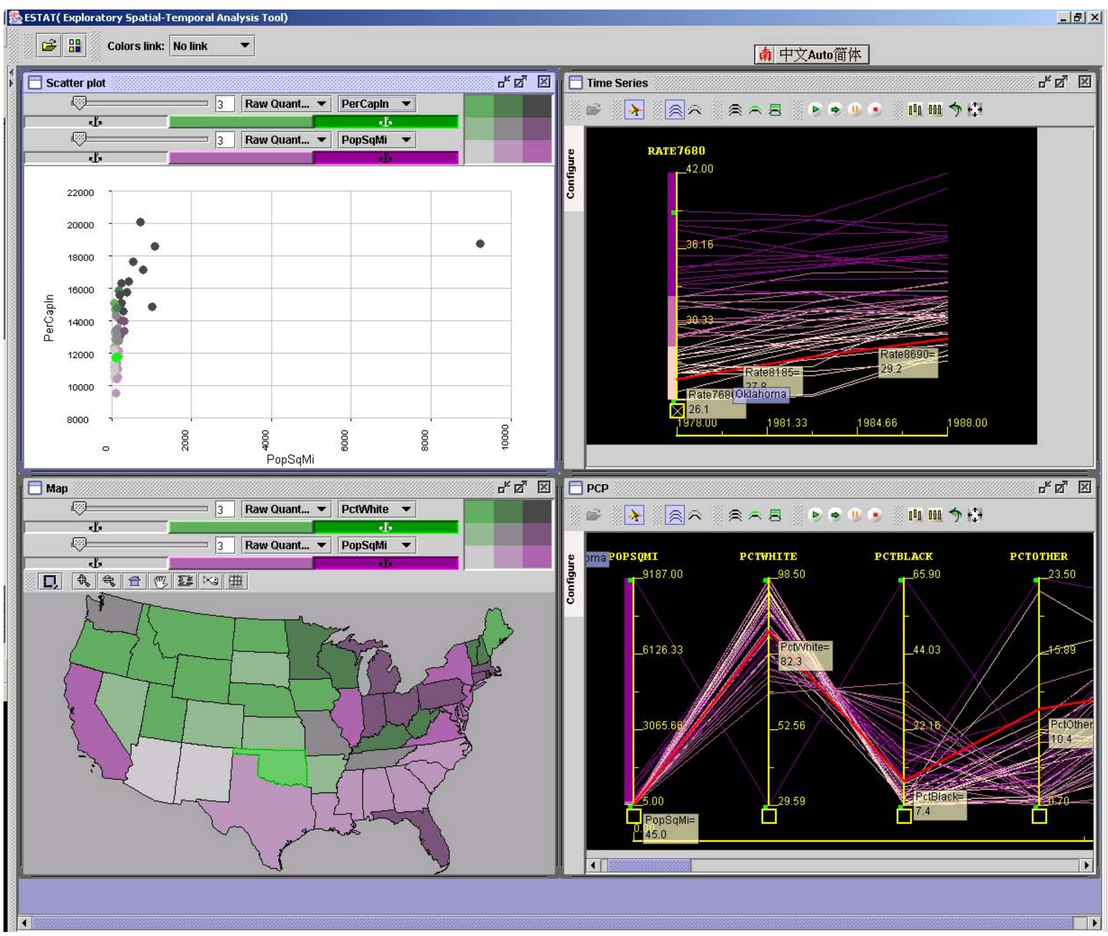




Over the past year, (in addition to enhancement of existing tools), new multivariate analysis and visualization tools and functionalities added to *Studio* include: (a) a feature selection and multivariate clustering tool, (b) a custom parallel coordinate plot (PCP) and complementary time series plot, (c) extensions of ColorBrewer for bivariate mapping, and (d) (as mentioned above) integration of the GeoTools open source Java library for developing OpenGIS solutions to geospatial data access, analysis, and presentation tasks.

The new parallel coordinate plot (PCP) and time series analysis components were implemented and joined with existing components as a stand-alone application that includes a scatterplot and bivariate map (figure below). This application is designed specifically to meet National Cancer Institute data analysis needs. These needs include temporal data analysis, interactive data range setup, box plot analysis on each variable, and others. The application's PCP supports display of multiple variables at the same time by mapping an n-dimensional dataset to a two-dimensional space where variables are listed as parallel axes, and each observation is visualized as a polyline, connecting the points on axes, which are the observation's values on those axes.

Extending from the above, recent work described in the sidebar on *visual geospatial data mining* has focused on merging computational and visual methods for identifying clusters in high dimensional data spaces having a geospatial component (Guo et al., 2003).



Visual Geospatial Data Mining

(Example and figures courtesy of Diansheng Guo)

Diansheng Guo and colleagues have developed a comprehensive set of linked tools that support visually-enabled data mining applied to high-dimensional (many attributes) datasets having geospatial components. The goal has been to develop a human-centered, component-based, exploratory spatial data analysis environment for discovering patterns in large and high-dimensional data.

The implemented system shown in the figure below and the figure on next page includes a suite of computational and visual components, each of which focuses on a specific task or step in the overall data exploration process and together they can communicate with each other and collaboratively address complex problems. Specifically, this part of the research includes: (1) an interactive feature selection method for identifying interesting subsets of variables (see *figure 1*); (2) multivariate clustering and visualization with self-organizing maps (SOM), parallel coordinate plots (PCP), and geographic maps (see *figure 2*); and (3) a suite of coordinated visual and computational components centered around the above two methods to facilitate an visually-enabled, efficient, effective, human-led exploration of multivariate spatial patterns. {description continued next page}

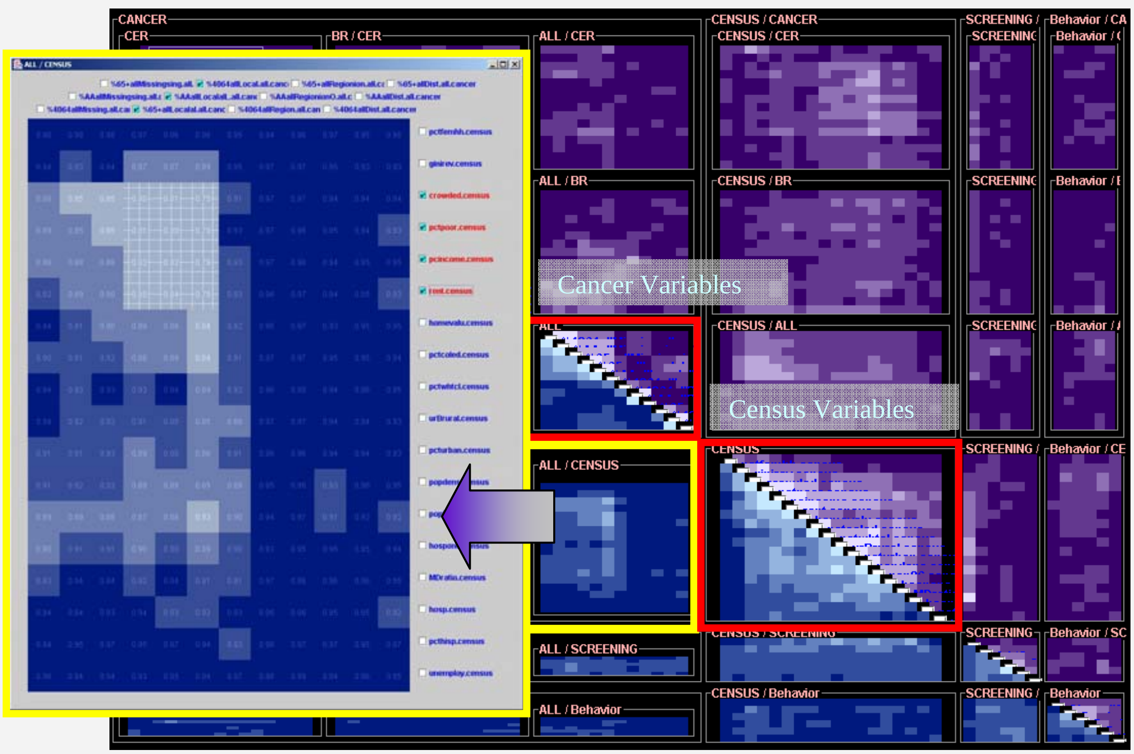


Figure 1: Interactive feature selection using a conditional entropy matrix, which involves several steps. First, a conditional entropy value is calculated for each pair of variables to measure their bivariate relationship. Then a matrix of all conditional entropy values is constructed, where each diagonal cell represents a variable and each off-diagonal cell represents a conditional entropy value. Bright cells represent strong relationships. Variables are first organized into categories (e.g., cancer, census, etc.) and then ordered (within each category) based on paired entropy values. Thus those subsets of variables that have good relationships with each other will be placed next to each other and form a block of bright cells. The user can zoom in on each such hot spot and pick variables based on her domain knowledge and interest.

A normal cycle within the iterative exploration process can be: loading data, clean the data, interactively select interesting subsets of variables for further analysis, identify multivariate clusters of the data (using selected variables), interactively explore and interprete those clusters, visualize the clusters in a map and examine the spatial distribution of discovered multivariate spatial relationships.

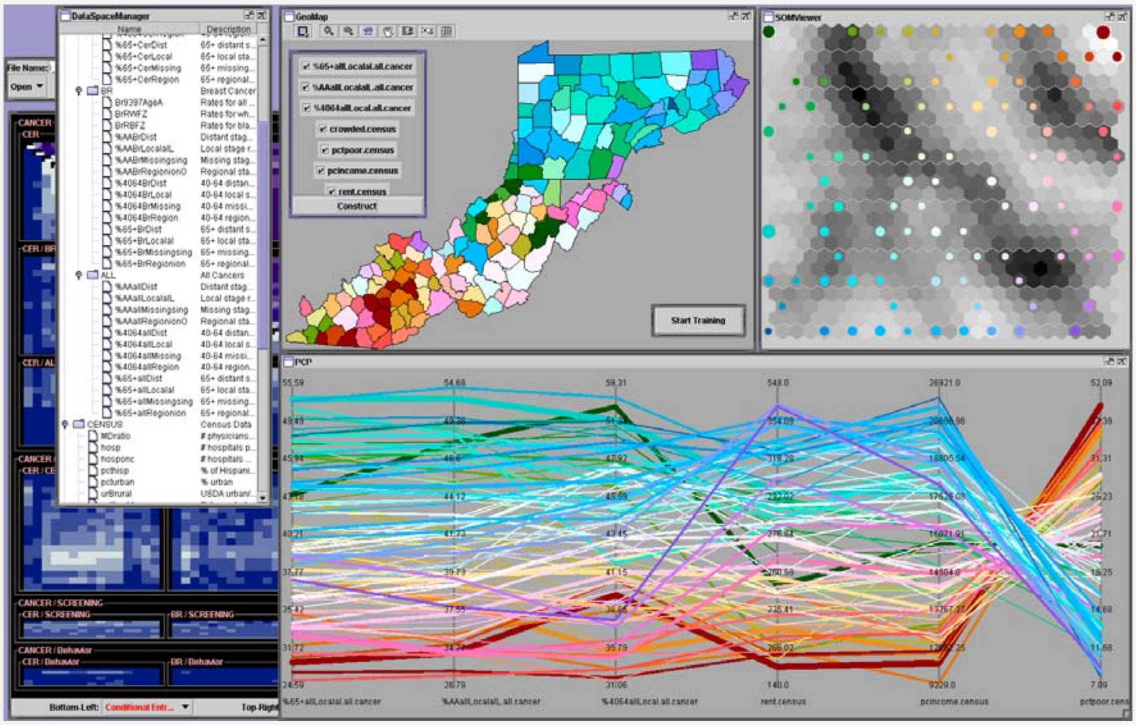


Figure 2: Multivariate clustering and visualization with self-organizing maps (SOM), parallel coordinate plots (PCP), and geographic maps. This is the next step after the selection of a subspace (subset of variables). The selected variable data are first input to a self-organizing map, where the data are organized into a 2-D layout of nodes. Each non-empty node contains one or more similar data objects. The data objects in nearby nodes are also similar to each other. A 2-D color scheme is used to assign each node a color. Nearby nodes have similar colors. Then these non-empty nodes are passed to a PCP component to visualize, with the colors assigned in the SOM and the thickness of each string representing (proportionally) the number of data objects contained in that node. Each data object (here each object is a county) is also assigned the same color as its containing node. Thus the spatial distribution of discovered multivariate patterns can be visualized using a map. The user can also interactively explore the data and discovered patterns via selection and focusing.

Details are described in:

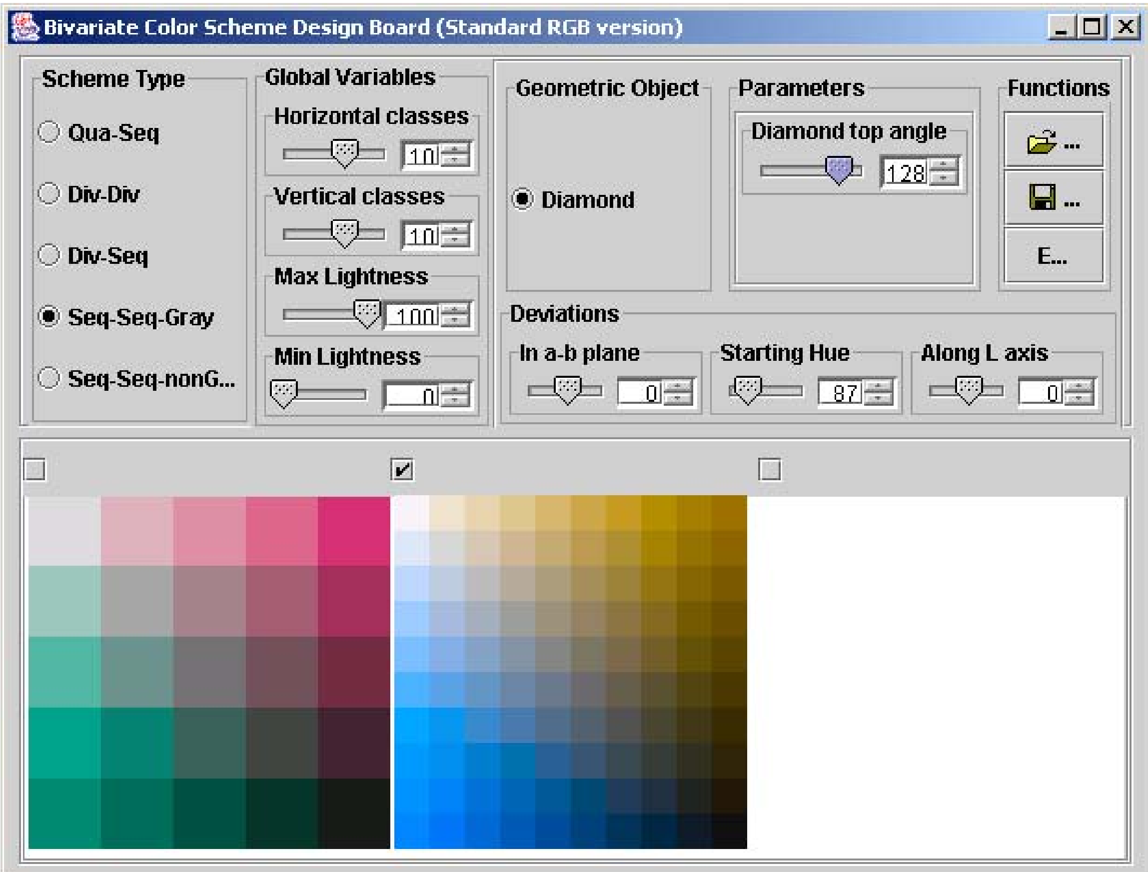
Guo, D. 2003, Coordinating Computational and Visualization Approaches for Interactive Feature Selection and Multivariate Clustering. *Information Visualization Journal,* **2**(4), 232-246.

Guo, D., Gahegan, M., Peuquet, D., & MacEachren, A. 2003, Breaking Down Dimensionality: An Effective Feature Selection Method for High-Dimensional Clustering*. Workshop on Clustering High Dimensional Data and its Applications, the Third SIAM International Conference on Data Mining*, San Francisco, CA, May 1-3.

Guo, D., Peuquet, D., & Gahegan, M. 2003, ICEAGE: Interactive Clustering and Exploration of Large and High-dimensional Geodata. *GeoInformatica,* **7**(3), 229-253.

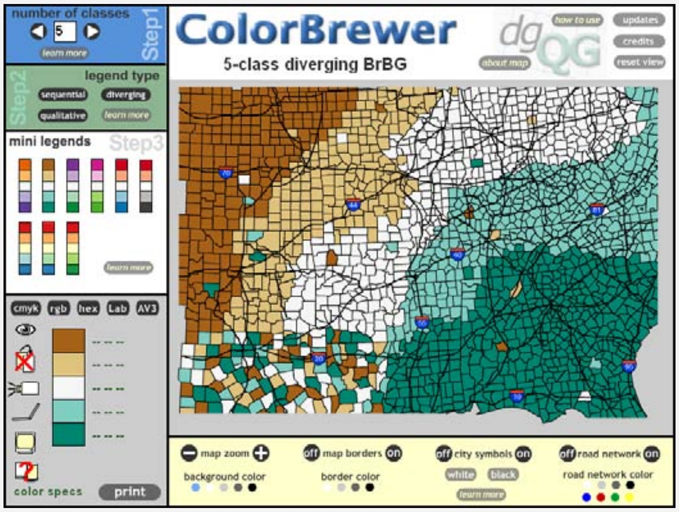
Color schemes play a critical role in displaying the patterns within multivariate data in geovisualization environments. To address color selection needs for multivariate mapping, a Bivariate Color Scheme Design Board (CSDB – figure below) has been implemented in *Studio* by Bilaing Zhou. The CSDB is aimed at advanced users who would like to explore the parameters of bivariate color schemes and/or to design custom schemes.

The schemes are constructed by sampling the surface of geometric objects within CIE L* a* b* color space, a perceptually scaled 3D color space (Zhou et al., 2003). The figure below shows a screen capture from a session in which the user was designing a sequential-sequential color scheme with a gray diagonal (for use in bivariate maps, scatterplots, and other display that depict two sequential/numerical variable; e.g., per capita income and cancer mortality rate).



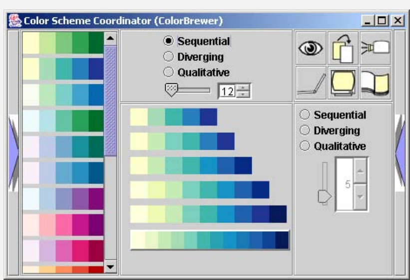
Once created, color schemes can be saved for later access using the ColorBrewer component. The ColorBrewer stores the information about recommended color schemes and can communicate with client components in *Studio* to apply the schemes. A set of scheme choices for each two-variable combination (e.g., sequential-qualitative, diverging-diverging) is implemented. See *ColorBrewer sidebar* for details.

ColorBrewer: Selecting an effective color scheme



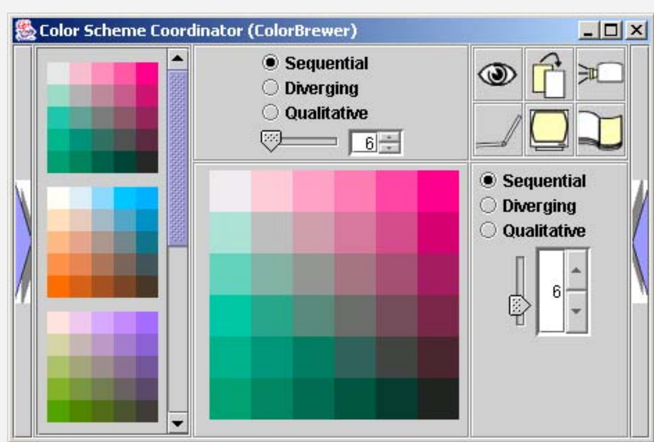
Cynthia Brewer and Mark Harrower developed a web-based application (ColorBrewer) to assist non-specialists in selecting logical and effective colors for typical thematic maps of statistical data. This tool (see figure above) is available at: www.colorbrewer.org. The web-based ColorBrewer allows users to explore a range of recommended color schemes for univariate map representation, with choices of sequential (ordered), diverging (ordered around a central key value), and qualitative (categorical) schemes. When users select a particular scheme, they see what its result would be on a schematic display that simulates many of the issue of color use for thematic maps (with regions having high spatial homogeneity (as typical for isarithmic maps) and other regions with high spatial variability (as typical for choropleth maps). The ability to experiment with borders, overlaying text and line work, and backgrounds is also provided. In addition, users can check the usability of the color scheme for a range of situations (including projection and use by those with color vision deficiencies).

The recommended color schemes from ColorBrewer have been adopted for use with graphics within the R statistical package. In addition, Biliang Zhou has implemented the ColorBrewer strategy of providing a range of good color schemes and an ability to compare them quickly as JavaBean® components for use within GeoVISTA *Studio*. He has also extended ColorBrewer to include bivariate color schemes and implemented a JavaBean® component for accessing and comparing these schemes (see figure below) that can be linked through *Studio* to any display tools using bivariate colors.



Figures above and below right courtesy of Biliang Zhou

Development of ColorBrewer is supported through an NSF Digital Government Grant (9983451).



Details are described in:

Brewer, C. A. 2003, A Transition in Improving Maps: The ColorBrewer Example, in U.S. Report to the International Cartographic Association. *Cartography and Geographic Information Science,* **30**(2), 155-158.

Harrower, M. & Brewer, C. A. in press, ColorBrewer: An Online Tool for Selecting Color Schemes for Maps. *The Cartographic Journal,* **40**(1), 27-37. Z

Zhou, B., Brewer, C. A., & Hardisty, F. 2003, ColorBrewer in GeoVISTA Studio: Construction and application of bivariate color schemes*. Proceedings, 2003 Joint Statistical Meetings - Section on Statistical Graphics*, San Francisco, CA, Aug. 3-7, 2003, pp. 4771-4778.

Two key architectural changes have been made to the *Studio* environment during the 2003-2004 academic year. The first is the development of 'invisible' adapters, which automatically translate data structures between different components and thus greatly ease the process of integrating components into an analysis environment. The second adds the ability to attach notes (or metadata) to *Studio* designs and thus help non-developer users (e.g., epidemiologists) understand the use and purpose of the design. The research also supported experimentation and re-engineering of interfaces that conforms to standard GIS and database data formats, including Open GIS Consortium standards for describing data and describing the visual appearance of maps and displays.

The applications described above follow a component based software design standard; they are implemented as independent but coordinated JavaBeans®. These components are "coordinator-aware" and make use a coordinator bean to communicate with each other, as well as other existing tools, such as maps, matrices, spread sheets, etc. The concept of dynamic coordination, supported by these independent components, is implemented as data sharing, selections, classifications and focusing, and enables a dynamic and comprehensive multivariate analysis of geospatial data.

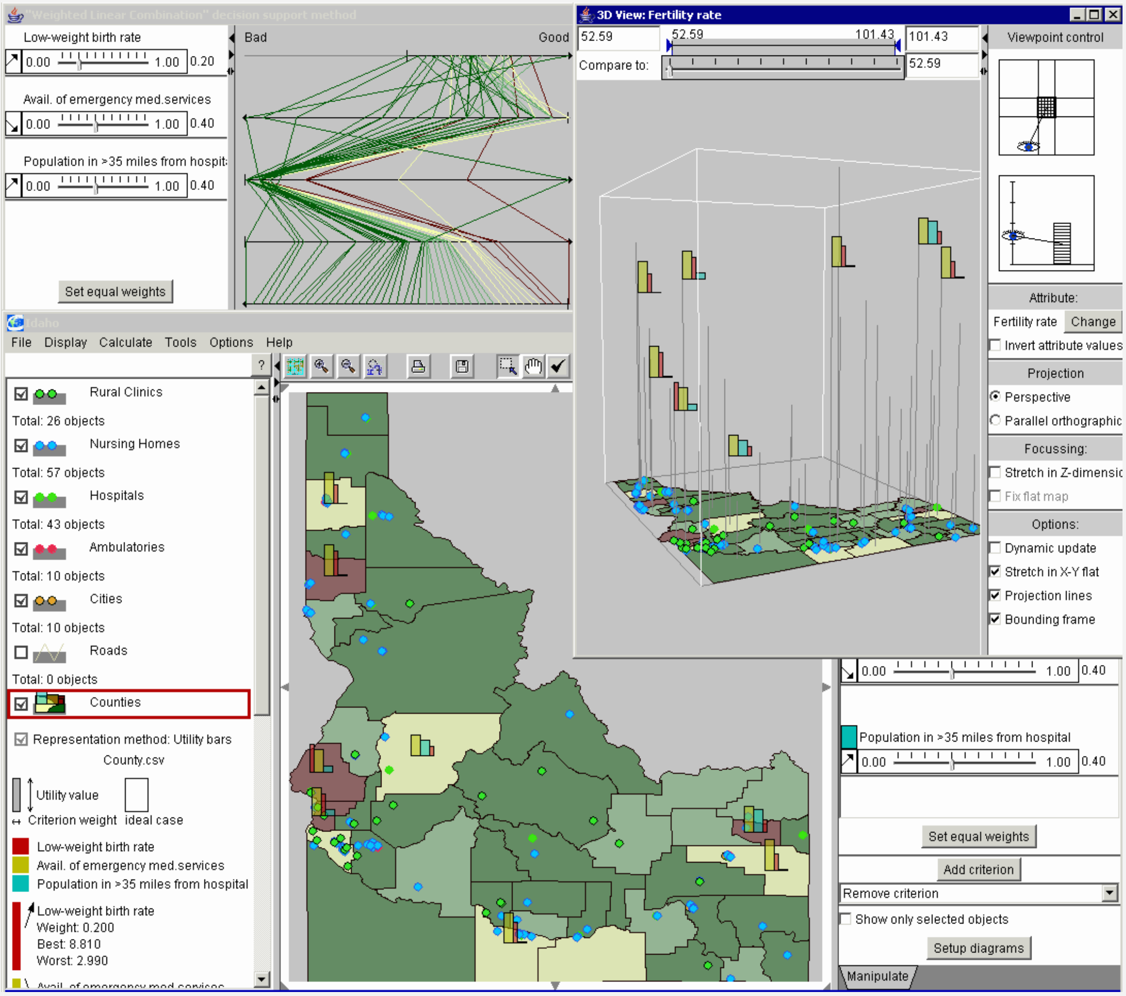
Distributing geovisualization among collaborators[6]

Real world problems that require geospatial information are often ill-defined and require groups/teams to interact in producing solutions. Examples include: regional planning, crisis management, business location decisions, scientific study of human implications of global warming, military strategic assessment. In all of these domains (and others) the problems addressed typically demand that multiple kinds of expertise be integrated, both to assess the situation and to arrive at strategies and solutions. Visualization of geospatial information can act as an important mediator for group work with geospatial information in these contexts. See sidebar on *geovisualization for decision-support* for an example of recent efforts to integrate exploratory geovisualization methods (and exploratory data analysis methods from statistics) with multi-criteria evaluation methods from decision-sciences for application to group decision making.

Visual displays of geospatial information in the form of maps and images have long served as enabling devices for group work. Urban and regional planners, for example, often gather around large paper maps to discuss master plans or specific development choices and these same large format maps are used as the object of discussion at subsequent public meetings. Similarly, teams involved in crisis management use large maps in both situation-assessment and response activities and earth scientists (e.g., geologists, ecologist) often work collaboratively on development of map categories and on planning for field research activities.

The examples above are rudimentary examples of *geocollaboration.* As an activity, geocollaboration can be considered to be "group work about geographic scale problems

[6] This section provides a brief introduction to ideas presented in several recent publications. Two of these are available in preprint form (MacEachren, in press; MacEachren & Brewer, 2004), see URLs in main text below. One additional paper was presented at an International Cartographic Conference (MacEachren et al., 2003b), and is included as a supplement to the course notes, courtesy of the International Cartographic Association.



Example and figure courtesy of Natalia and Gennady Andrienko

Geovisualization for Decision-Making – Supporting Multiicriteria Evaluation

This screen capture from an interactive application shows combined use of multiple dynamically linked displays for multi-criteria evaluation and decision making. On the map, counties of Idaho are evaluated according to several criteria reflecting the availability of medical services. The map is combined with a parallel coordinates plot that shows values of the criteria for counties, and with 3D representation where the "elevation" of few top-ranked options corresponds to another criterion. All these displays are dynamically coordinated. Thus, changing criteria weights results in re-evaluation of options, selection of a given number of best options, and re-displaying the results.

Details are described in:

Andrienko, N., Andrienko, G. 2003. Informed Spatial Decisions through Coordinated Views, *Information Visualization*, 2(4): 270-285

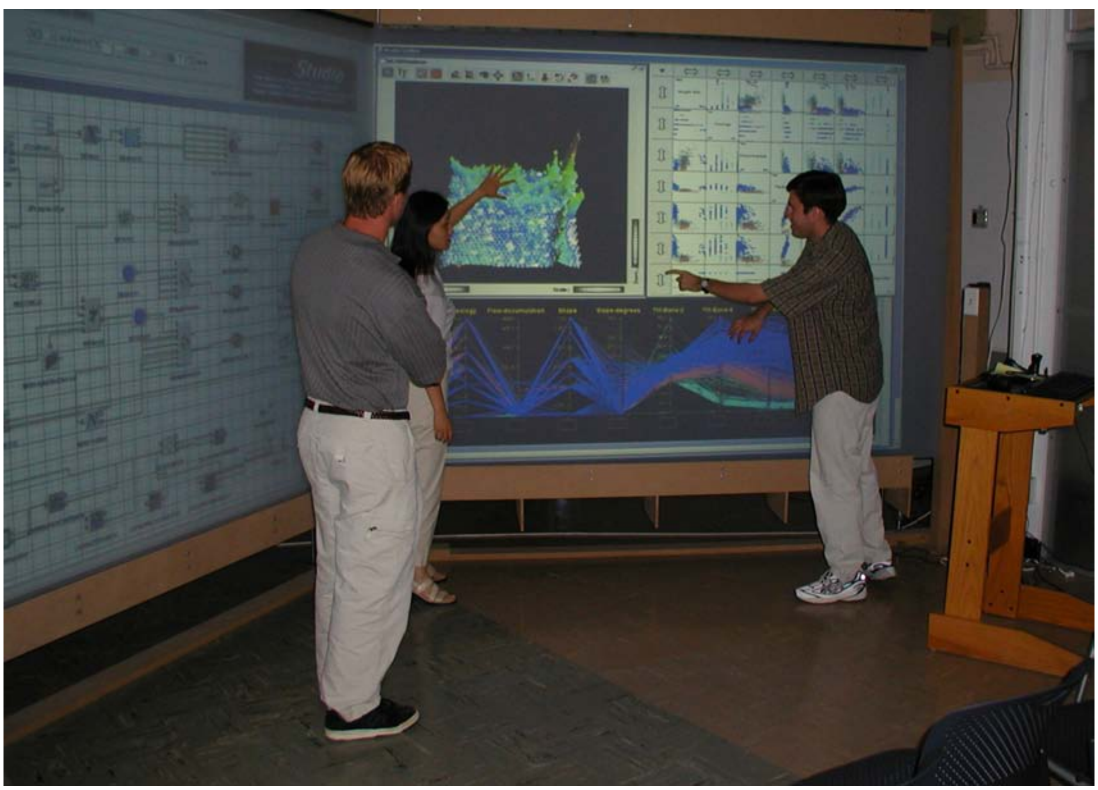
Gennady Andrienko, Natalia Andrienko, and Piotr Jankowski, 2003. Building Spatial Decision Support Tools for Individuals and Groups *Journal of Decision Systems,* 12(2): 193-208

Jankowski, P., Andrienko, N., and Andrienko, G. 2001. Map-Centered Exploratory Approach to Multiple Criteria Spatial Decision Making, *International Journal Geographical Information Science*, 15(2): 101-127.

facilitated by geospatial information technologies" (MacEachren et al., 2003b). As a field of research, geocollaboration can be considered to be "the study of these group activities, together with the development of methods and tools to facilitate them" (MacEachren et al., 2003b).

Recent technological advances in display hardware and multimodal interfaces are making it possible to merge the advantages of large format representations that facilitate group work with those of dynamic, interactive displays (applied over the past decade to desktop mapping and GIS applications designed for individual use). This merger is likely to have a substantial impact on group productivity. In addition, dynamic, large-format displays having natural interfaces designed specifically to support group work have the potential to dramatically (and qualitatively) change the way groups work with geospatial data, thus to create fundamentally new kinds of geocollaboration.

In the display below, a group of grad students are interacting with a *Studio* application directed to a complex land-cover classification problem using remotely sensed data. The dual screen display being used (located in the Immersive Environments Lab at Penn State) is the joint creation of the Penn State Information Technology Services Visualization Group and the School of Architecture and Landscape Architecture. The screens both support stereo display (using inexpensive polarized glasses).



While large-screen displays have obvious advantages for group work, particularly work with map-based displays, these displays are currently hard to interact with. Thus, we trade off the size of display (which facilitates group interaction) for cumbersome interfaces that are both difficult to use and not built to support group work.

As one step toward addressing these issues, our research group in the Penn State GeoVISTA Center has been developing multimodal, group-enabled interfaces to map-based displays linked to geographic information systems (GIS). Our Dialogue-Assisted Visual Environment for Geoinformation (DAVE_G), and its application to emergency operation center uses, is described in the supplementary papers.

For a conceptual overview of visually-enabled geocollaboration (and more on the role of large-screen display), see: (MacEachren & Brewer, 2004) – preprint available at: http://www.geovista.psu.edu/publications/2003/MacEachren-Brewer_IJGIS.pdf

For specific attention to the multiple roles of visualization in supporting geocollaboration, see: (MacEachren, in press) – preprint available at: http://www.geovista.psu.edu/publications/2003/MacEachren_movingGeoViz.pdf

Distributing Geovisualization Spatially[7]

Extension of visualization methods to support a range of group activities has addressed virtual as well as co-located groups. Research and developments in this area have borrowed heavily from complementary work in computer-supported cooperative work. Some of that work (and results of efforts to borrow from it) are detailed in (MacEachren & Brewer, 2004; MacEachren et al., 2001a), with the 2001 paper included in course notes and a preprint of the 2004 paper available at the URL above.

As computational power and network connections improved in the latter half of the 1990s, several research groups explored the possibilities of different-place collaborative visualization and many of these efforts focused on geospatial displays (e.g., (Brown et al., 1996; Pang & Fernandez, 1995; Rhyne, 1994b; Wood et al., 1995)). One example of this work, by Alex Pang and colleagues, is detailed in the sidebar on *Collaborative visualization – supporting different place group data exploration.* A review of work relevant to collaborative geovisualization and other group use of geospatial technologies (through 2001) is available in (MacEachren, 2001) (preprint online at: http://www.geovista.psu.edu/publications/amm/ammP00.pdf).

It was clear to most early developers of collaborative visualization tools designed for application to geospatial data analysis, and/or for geographic decision-making, that too little was known about how to enable map-based interaction at a distance. Although there have been many studies of remote group work, relatively few studies have focused on the role of visual display as a mediator for collaboration (exceptions include: (Hindmarsh et al., 2000; Mark et al., 2003a; Mark et al., 2003b; Roussos et al., 1999)) and fewer still

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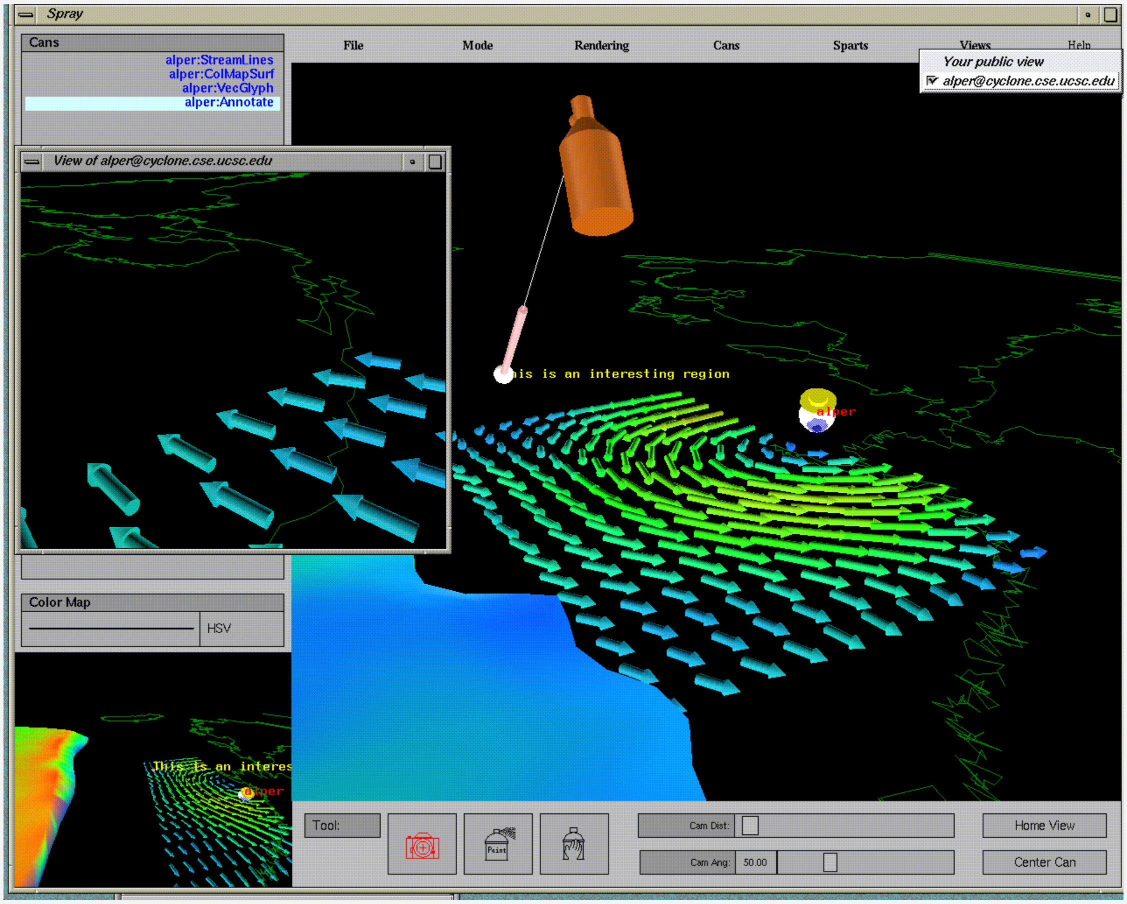
[7] This section also draws upon the two conceptual papers cited above, plus on additional published research results. The latter includes: (a) (Brewer et al., 2000), available from the authors at: http://hero.geog.psu.edu/products/IBAMivis.pdf; (b) a paper in the 2001 Proceedings of the International Cartographic Conference (MacEachren et al., 2001a), reproduced by permission of the International Cartographic organization as a supplement to these course notes; and (c) two short descriptions focused on a project to develop visually-enabled interfaces for both same-place and different-place collaboration using geospatial information in the context of crisis management (Cai et al., 2004; MacEachren et al., 2004) in the Proceedings of the NSF Digital Government Conference (also reproduced, with the permission or the publisher) as supplements to the course notes.



Example and figure courtesy of Alex Pang

Collaborative visualization – supporting different place group data exploration

Alex Pang and colleagues began to explore the realm of group interaction and collaboration over the internet about a decade ago. Their early work focused on providing a small group of geographically distributed scientists the means of sharing their data and interactively creating visualizations and analyzing them. One goal was simply to overcome the inconvenience of driving the 40 miles to meet with science application colleagues.

The system provided tools to collaborate in a shared 3D virtual workspace and interactively create visualizations. One of the sticky points when working with scientists is ensuring data privacy. For this reason, the raw data used in the collaboration is not necessarily distributed, and authentication and permissions to access the sensitive data had to be in placed as well. Another important issue addressed was session management -- bringing late comers up to date on what's happening in a session and what to do with the visualizations/data when somebody leaves a session. Also, floor controls for shared resources were provided -- in this case, the shared resources were the spray cans tied to the data sets that were used to generate visualizations.

For interactions, the tools implemented 3D pointers (as a special spray can). In the figure, one of multiple available 3D "spraycans" is used to add annotation to a particular feature in the 3D scene. The system also implemented *eye-cons* to represent positions of different participants in the virtual space. The eye-cons also allow participants to look over somebody else's shoulder (or to take someone else's perspective even more directly, by looking directly through their eyeballs).

Details are described in: Pang, A. & Wittenbrink, C. 1997, Collaborative 3D visualization with CSpray. *Computer Graphics and Applications, IEEE,* **17**(2), 32-41.

have focused explicitly on map-based remote collaboration (exceptions include (Brewer et al., 2000; Johnson et al., 1999)). As a result, we continue to rely too much on the intuition of developers. The methods and tools being developed are not well grounded in scientific understanding of group work developed over the last several decades in other domains (e.g., on virtual conferences for business). Issues that need to be addressed in the context of remote, collaborative geovisualization include (but are not limited to): activity awareness among participants, how to control what to share when and with whom, and (perhaps more challenging) how to use the map-based display to connect the different semantic frameworks brought to the collaboration by participants having different disciplinary backgrounds, domain knowledge, and points of view.

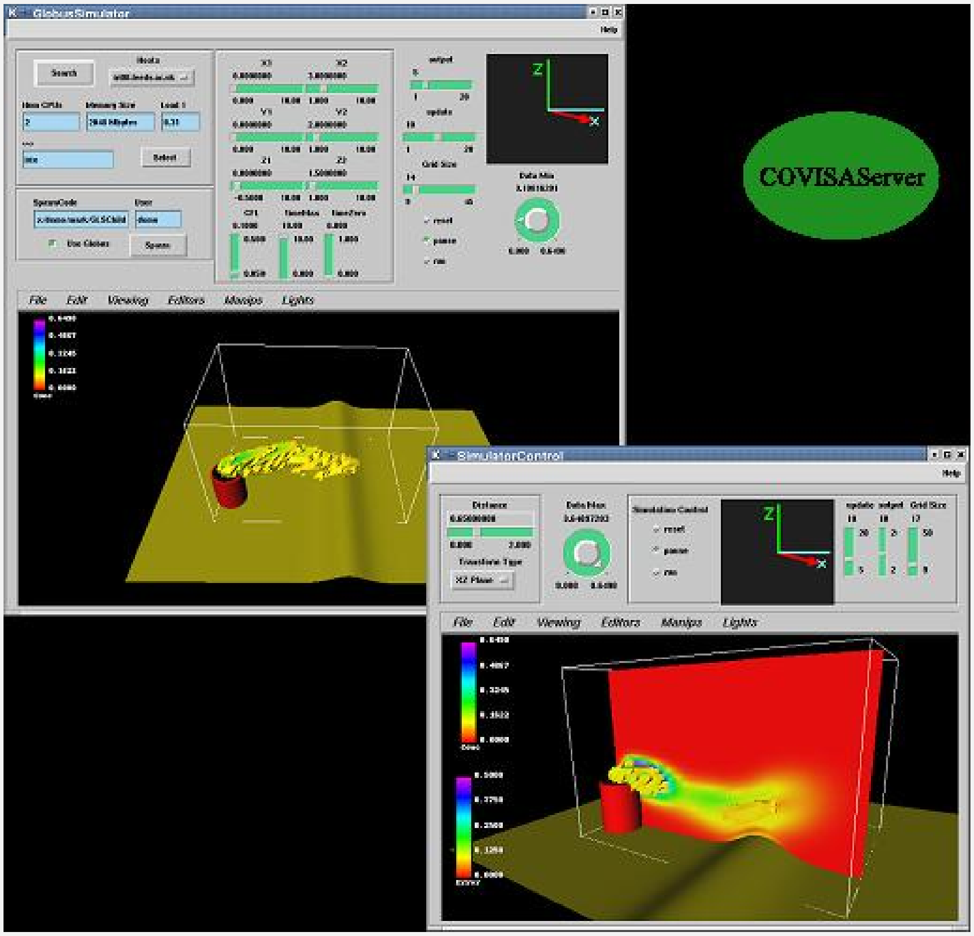
As computational power and bandwidth has increased, the potential to integrate collaborative visualization with other CSCW methods and tools has increased. Grid technologies are making it possible to support real-time remote interaction with complex models – through a visualization interface (Brodlie et al., in press). Technology is maturing to the point that there are now international workshops on Grid-based collaborative visualization: http://wwwbode.cs.tum.edu/~luksch/ICCS2004-WS-Collaborative/, as well as Grid outreach efforts in collaborative visualization: http://www.gridoutreach.org.uk/themes/cv_intro.htm. One example of a recent effort in this area that is focused on collaboration with geospatial information is provided in the sidebar on *Grid-based collaborative visualization.*

The challenges of remote collaborative geovisualization (or remote visually-enabled collaboration more generally) are increased substantially as we attempt to move from efforts to connect remote laboratories (using workstations and desktop computers) into the field, with tablet computers, PDAs, and cell phones. Some of these possibilities were outlined by Theresa-Marie Rhyne in her part of this course and previewed in her Eurographics 2002 Keynote paper: ttp://lts.ncsu.edu/staging/Theresa/eurouk02.pdf.

One current GeoVISTA Center project (on GeoCollaborative Crisis Management) has been making progress on this issue of mobile visualization of geospatial information. Specifically, we have developed an initial prototype of a field-based, map-enabled collaboration tool for facilitating coordination between an emergency operations center and field personnel involved in crisis management activities. The prototype uses a speech-gesture interface to a tablet computer, see: (Cai et al., 2004; MacEachren et al., 2004) – preprints included in supplementary material.

Understanding use and usability of geovisualization

As in all aspects of visualization, advances have been rapid over the past decade or more. Many new forms of visual display and new methods of display manipulation have been created. With these advances come a wide range of questions about use and usability of these display and interaction forms (Slocum et al., 2001). As we move from self-contained, individual, fixed-location geovisualization to distributed geovisualization, the issues that must be considered in design of effective geovisualization methods and tools are multiplied (Muntz et al., 2003).



Example and figure courtesy of Ken Brodlie

Grid-based collaborative geovisualization

Illustration of toxic plume simulation from the 'gViz' e-science project. Ken Brodlie and colleagues have grid-enabled IRIS Explorer, allowing modules in a pipeline to run securely on different Grid hosts. In this illustration, two collaborators are analyzing the dispersion of a pollutant from a chemical factory under the action of wind. Top left shows the mathematical modeler trying to understand the way the plume of pollutant will travel... and lower right is the meteorologist who is trying some likely different wind directions (by orienting the arrow). The simulation is steered collaboratively from the desktop. This implementation leverages COVISA to enable different-places human collaboration.

For more information, see: Jason Wood, Helen Wright and Ken Brodlie, Collaborative Visualization, Proceedings of IEEE Visualization 1997 Conference, edited by R. Yagel and H.Hagen, pp 253--260, ACM Press.

For more about related collaborative scenarios, see: Brodlie, K., Fairbairn, D., Kemp, Z., Schroeder, M., & Blechschmied, H. in press, Connecting People, Data and Resources - Distributed Geovisualization. In J. Dykes & A. M. MacEachren & M.-J. Kraak (Eds.), *Exploring Geovisualization*. Amsterdam: Elsevier.

Cartographic research includes a strong tradition of attention to both usability of maps and the underlying perceptual and cognitive factors that underpin *how maps work* (MacEachren, 1995). That tradition traces to the 1950/60s with early steps toward application of perceptual theory to map design, e.g., (Robinson, 1952, 1967), through the 1970/80s with attention to the interaction between human cognition and map use tasks, e.g., (Lloyd & Steinke, 1976; MacEachren, 1989), to the 1990s through the present with attention to the implications of dynamic behavior of our map-based and other geographic displays, driven by changing data and user behavior (Hedley et al., 2002; MacEachren et al., 1998; Slocum et al., 2003).

There are currently two complementary approaches applied in cartography (and GIScience more broadly) to understanding use and usability of geovisualization – and ultimately to making geovisualization more effective. One is grounded in cognitive science, the other is grounded in usability engineering and user centered design. Below, one example from each approach is discussed.

Cognitive science approach: The cartographic/geographic tradition of attention to perceptual and cognitive aspects of map understanding and use has been applied to assess a fundamental assumption of many InfoVis displays, *that users will intuitively understand what distance in the display means because the display is map-like*. Montello, Fabrikant, and colleagues (Montello et al., 2003) found that users of displays made up of point representations (e.g., as used in scatter plots and related displays) assume that metric distance in the display represents semantic similarity. While this may be true for simple scatterplots, this assumption will lead to misconceptions in the interpretation of information landscapes such as that in the spatialization sidebar above. In such displays a highly multivariate space is collapsed to 2 or 3 dimensions and, thus, only relative location can be maintained (and even that only in a limited way). The sidebar detailing Mark Harrower's research on the question, *Can Visual Benchmarks help users understand map animations?*, provides another recent example of a formal, cognitively informed study of effectiveness of one strategy for making map animations more effective (Harrower, 2003).

Usability engineering / user-centered design approach: As tools for visualizing geospatial data become more complex, efforts have been made to adapt usability engineering and user-centered design methods to creation of visualization environments that work. One effective recent application of these methods is a project by Slocum and colleagues (Slocum et al., 2003) to develop visualization tools targeted to helping a group of decision-makers understand uncertainty within the context of water resource problems (e.g., uncertainty related to climate change). These tools were designed for use with a wall-sized display (see figure below). Through an iterative process design, assessment, implementation, and redesign, Slocum and colleagues were able to identify and adjust for a variety of usability problems with their initial system design and (perhaps more importantly) identify some of the challenges associated with adapting standard usability methods (developed to build products with rather specific use goals) to design of visualization tools that support work on ill-structured problems in science and environmental management. Related work on application of usability engineering and user-centered design methods to development of a desktop geovirtual environment for

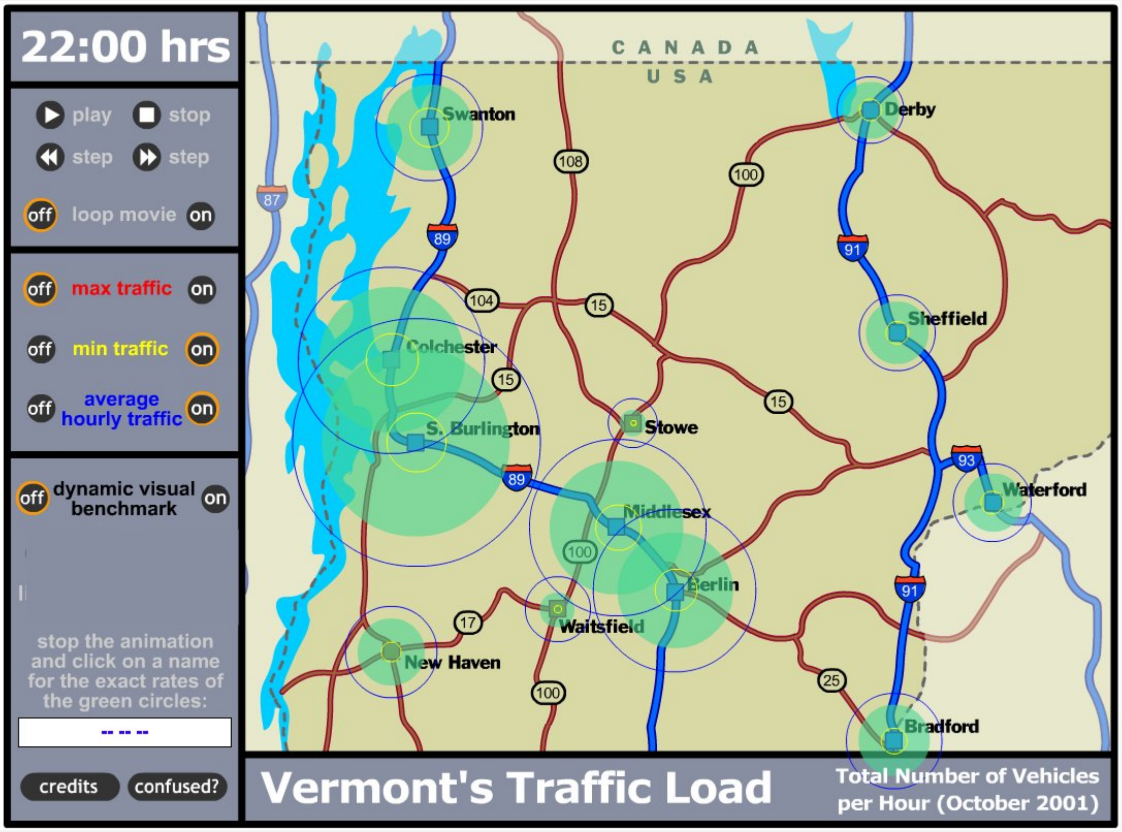


Figure and explanation courtesy of Mark Harrower

Can Visual Benchmarks help users understand map animations?

Cartographer Mark Harrower built and tested a series of animated maps that incorporate innovative temporal controls called *visual benchmarks*, a technique that allow users to display multiple time periods simultaneously in animated maps. Although map animation is a powerful and intuitively appealing approach to representing change, long and complex animated map sequences burden the short-term memory skills of most users. Visual benchmarks were designed to help map readers cope with long, complex animations by shifting some of the cognitive burden of understanding patterns of geographic change from short-term memory to the display itself. Benchmarking is a form of bivariate mapping—the second "variable" is the *same* variable but at a *different point in time* —which allows map readers to compare different moments of the animation simultaneously in an integrated display.

Harrower refined these maps using focus groups and a pilot study, and tested them with formal task-based experiments. He discovered that although benchmarks were not used as often by test subjects as hoped (which raises interesting questions about how to best train users on the use of new visualization tools), results suggest that benchmarks were more helpful on proportional symbol maps (as above) than on isoline maps (not shown), leading to a small but significant increase in the test score accuracy of subjects (but at the cost of increasing response time).

Details are described in:

A Harrower, M. (2002). *Visual Benchmarks: Representing Geographic Change with Map Animation* (PhD Dissertation). The Pennsylvania State University.

Harrower, M. (2002). "Visual Benchmarks: A new method for enhancing animated maps." Paper presented at *North American Cartographic Information Society (NACIS) XXII*, Columbus, Ohio, October 2002.

Harrower, M. 2003, Tips for Designing Effective Animated Maps. *Cartographic Perspectives* (44), 63-65.

See online examples at http://www.geography.wisc.edu/~harrower/dissertation/index.html

Figure courtesy of James R. Miller

landscape planning is described in the sidebar on *User-centered Virtual Environment design*.

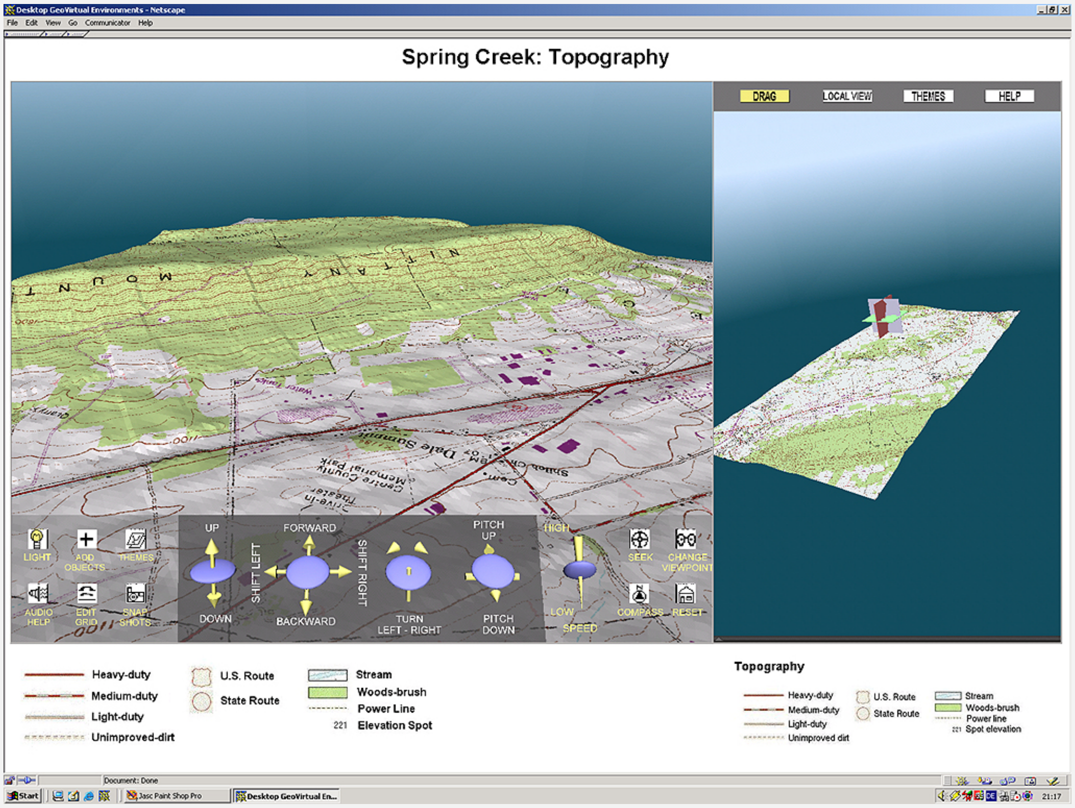
For a more comprehensive discussion of approaches to application of cognitive science and usability perspectives and methods to geovisualization, see: (MacEachren & Kraak, 2001; Slocum et al., 2001). Both papers are available in slightly extended, prepublication form from: http://www.geovista.psu.edu/sites/icavis/agenda/index.html

Conclusions

This short introduction to distributed geovisualization can only scratch the surface of the challenges and opportunities that exist for collaboration between GIScientists, computer scientists, designers, cognitive scientists, and others. The references below will allow the interested participant to follow some of the leads provided here. Another excellent source of information about ongoing developments in geovisualization is the web site of the International Cartographic Association Commission on Visualization & Virtual Environments: www.geovista.psu.edu/icavis.

Finally, a forthcoming book provides perspectives on visualization from more than 30 authors representing several disciplines: Dykes, J., MacEachren, A. M., & Kraak, M.-J. eds., in press, *Exploring Geovisualization*. Amsterdam: Elsevier.

User-centered Virtual Environment design



Example and figure courtesy of Sven Fuhrmann

Sven Fuhrmann examined how human wayfinding could be better supported in virtual environments. Virtual environments are used in a range of geovisualization contexts but many cases of humans feeling disoriented are reported. In his research Sven Fuhrmann utilized a “flying saucer” and the map concept as metaphors for designing graphic user interfaces for navigation. The flying saucer metaphor (pictured as a blue sphere in the figure above) was realized as heads-up display in the user’s egocentric frame of reference (left view) and provided basic navigation functions in the virtual space while the accompanying map (exocentric frame of reference; right view) displayed the user’s position, utilizing a movable position indicator.

The prototypes were designed using a user-centered design approach. During the design process landscape planners were volunteering as participants in knowledge elicitation sessions (user and task analysis) and as usability test participants. Interviews, questionnaires, and scenarios were used to capture knowledge and wayfinding tasks of landscape planners and built the basis for initial prototype designs. Focus groups, heuristic evaluations and thinking aloud studies were used to test the prototype designs on their usability.

The results of the usability studies indicated that three basic mechanisms can support wayfinding in virtual environments:

- displaying spatial frames of reference simultaneously ,
- providing corresponding navigation functions in both reference frames and
- integrating a "You-are-here"-symbol (position indicator) in the exocentric frame of reference.

Details are described in:

Fuhrmann, S. 2003, Supporting wayfinding in desktop geovirtual environments. In: M. P. Peterson (Ed.): Maps and the Internet, Elsevier, London, pp. 271-287.

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Topic 2: New Directions in Distributed Geovisualization

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Overview

A. **Brief background**
   1. cartography & geovisualization
   2. geovisualization, scientific visualization, and information visualization

B. **Distributed geovisualization defined**
   1. drawing upon distributed resources for geovisualization
   2. geovisualization distributed among individuals
   3. geovisualization distributed in the real world

C. **Use & Usability**

D. **Looking ahead**

A: Background

- **traditional foci in cartography:**
  - capturing information about and representing the physical world
  - developing innovative strategies for visual analysis and information abstraction that take advantage of the power of human vision
- **both are inputs to *geovisualization***

Geographic Visualization (geovisualization)

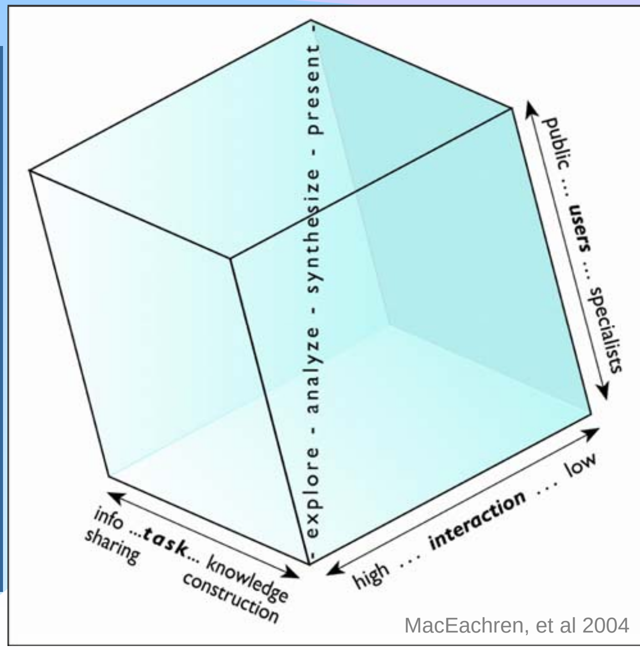
- **the use of visual representations—of geospatial information—to facilitate thinking, understanding, and knowledge construction—about aspects of the geographic scale human and physical environment**
- **the creation of those visual representations**

functions of geovisualization

explore
analyze
synthesize
present

dimensions of use

tasks
users
interaction



links to other developments in visualization

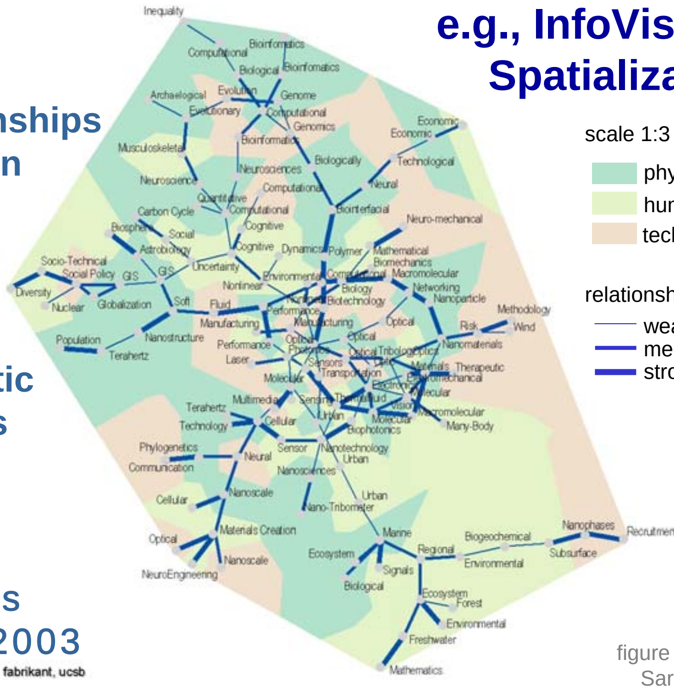
- **traditional foci in cartography:**
  - capturing information about and representing the physical world (e.g., visualizing landscapes, geology, climate processes) ←→ SciVis
  - developing innovative strategies for visual analysis and information abstraction that take advantage of the power of human vision (e.g., visualizing health statistics, demographic trends, multivariate inputs to landcover classification) ←→ InfoVis

e.g., InfoVis and Spatialization

lines = relationships between grants

color = semantic regions

NSF IGERT awards 1998-2003



scale 1:3

- physical
- human
- tech./eng.

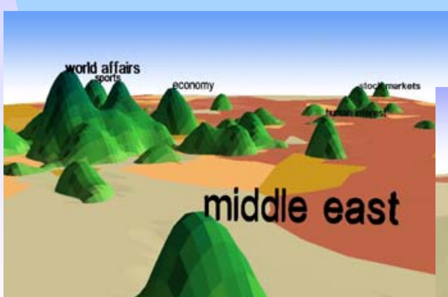
relationships

- weak
- medium
- strong

figure courtesy of Sara Fabrikant

e.g., InfoVis and Spatialization

a news landscape
peaks = dense document clusters



fog hides all news below a query threshold

figures courtesy of Sara Fabrikant

B: Distributed Geovisualization

- drawing upon **distributed** resources for geovisualization
- geovisualization use **distributed** among individuals – multiuser geovisualization
- geovisualization use **distributed** in the real world – multisite, synchronous geovisualization

GeoVISTA SIGGRAPH 2004 Course #30: Visualizing Geospatial Data –Topic 2, Aug. 10, 2004

B1: Distributed resources for geovisualization

- "traditional" modular visualization environments: e.g., AVS, IRIS Explorer, IBM DX
- open, component-based visualization environments
- GeoVISTA *Studio*

GeoVISTA SIGGRAPH 2004 Course #30: Visualizing Geospatial Data –Topic 2, Aug. 10, 2004

Open, component-based visualization environments

- **Snap-together-visualization:** **Chris North Center for Human-Computer Interaction, and Department of Computer Science, Virginia Tech** – infovis.cs.vt.edu/snap
- **Geovisualization:**
  - GeoTools: started in 1996, University of Leeds. GT1 – Java Applet API, now GeoTools-Lite. GT2 – seeks to implement OpenGIS Consortium (OGC) specifications – www.geotools.org
  - GeoVISTA Studio: Mark Gahegan, GeoVISTA Center, Penn State University – geovistastudio.sourceforge.net/

Maps in Snap: with ESRI *MapObjects*

- **DataMaps:** **To be distributed on the upcoming Counties USA cdrom by US Census Bureau**

Includes 8000 census variables, supports multiple Dynamic Queries, (developed with participation of HCIL, Univ. of MD, College Park)

figure courtesy of Chris North

SIGGRAPH 2004 Course #30: Visualizing Geospatial Data –Topic 2, Aug. 10, 2004

http://docs.codehaus.org/display/GEOTOOLS/Map+and+style+tutorial

Geotools: *OpenGIS* compliant components

map structure in GeoTools

can think of a map as an ordered list of layers, where each layer is rendered on top of the previous ones according to the data it contains (the feature source) following certain painting rules (the style).

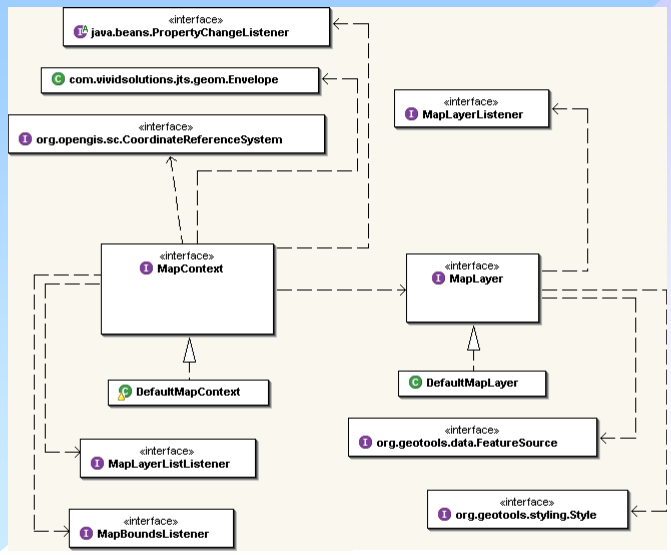


figure courtesy of James Macgill

http://docs.codehaus.org/display/GEOTOOLS/Map+and+style+tutorial

Geotools: *OpenGIS* compliant components

GeoTools2 maps

Geotools2 provides map symbolizing by implementing the **Styled Layer Descriptor** OpenGIS standard. Map shown with magnifier on.

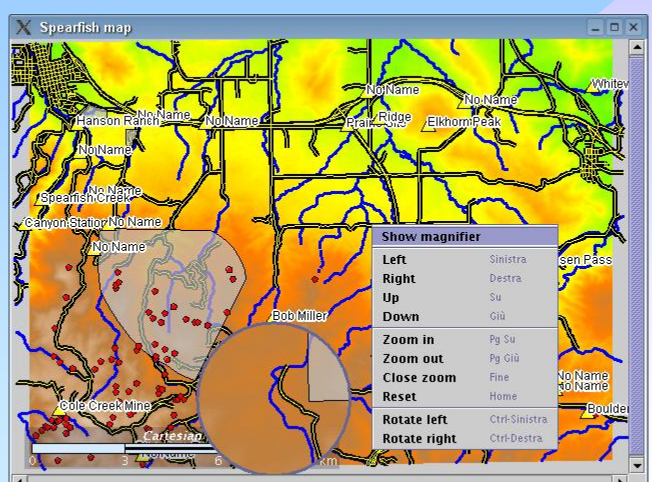


figure courtesy of James Macgill

Maps in Snap: with *Geotools*

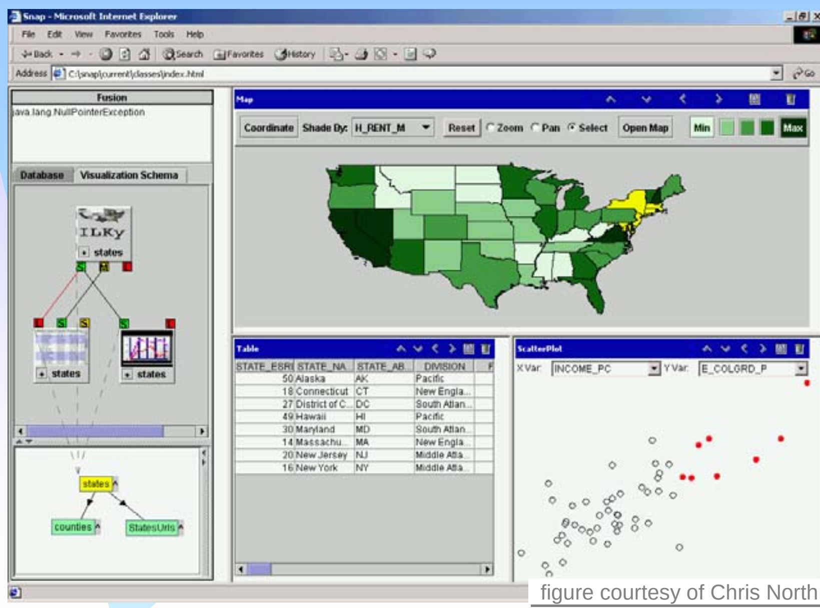
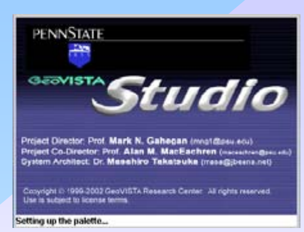


figure courtesy of Chris North

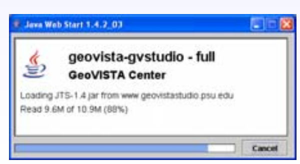
GeoVISTA *Studio*

- Conceptual background and architecture
- Multivariate visualization
- Color selection tools
- Geovisualization + computational analysis
- adding visual-computational knowledge representation tools

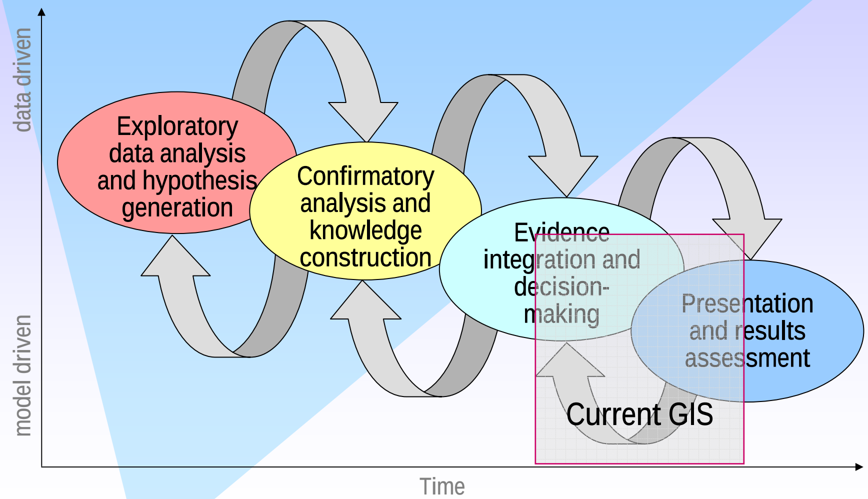
geovistastudio.sourceforge.net/



Project Director:
Dr. Mark Gahegan
system architect now:
Dr. James Macgill

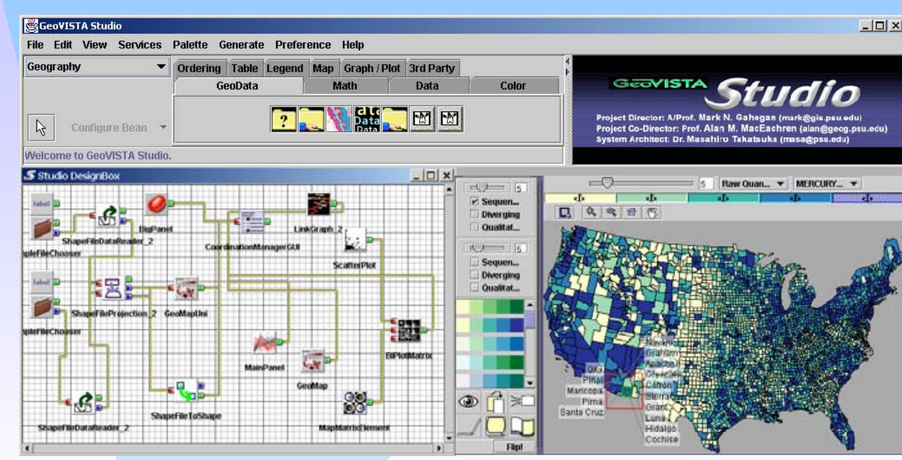


Conceptually … our focus is on understanding the *process* of geospatial information use



adapted from figure by Mark Gahegan

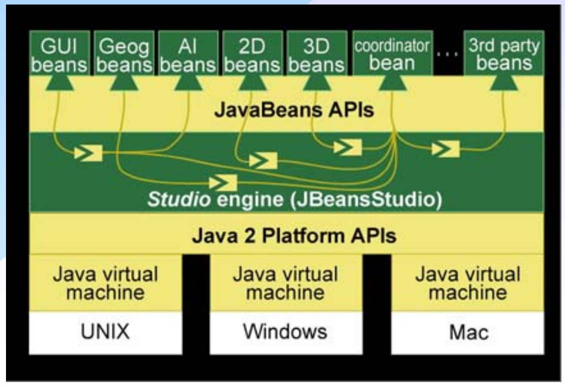
GeoVISTA *Studio*: typical application



A Java, component-based, visual programming environment for development of applications and applets that **integrate visual, statistical, & computational methods** for (geospatial) data exploration, analysis & knowledge construction

Studio Architecture: Application Builder

- *Studio* employs JavaBean technology to construct tools. The JavaBean specification defines a set of standardized APIs for the Java platform.
- From this, the *builder* automatically constructs a syntactic description of the functionalities and i/o methods of any bean.



GeoVISTA *Studio*: Types of Users

- **Component Developers**

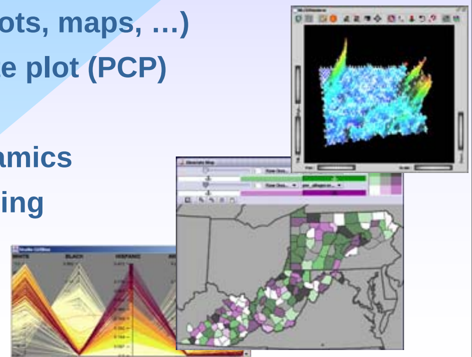
  Build JavaBeans components to produce new tools. These new tools are imported into *Studio* and tested.
- **Application Developers**

  Construct and disseminate data analysis/visualization applications to address specific problem domains
- **Application Users**

  Do not use *Studio* directly. Instead, use standalone applications or applets produced by *Studio*.

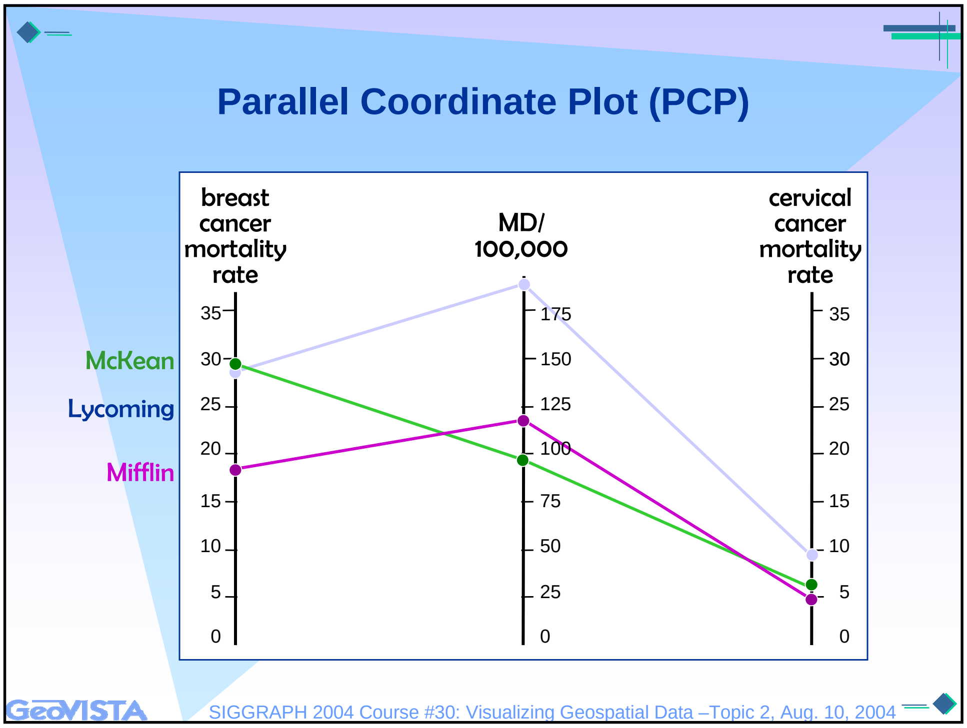
Studio functionality a sampling

- data transformation and statistics (conventional, spatial)
- a visual classifier including color selection (ColorBrewer)
- multivariate classification: self-organising map, learning vector quantisation, k-means, maximum likelihood
- a multiform matrix (scatterplots, maps, …)
- interactive parallel coordinate plot (PCP)
- 2D dynamic map
- 3D rendering, including dynamics
- spatial & multivariate clustering
- minimum spanning tree
- time series plots



Multivariate visualization methods

- Dynamic Parallel Coordinate Plot (PCP)
- Multiform Matrices


Parallel Coordinate Plot (PCP)
breast cancer mortality rate
MD/ 100,000
cervical cancer mortality rate
McKean
Lycoming
Mifflin
35
30
25
20
15
10
5
0
175
150
125
100
75
50
25
0
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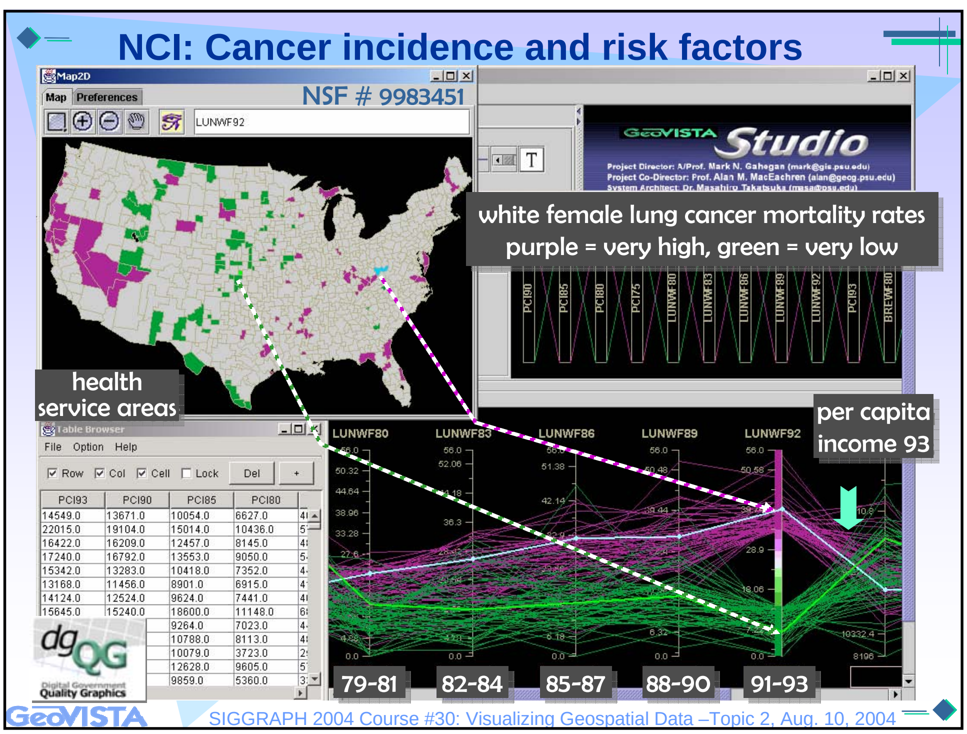
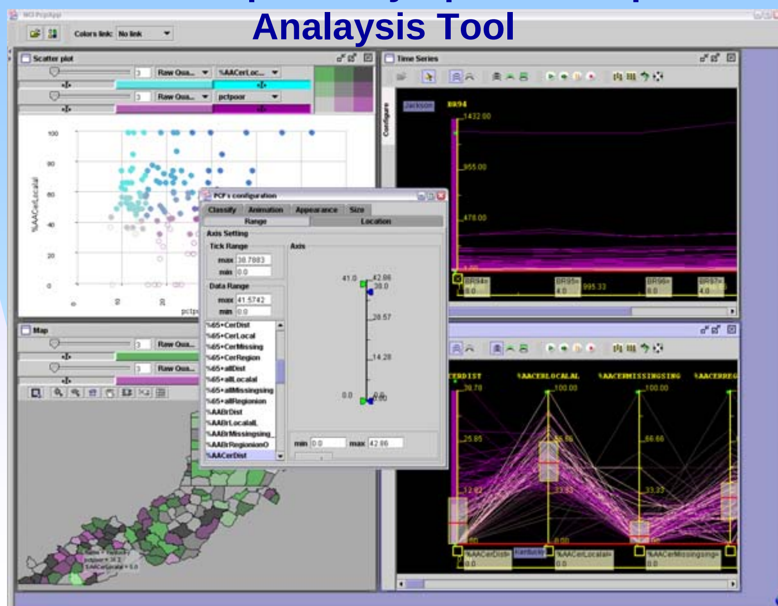
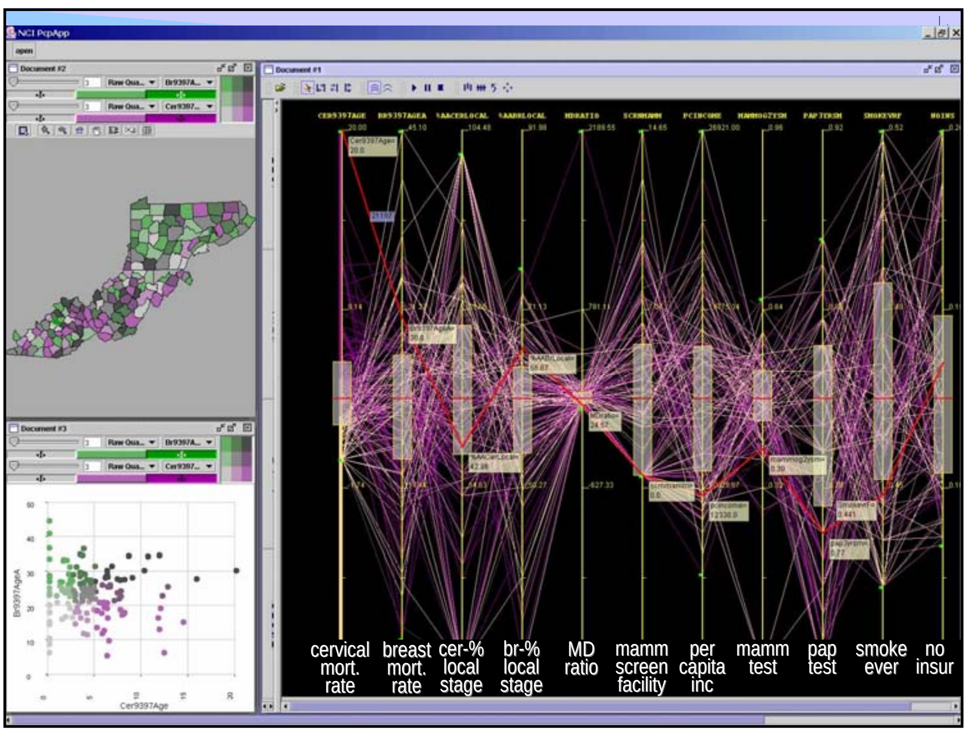
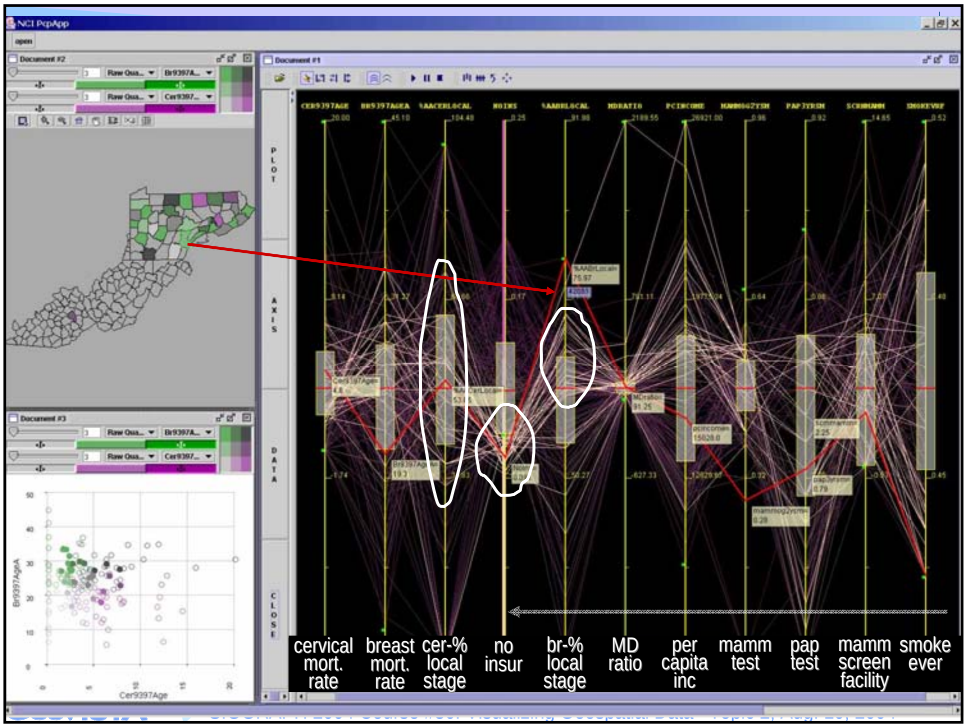

NCI: Cancer incidence and risk factors
Map2D
Map
Preferences
NSF # 9983451
LUNWF92
GeoVISTA Studio
white female lung cancer mortality rates
purple = very high, green = very low
health service areas
per capita income 93
Table Browser
File Option Help
Row Col Cell Lock Del
PCI93
PCI90
PCI85
PCI80
LUNWF80
LUNWF83
LUNWF86
LUNWF89
LUNWF92
79-81
82-84
85-87
88-90
91-93
Digital Government Quality Graphics
GeoVISTA
SIGGRAPH 2004 Course #30: Visualizing Geospatial Data –Topic 2, Aug. 10, 2004

ESTAT: Exploratory Spatial-Temporal Analysis Tool

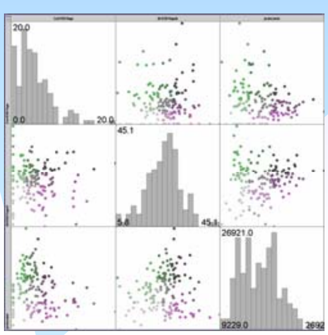




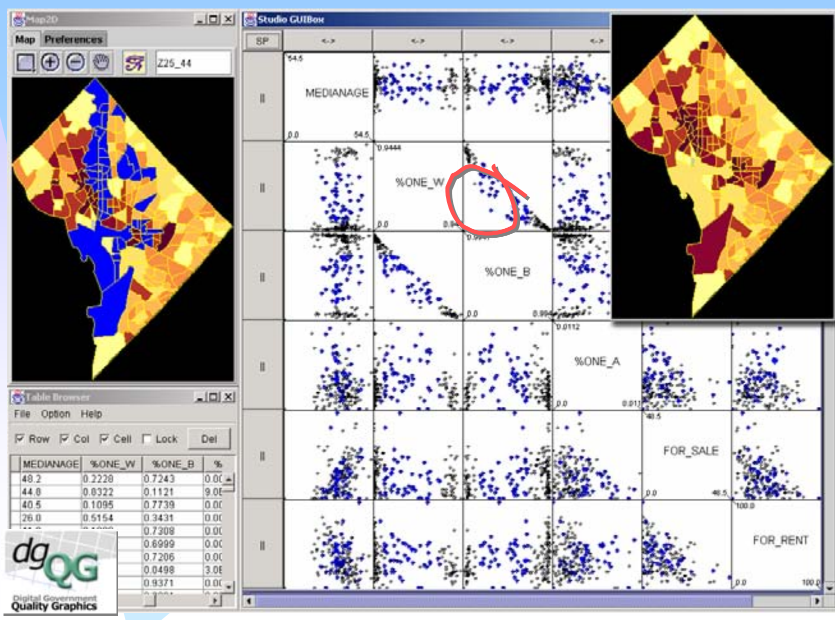


Multiform Displays

- **Bivariate Matrix – matrices extending the scatterplot metaphor:**
  - UniForm Bivariate Matrix – matrix with one representation form (e.g., all scatterplots);

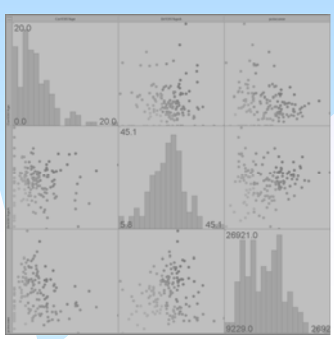


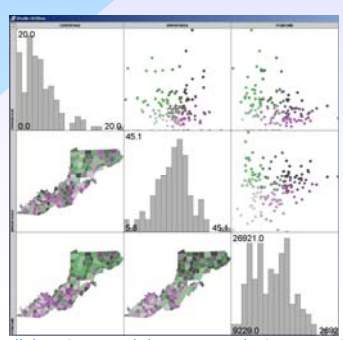
Census: DC race & housing

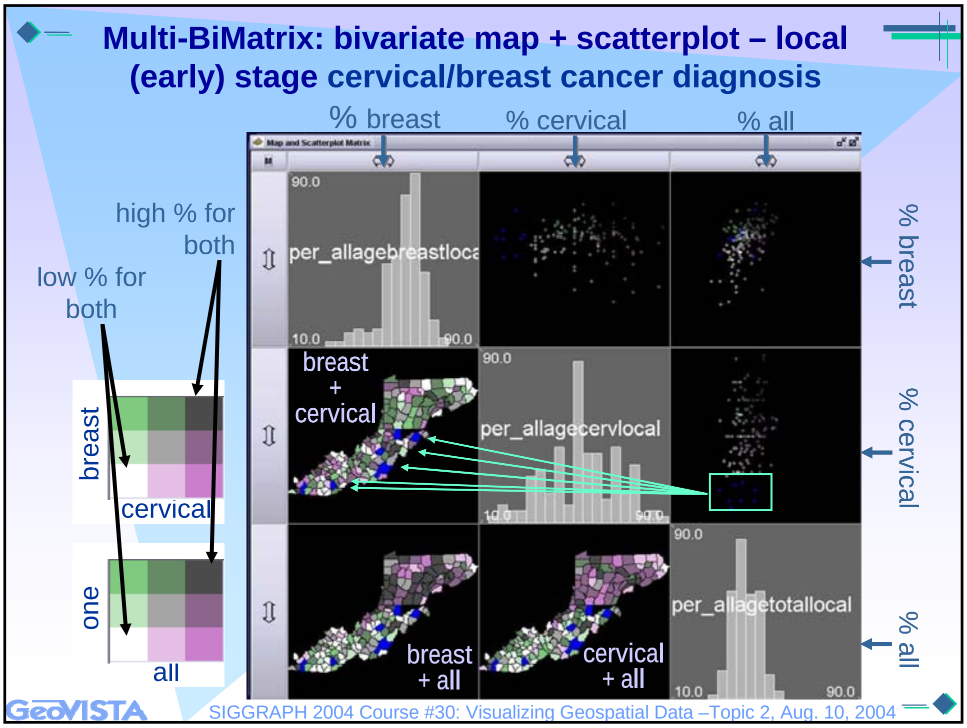


Multiform Displays

- **Bivariate Matrix – matrices extending the scatterplot metaphor:**
  - UniForm Bivariate Matrix – matrix with one representation form (e.g., all scatterplots);
  - MultiForm Bivariate Matrix – matrix with two (or more) bivariate representation forms (e.g., maps + scatterplots).






Multi-BiMatrix: bivariate map + scatterplot – local (early) stage cervical/breast cancer diagnosis
% breast
% cervical
% all
high % for both
low % for both
breast
cervical
one
all
Map and Scatterplot Matrix
90.0
per_allagebreastloca
10.0
90.0
breast + cervical
per_allagecervlocal
per_allagetotallocal
breast + all
cervical + all
% breast
% cervical
% all
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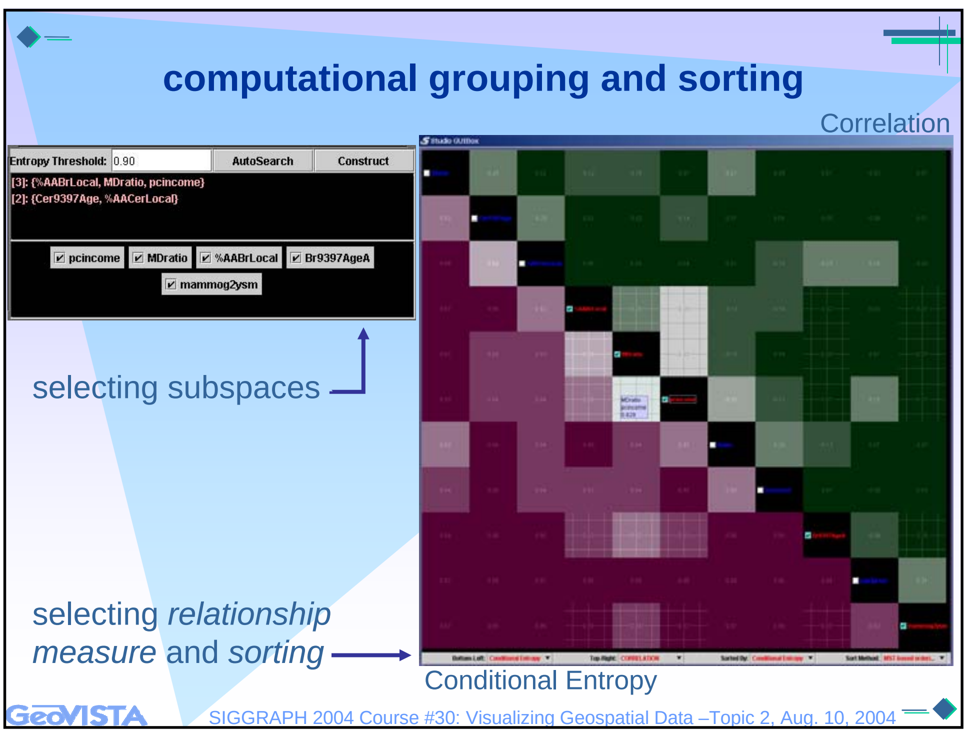
computational grouping and sorting
Correlation
Entropy Threshold: 0.90
AutoSearch
Construct
[3]: {%AABrLocal, MDratio, pcincome}
[2]: {Cer9397Age, %AACerLocal}
pcincome
MDratio
%AABrLocal
Br9397AgeA
mammog2ysm
selecting subspaces
selecting relationship measure and sorting
Conditional Entropy
GeoVISTA
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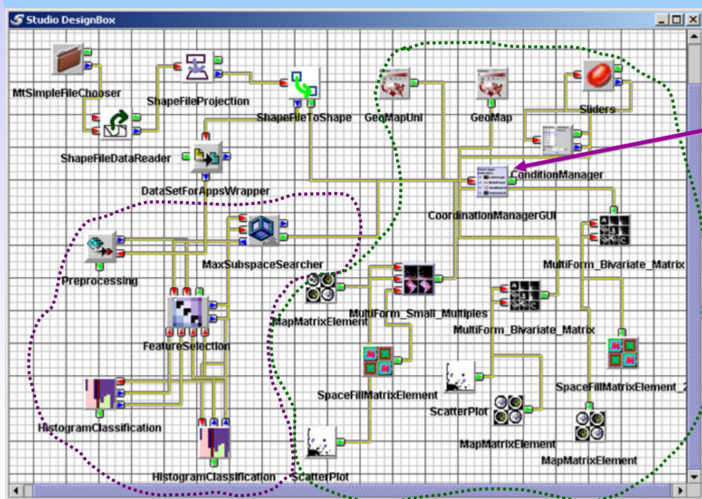
design incorporating several multiform displays and computational sorting



Coordination manager

computational sorting

multiform displays

Typology of interaction, an (Inter)action ontology

(with Mark Gahegan, Frank Hardisty & Junyan Lou)

Session events: start, end

Selection events: brush, focus, sample, indication

Data events: data, metadata

Visual events: visual classification, visual mapping

- How should different components respond to these events?
- Which events should they respond to?
- Do all users and applications share this list?
- How can we be more flexible?

Color schemes

- ColorBrewer – online univariate color scheme selectin tool
- *Studio* ColorBrewer extended

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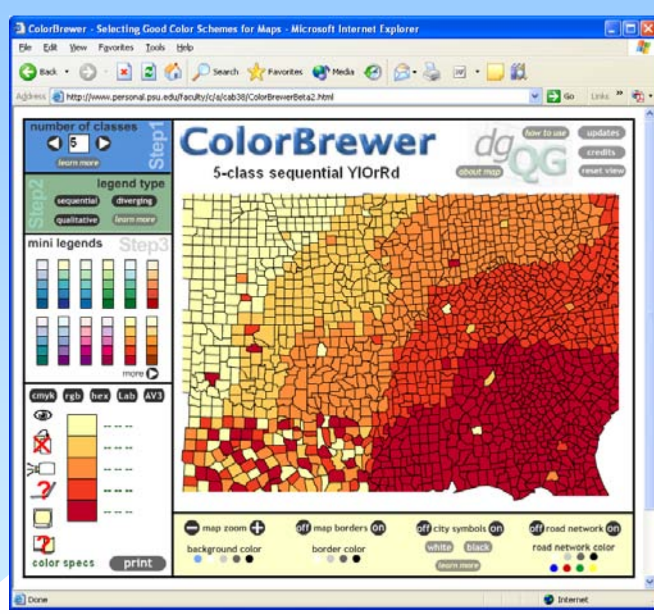
ColorBrewer

promoting logical & effective use of color for data visualization



Cynthia Brewer & Mark Harrower
NSF (EIA-9983459)

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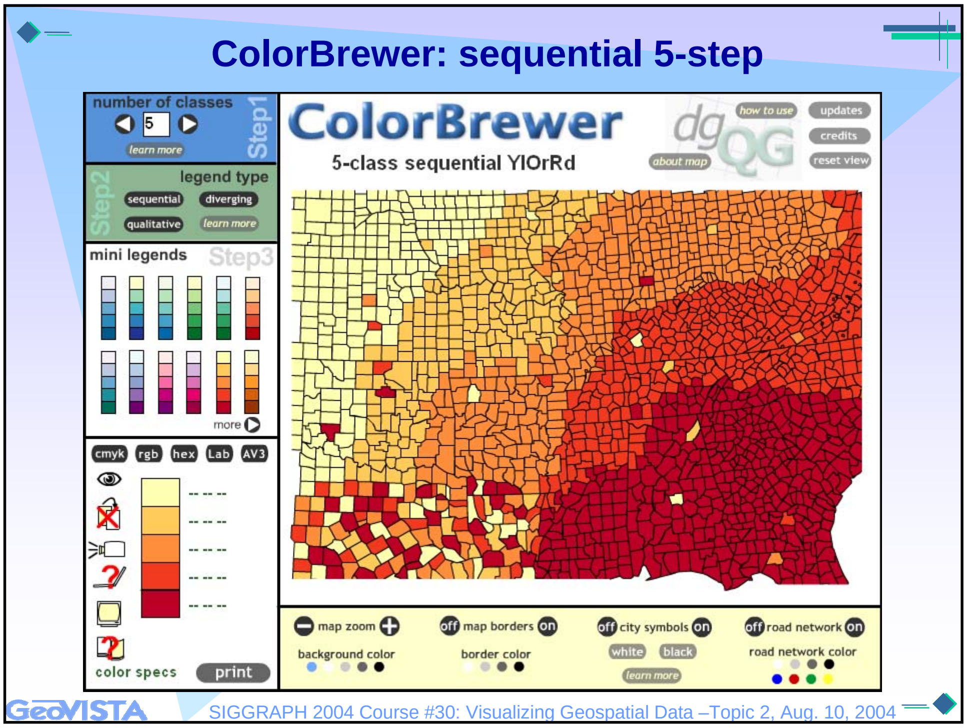
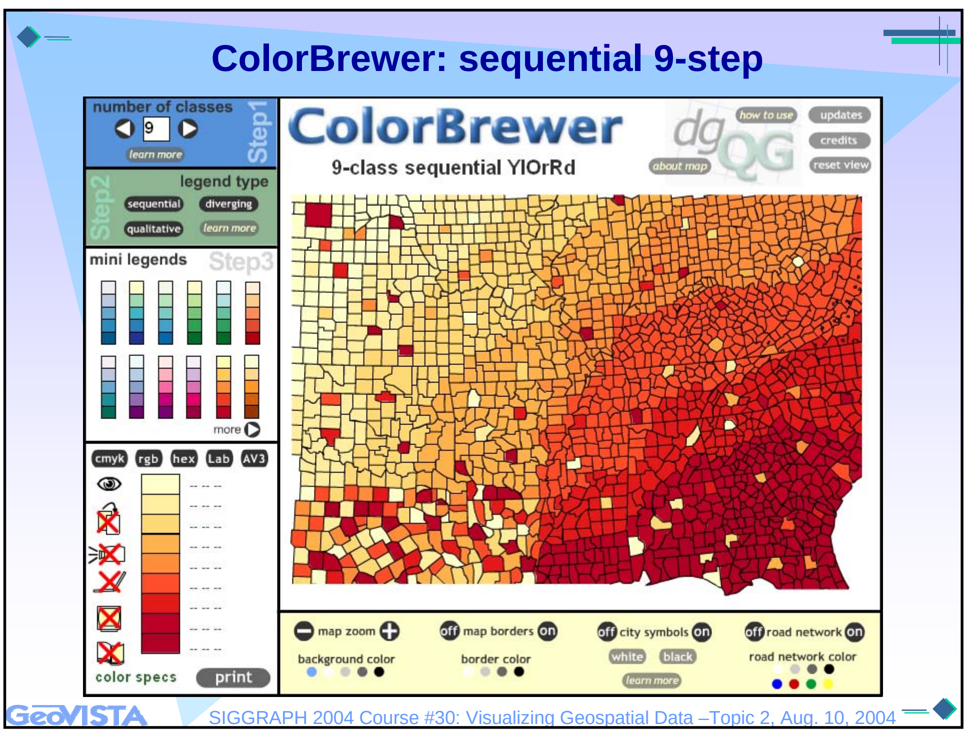
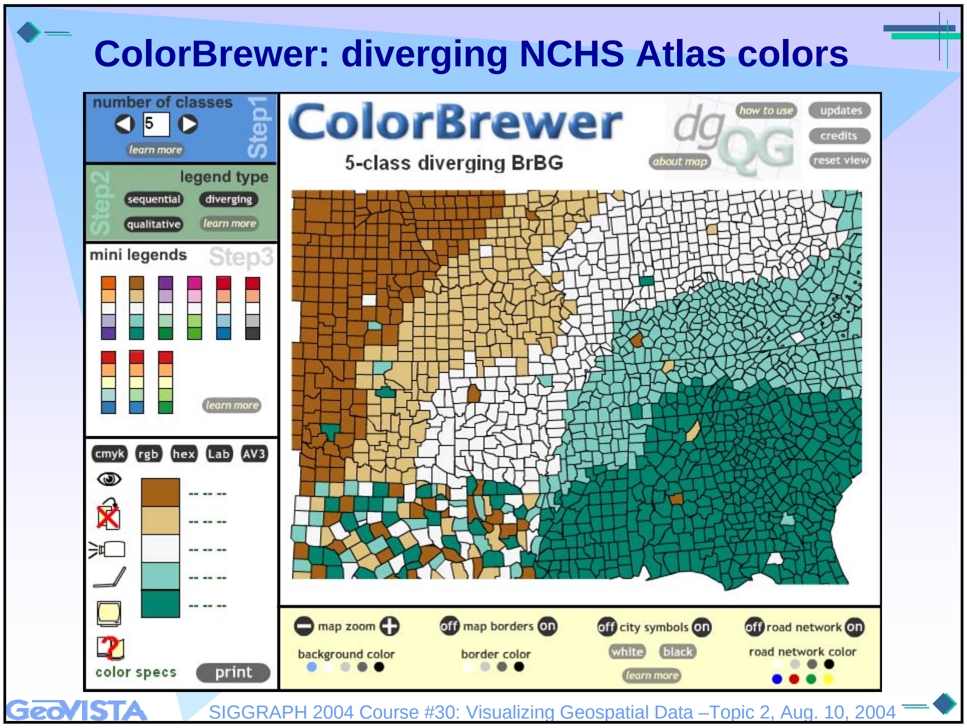
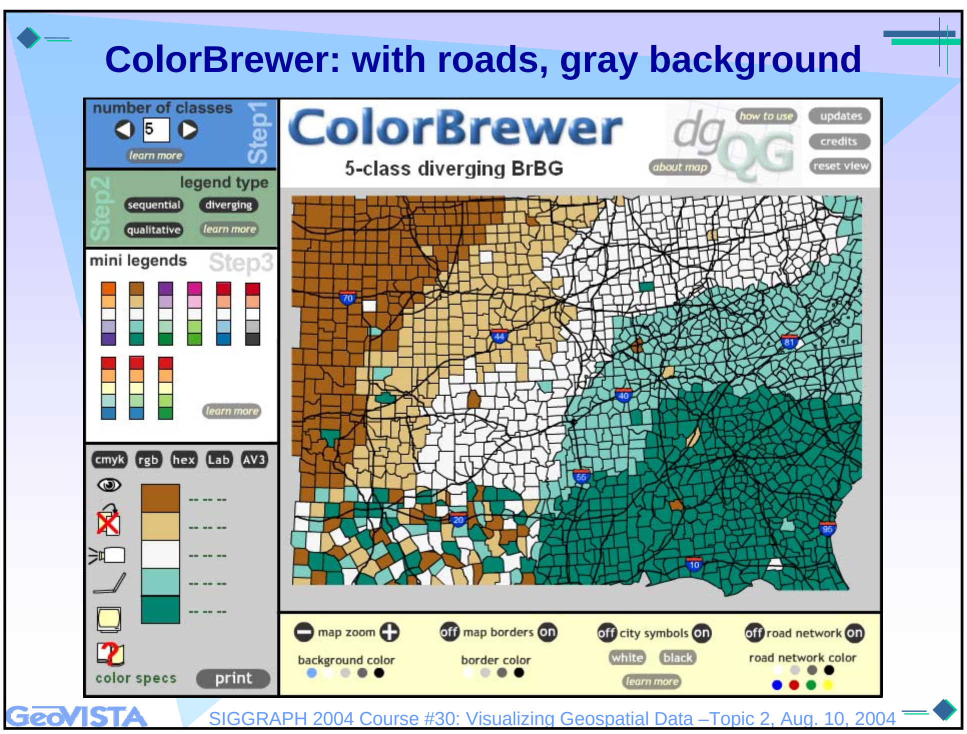


ColorBrewer: sequential 5-step
number of classes
5
learn more
Step1
Step2
legend type
sequential
diverging
qualitative
learn more
mini legends
Step3
more
cmyk rgb hex Lab AV3
color specs
print
ColorBrewer
5-class sequential YlOrRd
how to use
updates
credits
reset view
about map
map zoom
off map borders on
off city symbols on
off road network on
background color
border color
white black
learn more
road network color
SIGGRAPH 2004 Course #30: Visualizing Geospatial Data –Topic 2, Aug. 10, 2004



ColorBrewer: sequential 9-step
number of classes
9
learn more
Step1
Step2
legend type
sequential
diverging
qualitative
learn more
mini legends
Step3
more
cmyk rgb hex Lab AV3
color specs
print
ColorBrewer
9-class sequential YlOrRd
how to use
updates
credits
reset view
about map
map zoom
off map borders on
off city symbols on
off road network on
background color
border color
white black
learn more
road network color
SIGGRAPH 2004 Course #30: Visualizing Geospatial Data –Topic 2, Aug. 10, 2004


ColorBrewer: diverging NCHS Atlas colors
number of classes
5
learn more
Step1
legend type
sequential
diverging
qualitative
learn more
Step2
mini legends
Step3
learn more
cmyk rgb hex Lab AV3
color specs
print
ColorBrewer
5-class diverging BrBG
how to use
updates
credits
reset view
about map
map zoom
off map borders on
off city symbols on
off road network on
background color
border color
white black
learn more
road network color
GeoVISTA
SIGGRAPH 2004 Course #30: Visualizing Geospatial Data –Topic 2, Aug. 10, 2004


ColorBrewer: with roads, gray background
number of classes
5
learn more
Step1
legend type
sequential
diverging
qualitative
learn more
Step2
mini legends
Step3
learn more
cmyk rgb hex Lab AV3
color specs
print
ColorBrewer
5-class diverging BrBG
how to use
updates
credits
reset view
about map
map zoom
off map borders on
off city symbols on
off road network on
background color
border color
white black
learn more
road network color
GeoVISTA
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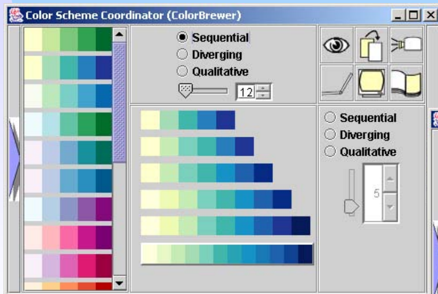
ColorBrewer in *Studio*

Sequential
univariate schemes

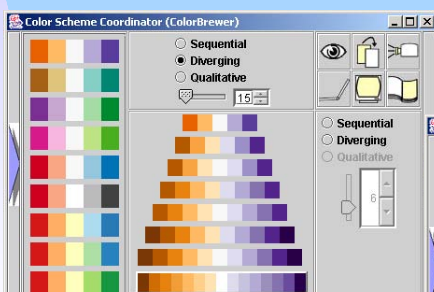


Sequential
bivariate schemes

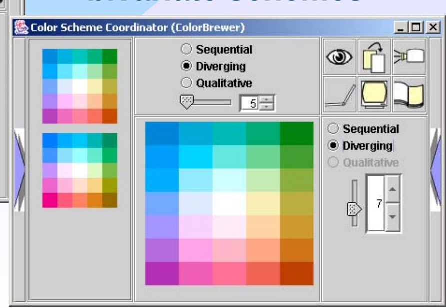
implemented by Biliang Zhou,
Geography MS student

ColorBrewer in *Studio*

Diverging
univariate schemes



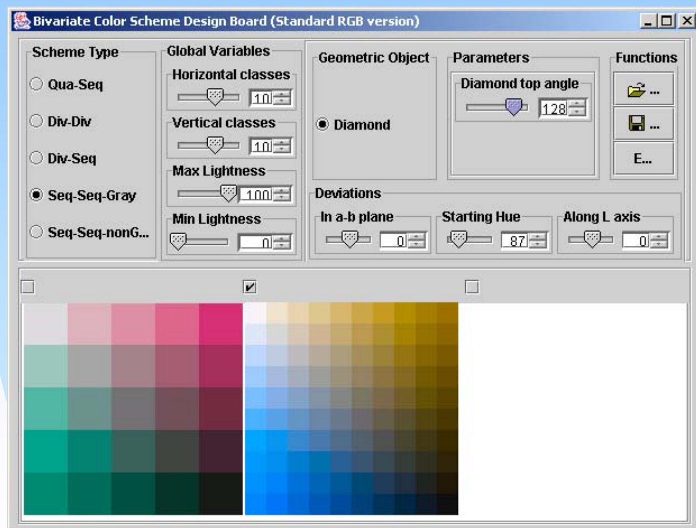
Diverging
bivariate schemes



implemented by Biliang Zhou,
Geography MS student

Bivariate color scheme design board

building sequential-sequential schemes



implemented by Biliang Zhou, Geography MS student

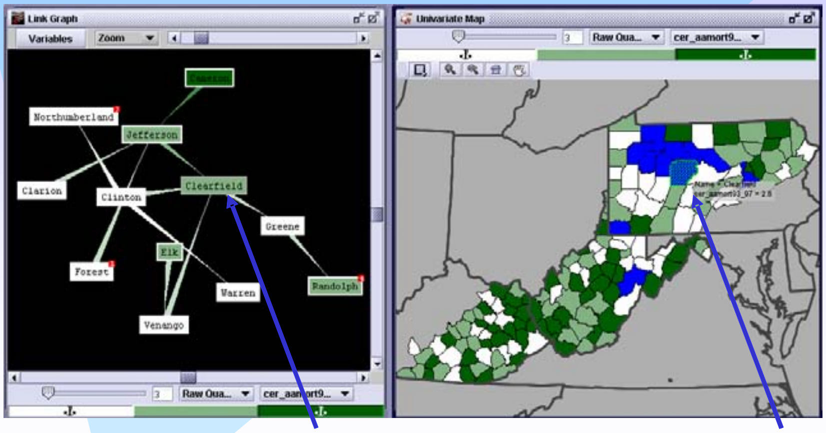
Integraing computational methods

- Minimum spanning tree method to find related places – depicted with a dynamic link graph
- multivariate cluster detection and geospatial data mining

GeoVISTA SIGGRAPH 2004 Course #30: Visualizing Geospatial Data –Topic 2, Aug. 10, 2004

link graph depicting a minimum spanning tree search through a multidimensional space

tool developed by Frank Hardisty (hardity@sc.edu)

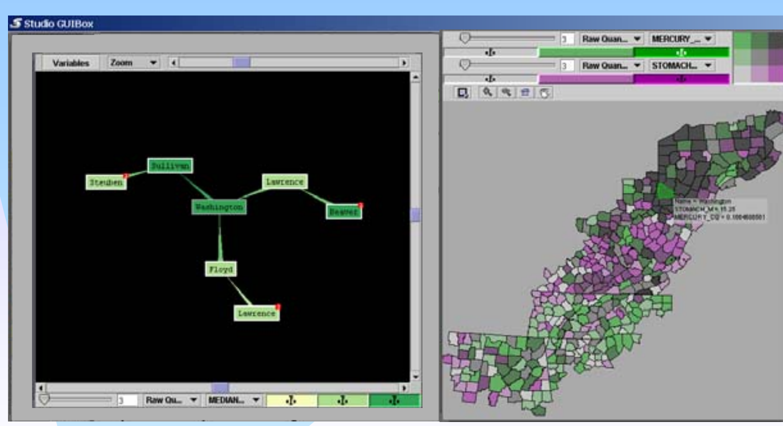


Clearfield

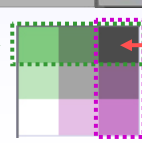
Clearfield

link graph … ***dynamically linked to*** … **map**

NCI/EPA: Cancer incidence and risk factors



high mercury emissions →



high on both

high stomach cancer mortality rate

visual geospatial data mining

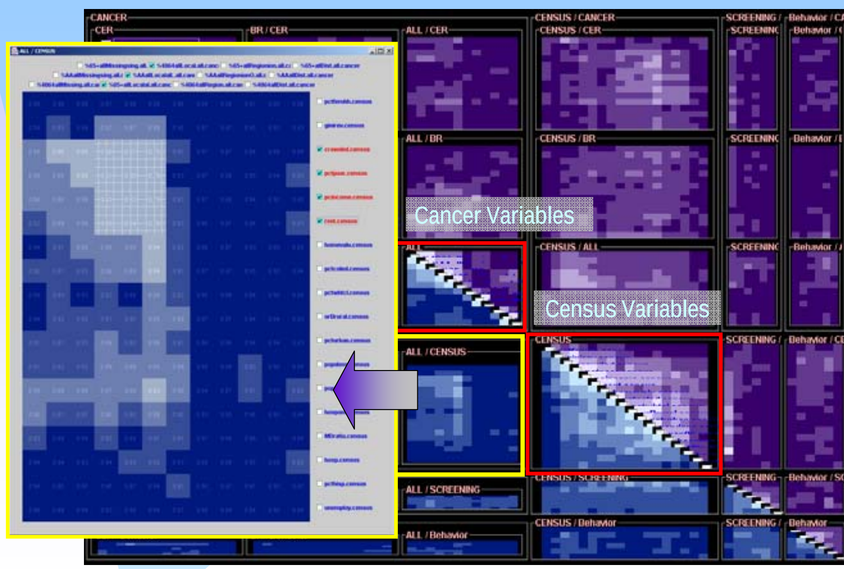


figure courtesy of Diansheng Guo

visual geospatial data mining

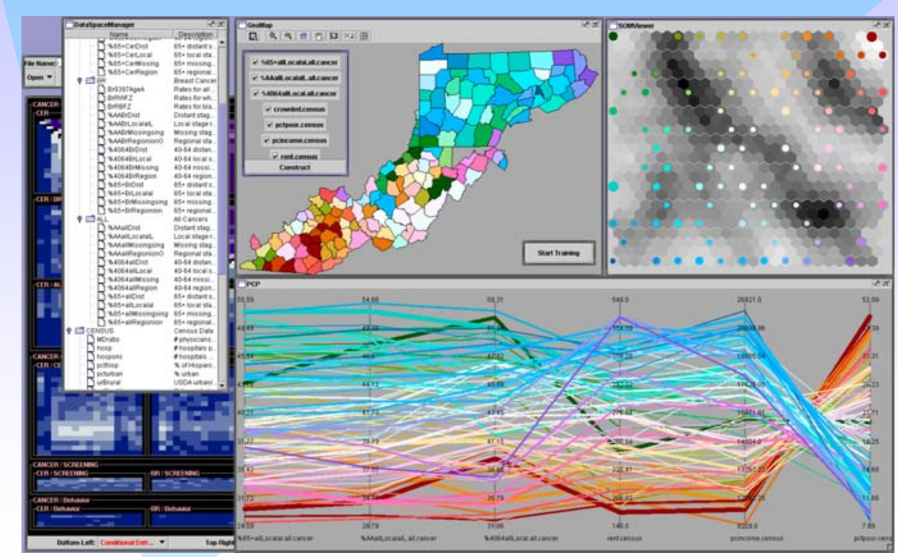


figure courtesy of Diansheng Guo

Final *Studio* comments

- *Studio* is FREE and open source, you can download it from:
  - geovistastudio.sourceforge.net/
- If you develop tools in Java, we would be delighted to work with you so that they work effectively with existing *Studio* components.

B2: Geovisualization distributed among individuals

- some challenges
- geovisualization for geocollaboration: some definitions & concepts
- example: visually-enabled collaboration in an emergency operation center
  - human-system collaborative dialogue
  - human-system-human dialogue

geovisualization for geocollaboration: definitions

- **computer-supported *cooperative* work (CSCW):** computer-enabled group work with information (can be by "agents" performing very different tasks)
- **collaboration:** a cooperative activity in which two or more "agents" work on a single task or closely related subtasks, constructing and maintaining a shared problem conception

→→ Geocollaboration:

group work *with* geospatial information *through* geospatial technologies

	same time synchronous	different time asynchronous
same place	emergency operations center	ship's navigation table
different place	Web video/data conferencing & chat	science work eDelphi Codex

visually-enabled geocollaboration

e.g. geovisualization + multicriteria decision tools

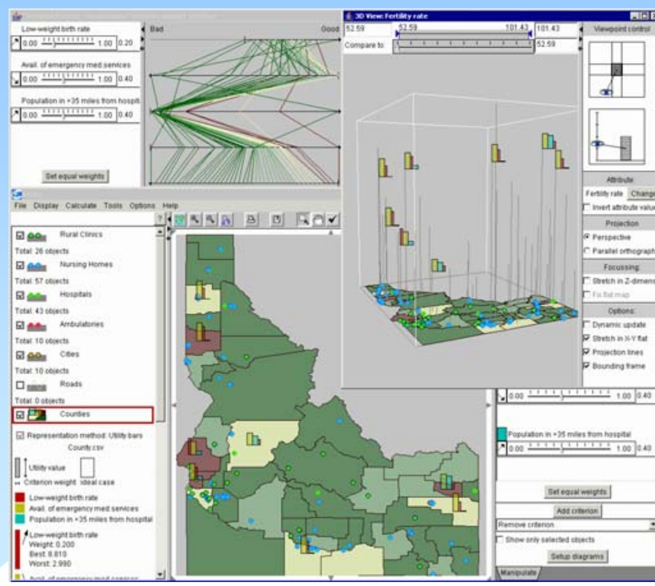


figure courtesy of Natalia & Gennady Andrienko

Concepts: Visual representation to mediate geocollaboration = boundary objects

- **shared objects to talk about**: frame the work context, e.g. maps to provide geo-context
- **shared objects to think with**: support idea sharing and structure decision-making, e.g., argument visualization and SDSS
- **shared objects to coordinate actions**: provide activity awareness and support action, e.g., visualization of the work process and command/control

→ *visual tools to enable dialogue*

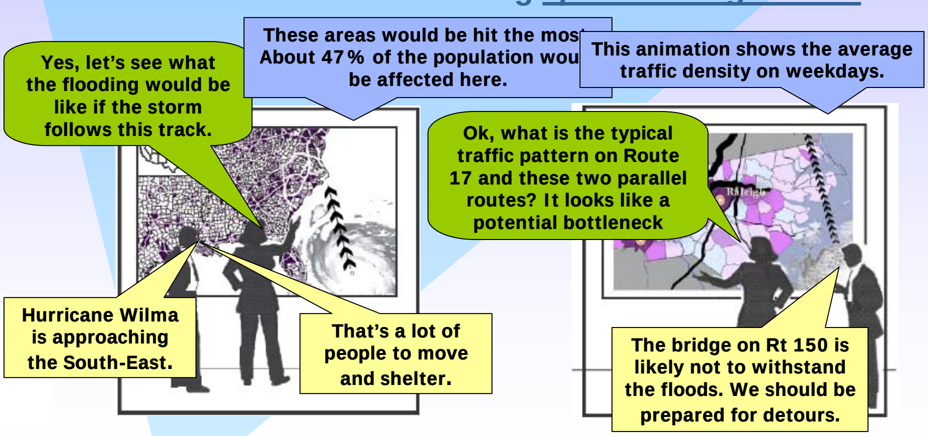
concepts: metaphors for geocollaborative tools

- space
- wall map/white board
- drafting table
- notebook

e.g., enabling collaboration in an EOC

Dialogue-Assisted Visual Environment for Geoinformation

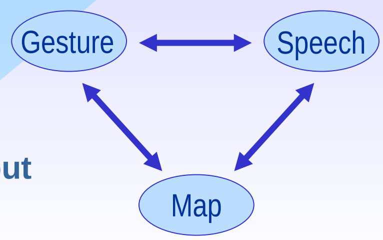
- DAVE_G: Intelligent GIS that understands natural, human communication using ***speech and gestures***



NSF ITR project (BCS-0113030); CoPIs: Rajeev Sharma & Guoray Cai

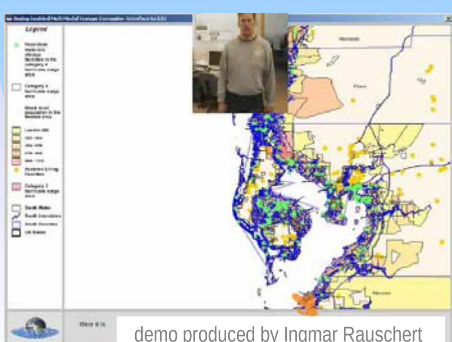
Challenges in multimodal interfaces

- **Sensing multimodal data**
  - detection/localization/tracking
  - signal capture
- **recognizing user's communication acts**
  - speech recognition
  - gesture recognition
- **fusing modalities**
- **interpreting multimodal input**
  - using context and dialogue

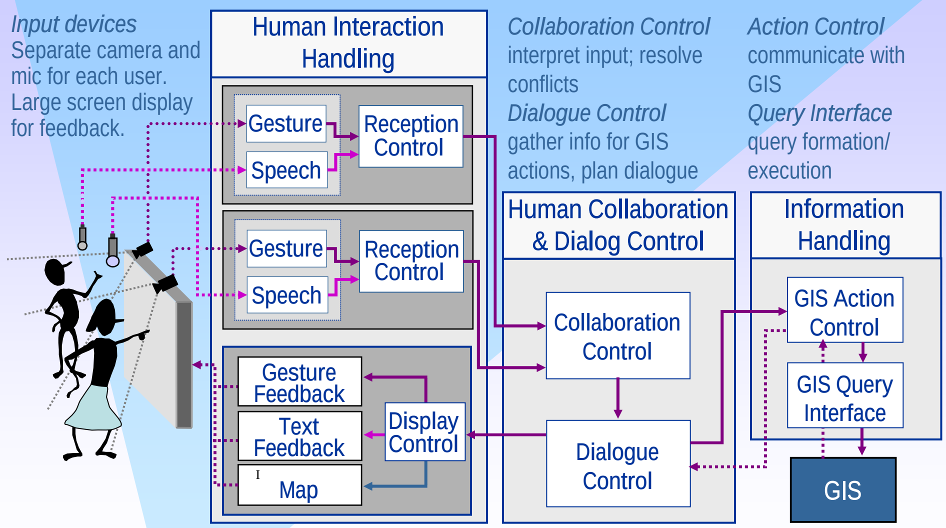


Details: Sharma, R., Yeasin, M., Krahnstoever, N., Rauschert, I., Cai, G., Brewer, I., MacEachren, A. M., & Sengupta, K. 2003, Speech-gesture driven multimodal interfaces for crisis management. *Proceedings of the IEEE,* **91**(9), 1327-1354.

DAVE_G prototype human-system "collaboration"



DAVE_G System Architecture



Reception Control: analyze and fuse multimodal inputs

Display Control: decide how feedback is presented

B2: Geovisualization distributed in the world

- **remote collaborative visualization**
- **mobile, multimodal, visually-enabled collaboration for crisis management**
- **asynchnonous geocollaboratory tools for science**

e.g., collaborative visualization w/cspray

Alex Pang and colleagues:

tools to collaborate in shared virtual workspace

eye-cons depict participant positions in virtual space

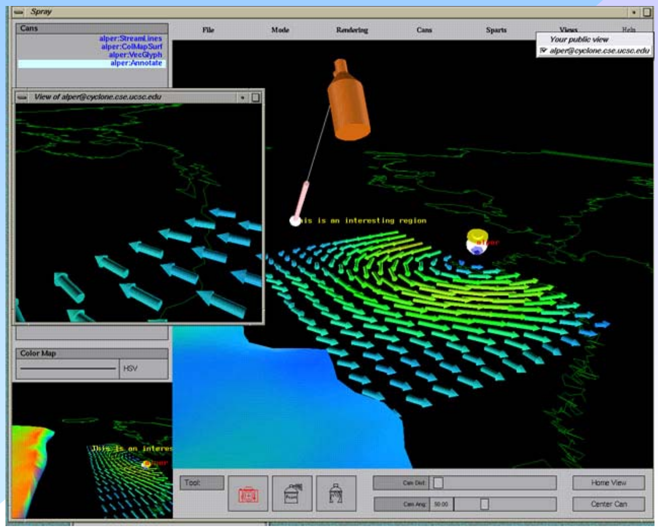


figure courtesy of Alex Pang

Requirements analysis for collaborative geovisualization: four steps

www.geovista.psu.edu/publications/IBAMivis/IBAMivis.pdf

- What kinds of collaborative work are done currently?
- How do maps facilitate same-place collaboration?
- What is needed to support large scientific teams?
- What additions are necessary for different place collaboration?

collaborative tools extended from VisAD – thanks to Bill Hibbard for guidance

Results

- **maps as objects to talk about:**
  - **Maps provide context: *"We can't communicate (spatial characteristics) without a map."***
  - **Maps integrate across scales, domains, & variables**
  - **Visual displays facilitate "what-if" questions**
  - **Maps enable spatiotemporal analyses**
- **needed to support maps as objects to think with:**
  - **mechanism for shared control**
  - **tools for drawing attention**
  - **tools for focusing (on locations and times)**
  - **private workspaces**
- **needed to support maps as objects to coordinate action:**
  - **voice/chat**
  - **view/representation of collaborators**
  - **"metadata" on collaborators**
  - **activity logging and log annotation**
  - **history functions / session replay**

Grid-based collaborative geovisualization

toxic plume simulation – 'gViz' e-science project

Ken Brodlie and colleagues have grid-enabled IRIS Explorer, allowing modules in a pipeline to run securely on different Grid hosts

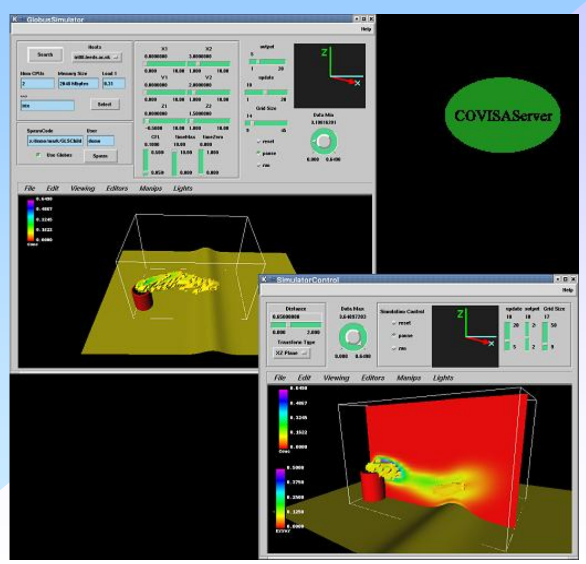
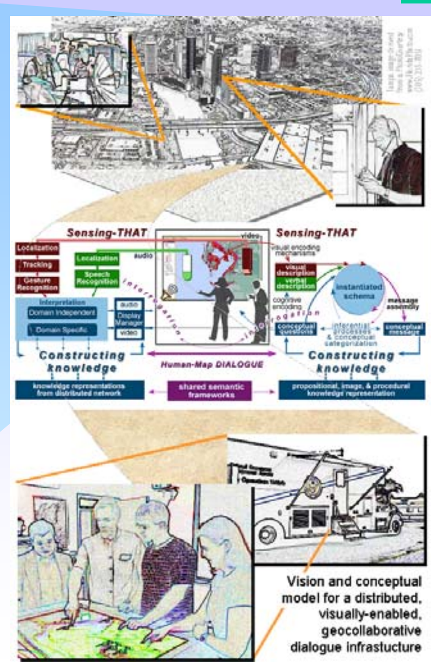


figure courtesy of Ken Brodlie

GeoCollaborative Crisis Management

visually-enabled support for distributed group work with geospatial information to support all phased of crisis management



Vision and conceptual model for a distributed, visually-enabled, geocollaborative dialogue infrastucture

NSF ITR project (EIA-0306845); CoPIs: Guoray Cai, Sven Fuhrmann, Michael McNeese, Rajeev Sharma

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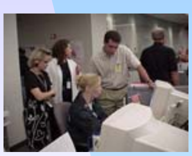
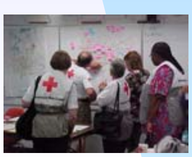
Impediments to effective, coordinated, distributed work with geospatial information for crisis management



current geospatial information technologies ***do not support group work effectively*** **– they are both hard to use and designed for individual rather than group use**



we *lack scientific understanding of how groups (or groups of groups) work* in crisis management using geospatial information and technologies

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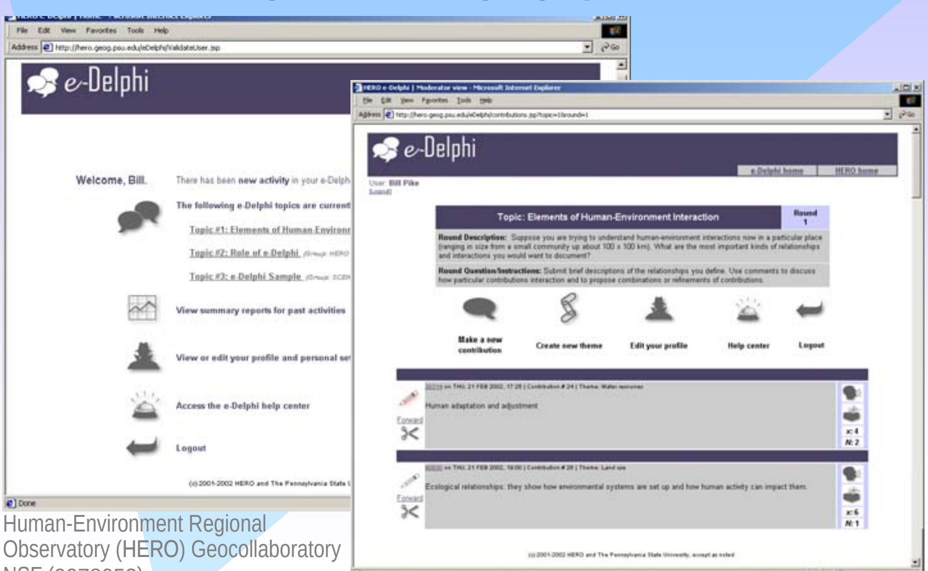
current development activity

- PA Dept. of Environmental Protection
- Centre Region Council of Governments
- NY/NJ Port Authority

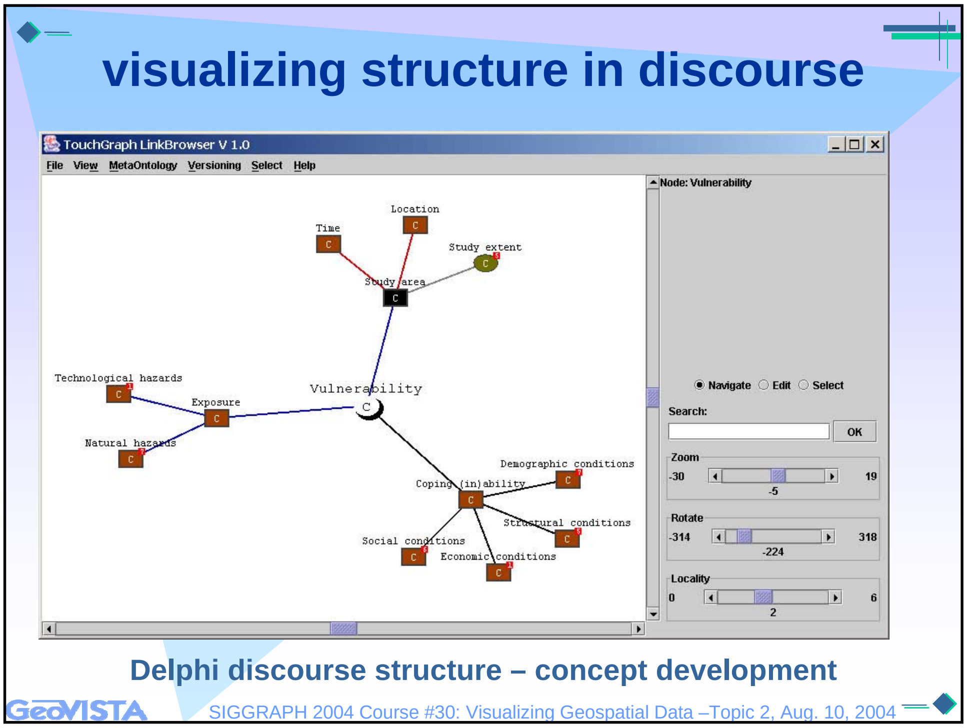
Handheld/GPS

Asynchronous geocollaboratory tools

visualizing structure in geographic discourse



Human-Environment Regional Observatory (HERO) Geocollaboratory
NSF (9978052)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-30 19 -5
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Delphi discourse structure – concept development
GeoVISTA
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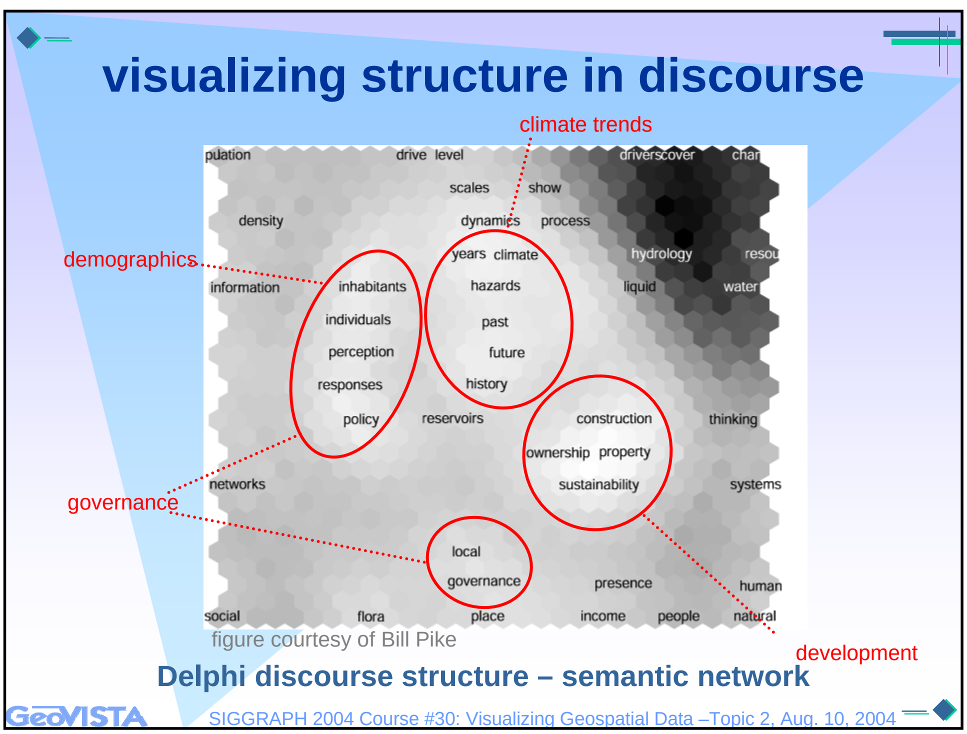
visualizing structure in discourse
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reservoirs
construction
thinking
ownership property
networks
sustainability
systems
local
governance
presence
human
social
flora
place
income
people
natural
figure courtesy of Bill Pike
Delphi discourse structure – semantic network
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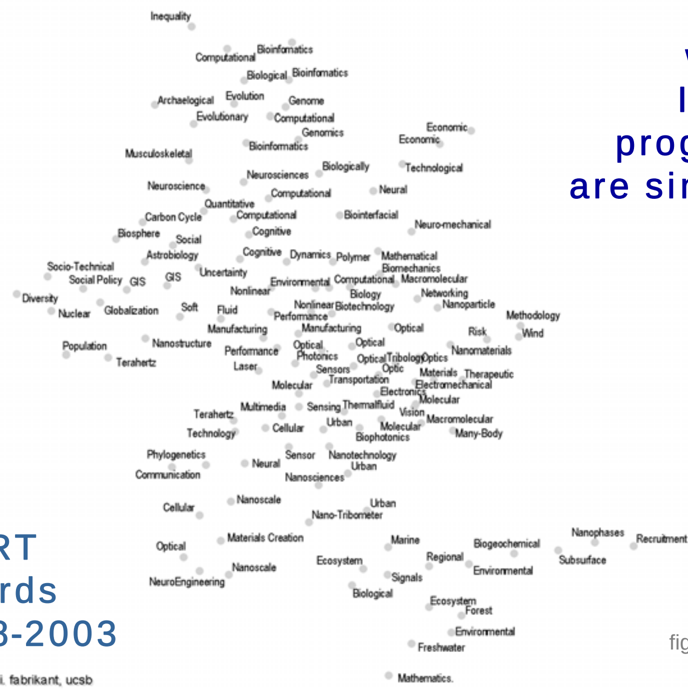
Some challenges for visually-enabled geocollaboration

- **cognitive science:** understand the role of visual display in:
  - framing the work context
  - supporting thinking and decision-making
  - providing awareness and taking actions
- **cognitive engineering:** implement, assess, and refine visual tools for geocollaboration environments that support situated work practices

C: Use & usability

- cognitive science
- usability engineering/user-centered design

which IGERT programs are similar?



NSF IGERT awards 1998-2003

figure courtesy of Sara Fabrikant

Usability engineering/ user-centered desgin

designing for wall display

figure courtesy of James R. Miller

Details: Slocum, T. A., Cliburn, D. C., Feddema, J. J., & Miller, J. R. 2003, Evaluating the Usability of a Tool for Visualizing the Uncertainty of the Future Global Water Balance. *Cartography and Geographic Information Science,* **30**(4), 299-317.

Cognitive science + Usability engineering/ user-centered design

metaphors

Details: Fuhrmann, S. 2003, Supporting wayfinding in desktop geovirtual environments. In M. P. Peterson (Ed.), *Maps and the Internet* (pp. 271-287).

figure courtesy of Sven Fuhrmann

D: Looking Ahead – Defining a Research Agenda for Geovisualization

- International Cartographic Association Commission on Visualization & Virtual Environments **Geovisualization Research Agenda**
- National Academy of Science, Computer Science and Telecommunications Board, **Committee for the Workshop on Intersections Between Geospatial Information and IT**

International Cartographic Association
Commission on Visualization and Virtual Environments

research challenges: *special issue of Cartography & Geographic Information Science,* 28(1), 2001

1. Fairbairn, D., Andrienko, G., Andrienko, N., Buziek, G., & Dykes, J. 2001, **Representation and its relationship with cartographic visualization**
2. Gahegan, M., Harrower, M., Rhyne, T.-M., & Wachowicz, M. 2001, **The integration of geographic visualization with databases, data mining, knowledge construction and geocomputation**
3. Cartwright, W., Crampton, J., Gartner, G., Miller, S., Mitchell, K., Siekierska, E., & Wood, J. 2001, **Geospatial Information Visualization User Interface Issues**
4. Slocum, T. A., Blok, C., Jiang, B., Koussoulakou, A., Montello, D. R., Fuhrmann, S., & Hedley, N. R. 2001, **Cognitive and usability issues in geovisualization**

preprint available at: www.geovista.psu.edu/icavis

International Cartographic Association
Commission on Visualization and Virtual Environments

Cross-cutting research challenges

MacEachren, A. M. & Kraak, M.-J. 2001, Research challenges in geovisualization, Cartography & Geographic Information Science, 28(1), 2001

1. **geovisualization to leverage *experiential* representation technologies**
2. **integrated geovisualization–geocomputation for exploration and analysis of very large data sets**
3. **geovisualization methods and tools that support group work**
4. **human-centered approach to geovisualization**

preprint available at: www.geovista.psu.edu/icavis

National Research Council Workshop Report
IT Roadmap to a Geospatial Future, 2003
Chapter 4: Human Interaction with Geospatial Information
research challenges

1. Harnessing Info Volume and Complexity
2. Geospatial for Everyone – Universal Access and Usability
3. Geospatial Everywhere – Mobile Information Acquisition, Access, and Use
4. Collaborative Work with GI

http://books.nap.edu/html/geospatial_future/

GeoVISTA

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Acknowledgments

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In addition, Advanced Interfaces, Inc. has provided access to their speech-gesture integration software.

Finally – I would like to thank **Theresa-Marie Rhyne** … for organizing this course + lots more

GeoVISTA

SIGGRAPH 2004 Course #30: Visualizing Geospatial Data –Topic 2, Aug. 10, 2004

SIGGRAPH 2004 Course #30 Notes

Visualizing Geospatial Data

Reprint Section of Course Notes:

We provide several reprints of previously published articles pertaining to geographic visualization. These reprints are presented here with permission of the publishers. These include the following:

1) Geovisualization of Knowledge Construction and Decision Support

2) Supporting visual integration and analysis of geospatially-referenced data through web-deployable, cross platforms

3) Web-Based Collaborative Tools for Geospatial Exploration

4) Visually-Enabled Geocollaboration to Support Data Exploration & Decision Making

5) Geovisualization to Mediate Collaborative Work: Tools to Support Different-Place Knowledge Construction and Decision-Making

6) Geocollaborative Crisis Management: Building better systems through advanced technology and deep understanding to technology-enabled group work

7) Geocollaborative Crisis Management: Using Maps to Mediate EOC-Mobile Team Collaboration

Editor: Theresa-Marie Rhyne

Geovisualization for Knowledge Construction and Decision Support

Alan M. MacEachren, Mark Gahegan, William Pike, Isaac Brewer, Guoray Cai, and Eugene Lengerich

GeoVISTA Center and Pennsylvania State University

Frank Hardisty

University of South Carolina

We now have access to vast digital data resources that include geospatial referencing. This referencing ranges from precise geographic coordinates, through street addresses, to codes for administrative or other types of regions (such as zip codes and drainage basin indices). GPS receivers in locations such as vehicles, PDAs, and cell phones generate an increasing protion of these data. Specific examples of geospatially referenced data include

- satellite remote sensing readings,
- meteorological measurements,
- telephone and credit card transaction information (with both purchase and billing addresses),
- stream gauge readings,
- land use categories,
- transportation records (linked to intersections, highway segments, and ticket offices),
- health statistics (collected with home and treatment addresses),
- tax and property records, and
- census enumerations (for population, agriculture, housing, manufacturing, and other topics).

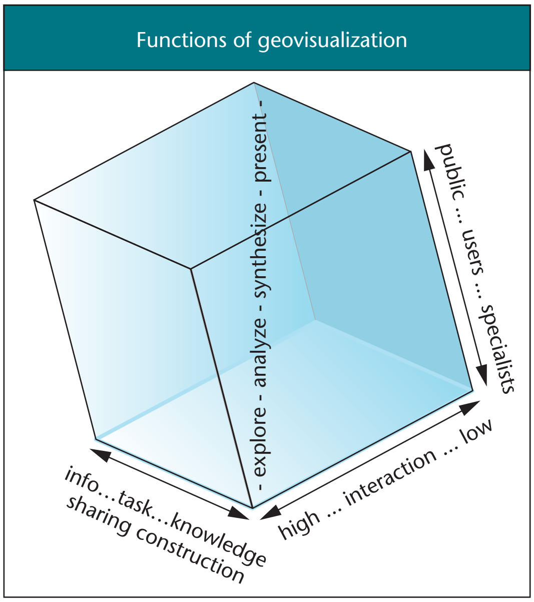
Geovisualization is both a process for leveraging these data resources to meet scientific and societal needs and a research field that develops visual methods and tools to support a wide array of geospatial data applications. While researchers have made substantial advances in geovisualization over the past decade, many challenges remain. To support real-world knowledge construction and decision making, some of the most important challenges involve distributed geovisualization—that is, enabling geovisualization across software components, devices, people, and places.

Integrating and extending perspectives

In her May/June 2003 Visualization Viewpoints article, Theresa-Marie Rhyne highlighted some of the commonalities between cartographic and geographic information representation techniques for scientific and information visualization. Geovisualization draws on these cartographic and geographic traditions, integrating their perspectives on representation and analysis of geospatial information with more recent developments in scientific and information visualization, exploratory data analysis (EDA), and image analysis. Geovisualization generally aims to integrate approaches from these domains "to provide theory, methods, and tools for visual exploration, analysis, synthesis, and presentation of geospatial data (any data having geospatial referencing)."[1] Figure 1 depicts the four geovisualization functions.

The term *geographic visualization* (as well as the related *cartographic visualization*) was prompted by a 1987 National Science Foundation report on visualization in scientific computing.[3] Research and practice in geovisualization, however, has roots dating at least a decade earlier to the French edition of Bertin's[4] book presenting cartographic and information design ideas for representing and exploring data.[5] Early work in geovisualization focused on the role of map-based dynamic visual displays as prompts for scientific insight and on the methods through which dynamic visual displays might leverage perceptual cognitive processes to facilitate scientific thinking.

In 1995, the International Cartographic Association established a Commission on Visualization, which expanded its focus in 1999 to visualization and virtual environments. This commission has played an important role in stimulating geovisualization research and in articulating an international, interdisciplinary research agen-



1 The central diagonal of this geovisualization-use space depicts four geovisualization functions. The space is defined by task types, user types, and interaction level enabled by the interface. (This figure is a modified version of Figure PIII.1 of MacEachren.[2])

GeoVISTA Studio

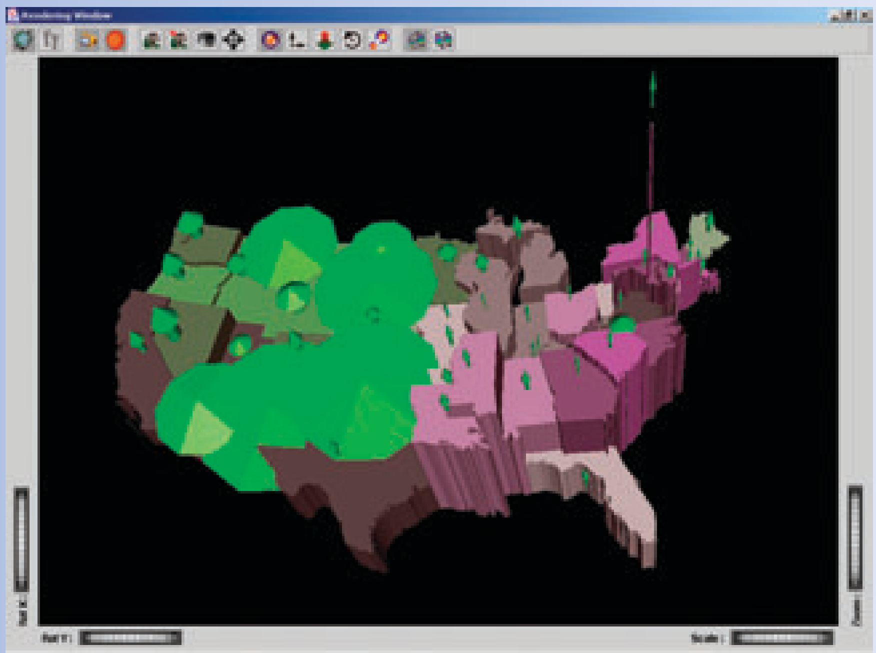
The GeoVISTA Studio project aims to improve geoscientific analysis by providing an environment that operationally integrates a wide range of problem-solving components and activities, including those both computationally and visually based (see Figure A).[1] Through support for geographic visualization and knowledge discovery, Studio lets researchers explore data; construct hypotheses; discover, refine, and test knowledge; construct analyses tasks; and evaluate results. It offers numerous specific features and advantages, including

- ease of program construction by visual programming—users drag components from a palette into the design box and link them together to create systems that they can run and test in real time;
- open (nonproprietary) architecture based on the JavaBeans environment;
- shared code-base—the Studio source tree and applications are distributed through SourceForge (http://www.sourceforge.net/projects/geovistastudio);
- simple component-based integration using Java introspection methods to expose Bean functionality and a sophisticated event coordination harness that maps user interactions in one component to equivalent actions in others;
- on-the-fly design modification; and
- advanced deployment methods using serialization, automatic application and applet creation and Java WebStart to facilitate the rapid construction, sharing, and deployment of tools developed.

This versatility could potentially change the nature of systems development, use, and deployment for the geosciences, providing better mechanisms to coordinate complex functionality. As a consequence, analyses and decision-making processes might be improved by closer integration of software tools and better engagement of the human expert.

Reference

1. M. Gahegan et al., "Introducing GeoVISTA Studio: An Integrated Suite of Visualization and Computational methods for Exploration and Knowledge Construction in Geography," *Computers, Environment and Urban Systems*, vol. 26, no. 4, 2002, pp. 267-292.



A Bivariate color represents percentage age 18 to 29 and percentage of females in each state. The arrows depict percentages for US Census designations Black (height), Divorced (length), and American Indian (thickness).

da.[1] ICA has also collaborated with the ACM Siggraph Carto Project (http://www.siggraph.org/~rhyne/carto/).

The ICA commission prompted research that focused on developing and implementing highly interactive, exploratory methods targeted at knowledge construction by specialists, providing support for visualization functions at the lower left corner of Figure 1 (this work balanced traditional cartographic research that was focused on presentation of existing information to the public).

The interdisciplinary geovisualization research agenda articulated a broader set of challenges that includes attention to visually enabled information retrieval and decision-making tasks for a wide range of users including groups as well as individuals. One component of a recent US National Research Council (NRC) report builds on this agenda to identify challenges for IT research related to human interaction with geospatial information.[6] Particular geovisualization issues targeted in this NRC report include

- advances in visualization to harness information volume and complexity (including attention to visual representation of knowledge);
- universal access and usability (including extensions of visualization to other modalities), mobile information acquisition, access, and use (including design of visualization methods suited to small, wireless devices); and
- collaborative work with geospatial information (including attention to the role of visual display as a mediator for same- and different-place group discussion).

Application domains

The wide range of available geospatial data creates a potential for geovisualization to support activities in an equally wide range of application domains. Here, we highlight applications in three domains, using examples from research underway in the GeoVISTA Center at Penn State.

Public health

Geospatial data about health outcomes, interventions, and risk factors offer an opportunity to understand (and do something about) the varied geographic distribution of disease. These data sets, however, are highly multivariate, and the complex multivariate relationships among variables are often unknown. Traditional statistical analysis methods aren't well suited to uncovering spatial aspects of these relations. Integration of traditional cartographic methods with those from information visualization and EDA can provide researchers and analysts with a range of tools for visually—as well as statistically and computationally—exploring these relationships. To enable such integration, we developed an open source application-building environment, GeoVISTA Studio. This environment provides a visual programming interface for application developers to construct analytical tools (and other forms of visualization applications) by quickly integrating Java components in the form of JavaBeans—see the "GeoVISTA Studio" sidebar for more information.

Figure 2 illustrates the use of a multiform bivariate matrix (part of an application built using Studio) to explore spatial and nonspatial relationships in a cancer mortality and risk factor data set. The figure depicts aggregate county data for

- two potential environmental risk factors (atmospheric emissions for arsenic and mercury),
- one health care access variable (proportion of individuals without health insurance), and
- a subset of age-adjusted cancer mortality rate data (for male and female stomach, lung, and esophageal cancer).

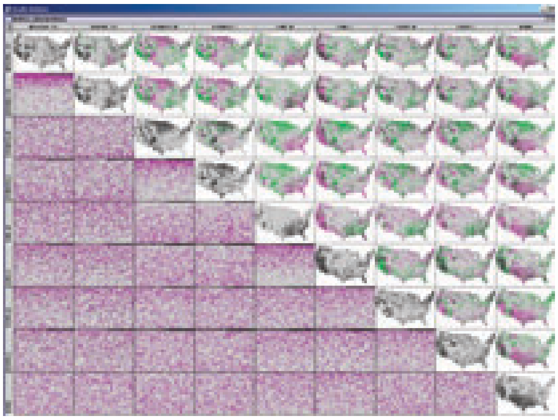
The matrix extends the well-known scatter plot matrix method into a generic visualization tool that accepts any bivariate representation forms. In this case, we use bivariate maps and space-filling visualizations, with the diagonal depicting univariate maps of each variable.

In Figure 2, we applied a visual classification tool to bin the data (for each bivariate representation) into four classes of counties, with values in

- the lower three-quarters of the data range for both variables (light gray on the maps),
- the highest quarter of the data range for both variables (dark gray on the maps),
- the top quarter on the column variable but not the row variable (purple on the map), and
- the top quarter on the row variable but not the column variable (green on the map).

The top row of maps matches data for atmospheric emission of mercury with data for all other variables. In that row, the male lung cancer mortality map (5th column) contains a broad purple region in the southeast US (indicating that this region is in the top quarter for lung cancer mortality but not in the top quarter for mercury emissions). The adjacent map (to the right) contains distinct regions (dark gray) in which the top quarter female lung cancer mortality rates match with the top quarter on mercury emissions (most noticeable in the far west, along the Gulf coast, and in Florida).

The space-fill visualization depicts each county as a



2 MultiForm bivariate matrix with space fill and map.

grid cell. In contrast to a scatter plot (a tool most potential users are familiar with), this depiction avoids overplotting of identical or similar data values. Thus, some relationships that a scatter plot would obscure will be evident in a space-fill visualization. The tradeoff is that the tool is less familiar than a scatter plot for most users, thus requiring training to use. In the view shown in Figure 2, scan-line cell order (from the lower left to upper right) depicts the column variable and color depicts the row variable (purple indicating values in the top quarter on that variable). Other orderings (for example, spiral) are user selectable.

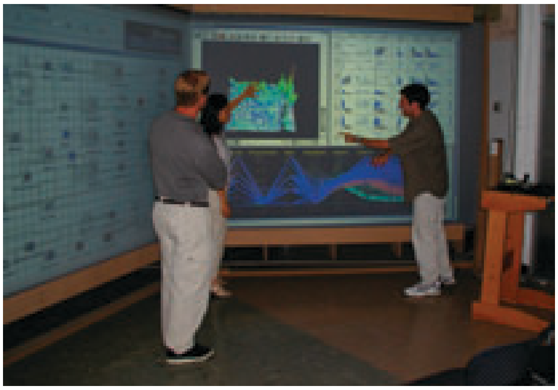
The upper left space-fill view shows a strong positive relationship between mercury and arsenic emissions (the purple band at the top of the space fill indicates that the two variables have substantial agreement in the top quarter of counties). Male and female stomach and lung cancers (3rd row, 4th column and 5th row, 6th column) both show similar (but weaker) relationships, while male and female esophageal cancer (7th row, 8th column) shows no relationship.

These and other components developed for integration with GeoVISTA Studio support many dynamic events that user action or input from other components can control. For example, manual highlighting in any map or space-fill will display highlights of selected entities in all displays, the order of matrix columns and rows can be driven computationally, and manual or computational adjustment of the color scheme assigned to one map can propagate to all coordinated views.

A separate coordinator component (that takes advantage of Java's introspection capabilities) handles these cross-component connections, enabling distribution of visualization functions across software components that don't need to be developed with specific support for cross-component coordination in mind.

Environmental science

We can apply many of the same EDA methods and tools useful for applications in public health data analysis to support research in environmental science. Figure 3 illustrates the use of these geovisualization methods on large displays to facilitate collaborative land cover data exploration. The left panel of this large display depicts the design of an application in Studio; the right panel depicts the resulting application. This application



3 Collaboration in a land-cover classification task. This display, with two large stereo screens, was created by George Otto, manager of the Penn State Information Technology Services, Visualization Group.

includes a dynamically linked scatter plot matrix, parallel coordinate plot, and self-organizing map (depicted in a 3D view). While not shown here, the screens can produce stereo views. The application's display depicts use of linked brushing among components (a region of dots selected on a scatter plot is highlighted in blue in all other views). The analysis session is focused on land cover classification and the task of identifying anomalies in a remotely sensed data set that result from the self-organizing map failing to distinguish among three similar vegetation types.

Our recent work in environmental applications has combined data visualization methods and tools derived from EDA and cartography with graph-based concept visualization methods and tools derived from information visualization. We're developing a distributed concept mapping tool, ConceptVISTA that runs in a stand-alone mode on a desktop or handheld device and through a Web portal used for scientific collaboration. Figure 4 depicts a portion of one researcher's concept map representing the vulnerability of people and places to environmental change. Such concept maps provide a vehicle for researcher teams to create and share depictions of complex knowledge. We're developing concept similarity measures for use within ConceptVISTA that help reveal levels of agreement between concept maps created by different people or for different problems. ConceptVISTA also has the ability to encode semantic relationships between the researchers, places, data, software tools, and analysis tasks depicted in a map; this information can represent a problem-solving approach much as a GeoVISTA Studio design does, but at a different level of abstraction. As a result, we anticipate that users will be able to build visual representations of problems using a ConceptVISTA-style interface, which Studio can use to select and connect appropriate data and components.

Crisis management

Geovisualization is not limited to supporting science. Rapid advances in geographic information systems and related technologies have created a potential for dynamic geovisualization methods to be integrated with GIS in support of a range of decision-making tasks. Crisis management is a prototypical example where we can use a visual, map-based display to integrate, assess, and apply multisource geospatial information.

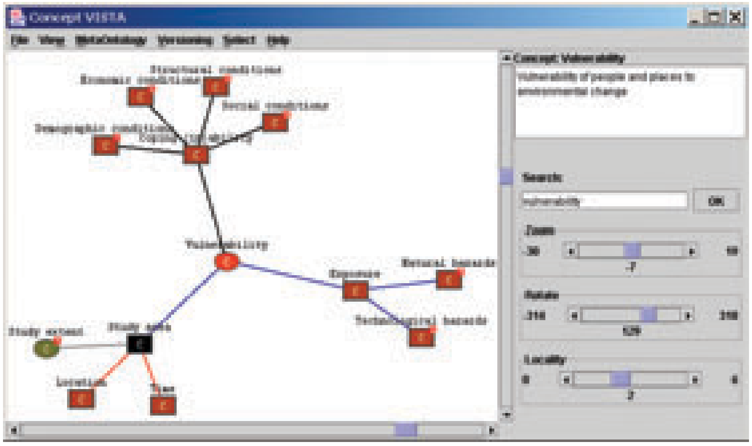
In time-critical crisis situations, it's imperative that access to geospatial information is not impeded by constraints in the software or interface. Moreover, emergency operations centers have been outfitted with large screen displays that provide collaborators with up-to-date information about hazards and their impact. In response to both of these factors, we need new interfaces that let users who lack GIS training quickly access complex geospatial information displayed on these large screens. Such interfaces should support untethered access to data exploration tools, such as those shown in Figure 3.

New collaborative geographical visualization environments that support decision-making activities must address two related challenges:

- the interruptions in cognitive problem solving and collaborative discourse caused by mouse or keyboard input, and
- the potential for cognitive overload from multiple visualization tools and their controls.

First, traditional visualization interfaces (using keyboard and mouse) demand user attention, thus they distract users from thinking about and discussing a problem. Second, geovisualization used in crisis management must often depict complex, multivariate information. Such depictions coupled with a complex interface will force a choice between devoting cognitive resources to understanding the display and understanding the display controls. Particularly for time-critical decision making, it's important to minimize the cognitive resources that must be directed to geovisualization controls.

To make GIS and geovisualization tools more accessible to crisis managers working with large screen map displays, we integrated solutions from natural language and speech processing, vision-based gesture recognition, and conversational dialogue technologies to enable multimodal dialogues with interac-



4 ConceptVISTA graph depicting components of water system vulnerability. This component builds on an open source graph drawing tool called TouchGraph (http://www.touchgraph.com).

tive maps served from GISs.[7] Figure 5 illustrates our Dialogue-Assisted Visual Environment for Geoinformation (DAVE_G). DAVE_G recognizes natural hand gestures and spoken requests, allowing device-free interaction.[8] Dialogues between the user and the system are mixed-initiative and collaborative, allowing cognitive load sharing between humans and the system.

A dialogue manager facilitates the human-map dialogue in DAVE_G. This computational agent plays the role of an intelligent information assistant, similar to the role of human GIS specialists in current emergency operations centers. The dialogue manager recognizes the users' goals and acts on their behalf in spatial data retrieval as well as generation of visual displays. The system is competent in various human-like dialogue strategies for resolving ill-defined requests, ambiguities, and vagueness of spatial concepts.[9] This research aims to free the user from the cognitive burden of complete and accurate data query and GIS command specification, allowing smoother, more natural interaction with the geospatial information. We're currently extending the system to support multiple users working collaboratively.

Some challenges

In a recent (March/April 2003) Visualization Viewpoints column, Shalf and Bethel argued that

> A new grid-aware framework is needed for distributed visualization that's easy to use, modular, extensible, and permits reuse of existing investments in visualization technology.

We face similar challenges to achieve distributed geovisualization that crosses the boundaries of software applications, devices, distance, and individual use.

Current geovisualization tools start with an assumption that a user's task will involve geovisualization exclusively (or at least primarily). This is an unrealistic assumption, particularly as geovisualization matures and the potential to play a role in a wide array of activities increases. A component-based approach to geovisualization tools—that distributes functionality among a set of independent modules—could potentially support more flexible integration of geovisualization with other information access and analysis tools as well as geovisualization that works across devices. The distributed Grid-based architecture that Shalf and Bethel envision is also critical to the challenge of support for same- and different-place collaborative visualization.

Like scientific and information visualization, geovisualization is maturing as a research field as well as a domain of practice. The potential is there to apply geovisualization as a tool for addressing critical issues in the fields of public health, environmental science, crisis management, and others. Achieving this potential will require multidisciplinary collaboration that integrates perspectives from cartography and geographic information science with those from computer graphics, information and scientific visualization, computer-supported cooperative work, diagrammatic reasoning, cognitive science, human–computer interaction, cognitive systems engineering, and other domains. ■


Photo courtesy of Greg Grieco

5 **Natural dialogue with a GIS, mediated by a map-based display.**

Acknowledgment

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Supporting visual integration and analysis of geospatially-referenced data through web-deployable, cross-platform tools

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1 INTRODUCTION

Federal government agencies generate massive volumes of statistical data. A substantial proportion of these data include geospatial referencing (in the form of geographic coordinates, zip codes, addresses or other location specifications). This "georeferencing" can be the key to integrating data across agencies, because it often provides the only common link through which diverse data sets can be joined. Joining statistical summaries produced by different agencies can result in critical insights about relationships among seemingly separate events and processes, relationships that might otherwise be ignored because the relevant statistics are generated by different federal agencies. As one example, consider demographic change (with statistics produced by the Bureau of the Census), evolution of changes in public health (with statistics collected and synthesized by the Centers for Disease Control), and shifting locations for human-induced environmental hazards (tracked by the Environmental Protection Agency). Integrating these data and supporting flexible visually analysis can prompt innovative hypotheses (and support subsequent rigorous analysis) about problems such as the evolution of disease-risk factor relationships.

As part of one National Science Foundation (NSF) supported Digital Government (DG) Collaborative Research project (*Quality Graphics for Federal Statistical Summaries,* #9983451; PIs: Dan Carr, George Mason, Alan MacEachren, Penn State, David Scott, Rice) MacEachren, Hardisty, Dai, and Guo are working with divisions in eight federal agencies that generate statistical summaries to develop visual-analytical methods that can support agency missions by enabling integrated analysis of geospatial data from within and across agencies. In a second NSF supported DG project (in which Gahegan is a collaborator, *Knowledge management over time-varying datasets,* PI, Peggy Agouris, Maine, #EIA-9983445), work is underway with four agency partners to develop approaches and tools that facilitate the mining of information from geospatial datasets across space and time and to improve (by better integration) knowledge management over these datasets. In both projects, we are leveraging a separately funded web-deployable, cross-platform, Java-based software development effort, GeoVISTA *Studio*. In this paper, we outline capabilities of *Studio*, discuss how it is being extended to support our joint Digital Government geospatial data integration and analysis goals, and provide examples of the kinds of multivariate geospatial data integration and analysis being undertaken.

2 GeoVISTA *Studio* – AN OVERVIEW

GeoVISTA *Studio* (subsequently referred to as *Studio*) is a component-based environment designed to support the fusing of diverse visual and analytical capabilities into custom analysis tools that enable a multi-perspective ('mixed initiative' ((Amant and Cohen, 1998)) approach to knowledge construction and dissemination (Takatsuka and Gahegan, in press). *Studio* provides a visual programming environment that allows an analyst to package assembled functionality into a working program (in the form of a cross-

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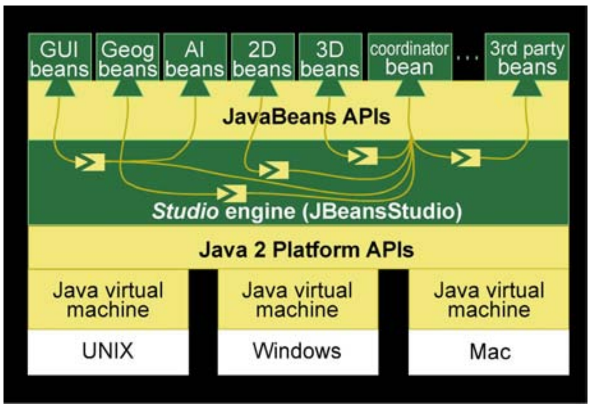
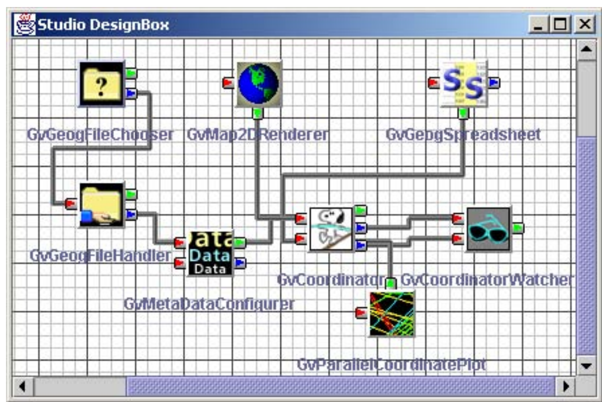
platform, JavaBeans component, an applet, or an application). The result can be easily disseminated or deployed on the Internet. Like past visual programming environments, designed to support rapid development of scientific visualization applications, *Studio* allows users to quickly combine components into flexible applications. But unlike many such environments to date, the available components address a range of activities that span statistical analysis, visualization and machine learning, i.e. a broad range of approaches to exploring and analyzing a dataset.

Another major difference from most past visual programming environments for building visual analysis tools is that the modules a user links together, in the program's *design box,* are true "components" – units that can be deployed independently and combined with third party applications. Thus, components developed by our research team to work within *Studio* can also function independently. These components can be used in other JavaBean applications or by third parties; and components developed by others can be used within *Studio* (as long as they meet the JavaBeans Application Programming Interface (API) standards). This flexibility is enabled through the "builder" (a component-oriented application construction





system), which connects components together at runtime, without the need for recompilation, linking or any other form of 'preparation'. By using Java's 'introspection' function, the builder obtains a syntactic description of all the services (methods) that a bean provides, and can expose these methods for linking to other beans. Thus it is not necessary to have source code available before a bean can be assimilated into the Studio environment, nor any prior knowledge of its methods. The figures above depict the system architecture (left) and the user's view of a set of components and their connections shown in a typical design box (right).

A third major difference between past visual programming environments and *Studio* is the potential for multi-way connections among components. Although the *Studio* builder supports a standard pipeline architecture, other forms of data communication and sharing are also possible. This difference is best illustrated by the "coordinator" bean developed to support the kinds of multivariate analysis critical for the two Digital Government projects cited above (second bean from the right in architecture view, above left, and center component in the design box, above right). The coordinator acts as a multiplexor that arbitrates the passing of events between beans that require a high degree of specialized, coordinated behavior without the need for highly coupled software. Without the need for a highly elaborate set of bean interconnections, it arbitrates the sharing of data, metadata, and several display and event properties among components, including selections, categorizations, and visual mappings (e.g., assignment of color, line weight, or other features to categories). Developers can chose to what degree beans coordinate their behavior and their data with other beans, easing the problem of providing many linked views onto the same dataset, via different visual and analytical methods. Section 4 provides some examples of 'coordination in action'.For

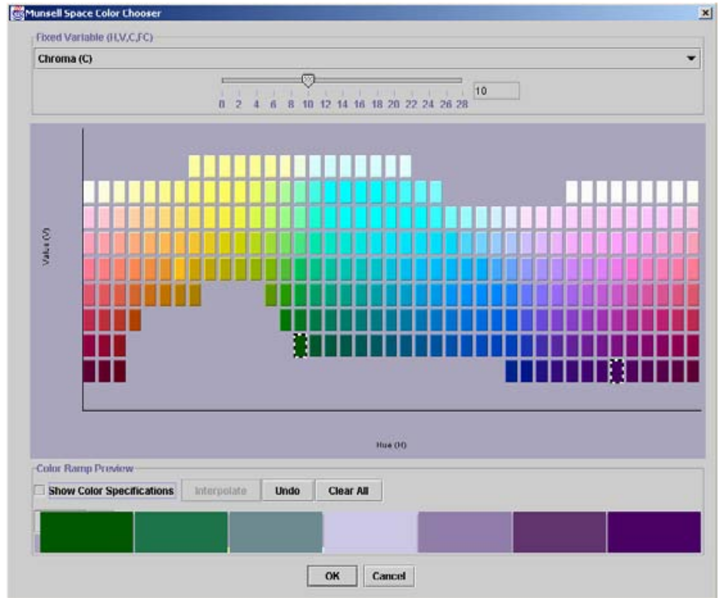
Studio applications built using the coordinator, beans can be designed specifically to take advantage of the ability to share parameters among components. Alternatively, for beans not originally designed to support coordinated behaviors, a wrapper must be added to make the bean "coordinator aware". In the application example described below, a commercial spreadsheet bean was downloaded from the web, a wrapper was added, and the spreadsheet is now able to share features such as changes in color scheme (assigned to value ranges within an attribute) and visual selection (and highlighting) of data subsets. As described above, the spreadsheet's capabilities were effectively customized for our own uses without requiring source code to be available.

3 EXPLORING MULTIVARIATE AND TIME SERIES GEOSPATIAL STATISTICS

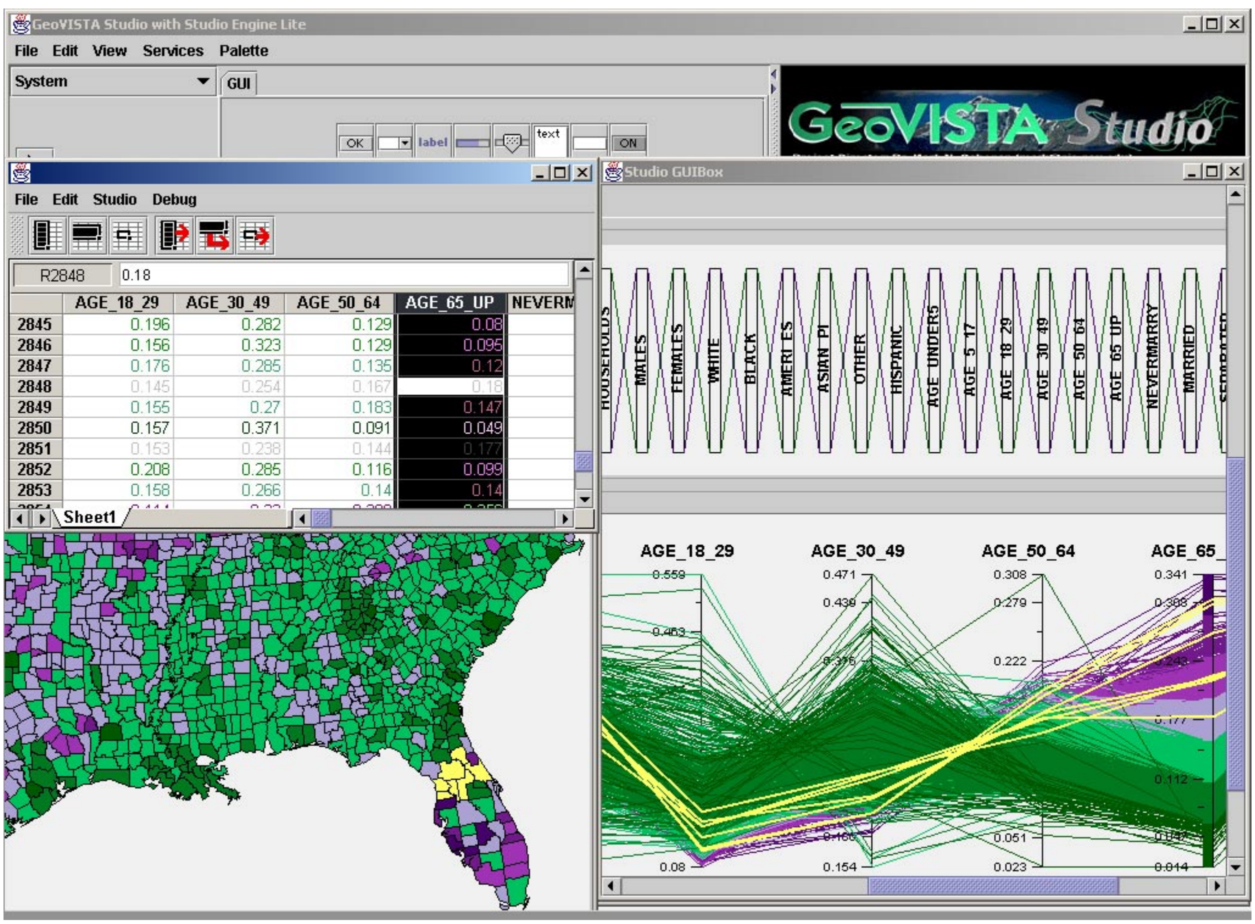
In the context of the two DG projects cited above, our research teams have developed or extended a suite of visual analysis components, for use within *Studio*, that support dynamic visual analysis of highly multivariate statistical data produced by our partner agencies. These tools build, in part, on our past work to develop, and explore the cognitive-usability implications of, a range of methods for multivariate visual (and computational) analysis of geospatial data (e.g., (Gahegan, 1998; MacEachren et al., 1998; MacEachren et al., 1999) While particular emphasis in our work is on data that include geospatial referencing, many of the visual and computational analysis tools we are developing are suited to analysis of any multivariate data.

To support visual data exploration and analysis, we are implementing (as JavaBeans) a suite of highly interactive representation forms that support different perspectives on data, along with several components that support manipulation of parameters to control the *data-to-display* mappings for each representation form independently, or globally for all representation forms. As noted above, our recent extensions to the *Studio* environment focus on use of the coordinator bean to support dynamic, multi-parameter links among different representation forms. Here, we sketch the functionality of several of these components and the dynamic linking supported between them, specifically the following beans: *2D renderer* (map display tool), *spreadsheet*, *parallel coordinate plot* (*PCP*), *visual data classification*, and *color scheme*. Other components implemented thus far or under construction include: a scatterplot matrix, a map matrix, a 3D renderer, image analysis tools, self-organizing map neural network, K-means clustering, and regression analysis.

The user controls the data-to-display mapping for display components through two other beans. First, the *visual classifier* allows the user to set the number of categories into which data are grouped and the method applied for determining where the category breaks are in the range of values (e.g., equally spaced values along the range, quantiles: breaks that group data so that the same number of counties is in each category, Jenks optimal: minimum variance categories in which all data values in a category are as similar to one another as possible, (Slocum, 1998)). Then, the *color scheme* bean is used to select color assignments for each category. In addition to allowing users to build color schemes using an RGB color picker, we have implemented a color picker that allows users to build schemes using the Munsell perceptually balanced color space (below-top), and to interpolate color assignments within this space between two (or more) chosen colors. In the figure, the endpoints of a diverging color scheme were selected in the "chroma" view (in which colors of the same chroma/ saturation that vary in value/lightness and hue are displayed) and a midpoint was selected in the "value" view (in which colors of different hue and chroma are depicted – not shown). The four intermediate colors are interpolated between these three anchor points in 3D perceptual color space. The color scheme selected can be applied to variables displayed in map, PCP, spreadsheet and other views (below-bottom). The figure shows the color scheme applied to a map of the proportion of the U.S. 2000 population by county that is 65 years of age or older (in this case, the map is a choropleth map that depicts aggregate interval or ratio level statistics for counties using color fills assigned to each county polygon).



Dynamic links between the different perspectives on multivariate datasets provided through different interactive representation forms in *Studio* (e.g., maps, scatterplot matrices, spreadsheet, PCPs) support exploration of many kinds of relationship. As one example, the screen capture above illustrates dynamic sharing of: (a) color schemes (here, assigned to one axis in the PCP and propagated to both the map and spreadsheet views); (b) axis selected (in the PCP and spreadsheet), and (c) user selection of an



interesting spatial cluster by "brushing" on the map (highlighted in yellow and propagated to both other views). Here, the high proportion of elderly residents noticed by the user on the map (for the section of South Florida, highlighted) can be seen to have a quite different age distribution than is typical for other states.

Our implementation of a PCP, as described above, supports interactive categorizing and coloring of the strings (where each string represents a data instance). In addition, several other interactive capabilities have been added that are designed to make the PCP more useable for exploratory analysis and to support larger data volumes than used typically with this graphical analysis tool in the past (e.g., the PCP above is displaying data for the 3000+ counties in the U.S.). Among the extensions implemented, users can: isolate the strings for one category of a variable (e.g., those counties with the lowest proportion of 18-29 year olds) by clicking on that category along the axis depicting the variable (which causes all other strings to temporarily be turned off), change the category breaks manually by grabbing the break point between categories on an axis and dragging it to the desired value, and reorder axes by picking up their icons in the inset above the PCP and dragging them to a new location. Users can also animate the rendering of the strings within the PCP in a couple of ways, to help overcome perceptual bias due to string drawing order and overwriting. In the first of these, strings are drawn onto a blank canvas in a specific order, defined by the user. It is then possible to get a sense of the number of strings that have been obscured, and their values. In the second, strings are highlighted, one at a time, in rapid succession, and again in a pre-specified order. This is very useful for exploring the range of data values that might make up a particular category of interest.

In addition to the multivariate visual analysis methods detailed above, *Studio* facilitates the multivariate analysis of geospatial attributes by supporting the linkage of analysis components and visualization components. Thus, the output of statistical tools like K-means clustering or regression analyses can be visualized as the parameters are set, making previously "black-box" techniques more transparent. The manner in which data are being visualized and analysed can be reflected across components, shortening the iterative visualize – analyse – visualize knowledge construction loop. This aspect of the environment is discussed in (Gahegan et al., 2000).

4 APPLICATION EXAMPLE

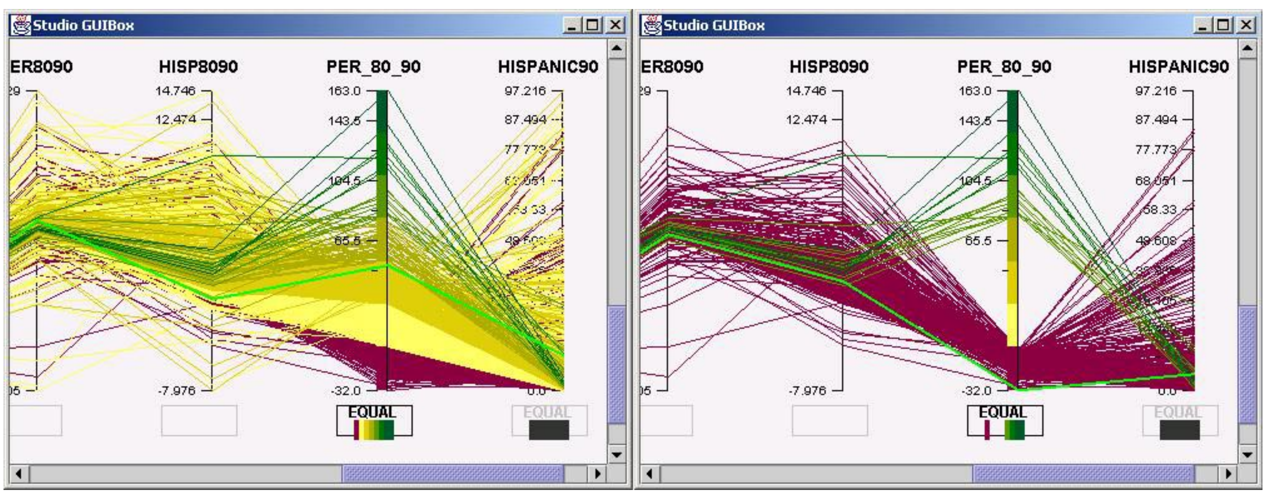
Here, we describe a case study application of the multivariate analysis environment described above, to illustrate possibilities raised by coordination of numerical analysis and visual analysis across components. This study focuses on changes in the spatial structure of the U.S. population, and particularly the relationship between the Hispanic population and population growth, as reflected in the 1980, 1990 and 2000 Censuses.

Many governmental and business organizations depend on accurate analysis of demographic trends for their planning efforts. The primary source for population information in the United States is the decennial census, so the release of data from the 2000 Census has occasioned a great deal of interest. The application of visual-analytical methods to these data sets can help investigators uncover unexpected relationships. For example, from reading the major news media, one might expect that among those counties with a quickly growing population, those with a high proportion of Hispanics would show the greatest growth in population. However, by using *Studio*, we uncovered exactly the opposite relationship between the 1980 and 1990 Censuses, which we hypothesize will extend to the 2000 Census.

One of the "big stories" of the 2000 Census so far is the growing importance of the Hispanic population in the demographic makeup of the United States. From accounts in important news outlets, one would expect that those counties which are growing quickly would have an especially high proportion of Hispanics, or a quickly growing proportion of Hispanics (Janofsky, 2001). County level demographic data was not yet available for the 2000 Census when we completed this analysis, so in this case study we examine the relationship between proportion of Hispanics and population growth at the county level between 1980 and 1990. The analysis will be extended as 2000 data becomes available.

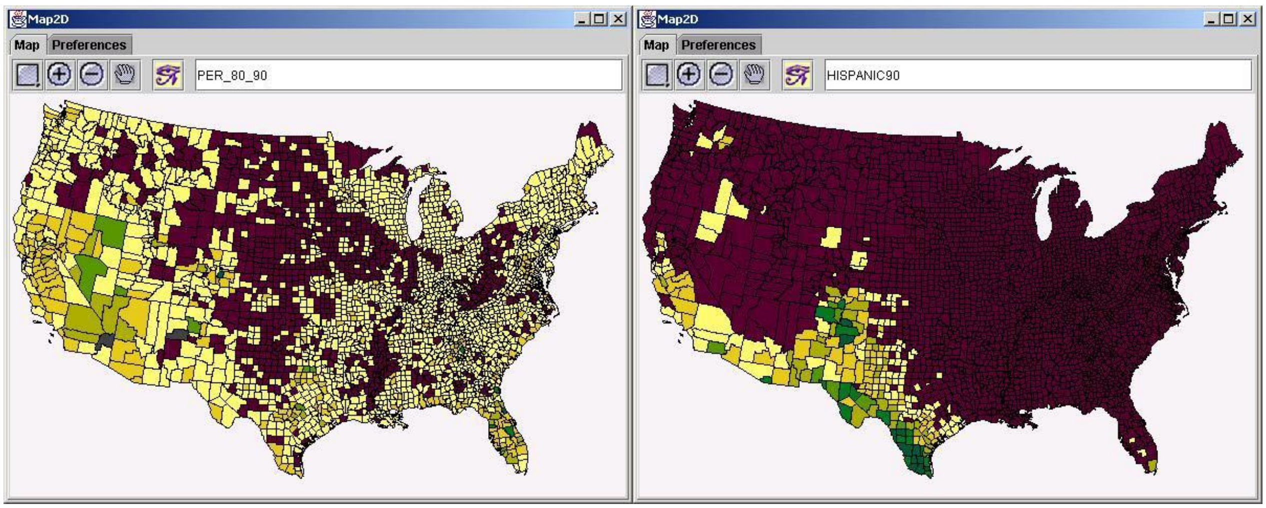
A strength of GeoVISTA *Studio* as an analysis tool is that we can examine, visually and numerically, the geographic and statistical relationships between phenomena of interest. Using *Studio* to examine the proportion of Hispanics in quickly growing U.S. counties and changes in population counts in those counties enables us to discover and confirm surprising relationships. One of these is that, between the 1980 and 1990 censuses, in the subset of counties that exhibited extremes in population growth (specifically, the top 100 and bottom 100) the relationship between the proportion of Hispanic and the rate of population growth is *negative*. The same surprising relationship holds between the growth in the proportion of Hispanics and the population growth overall. Both the discovery and the confirmation of these relationships are enabled by the use of *Studio*.

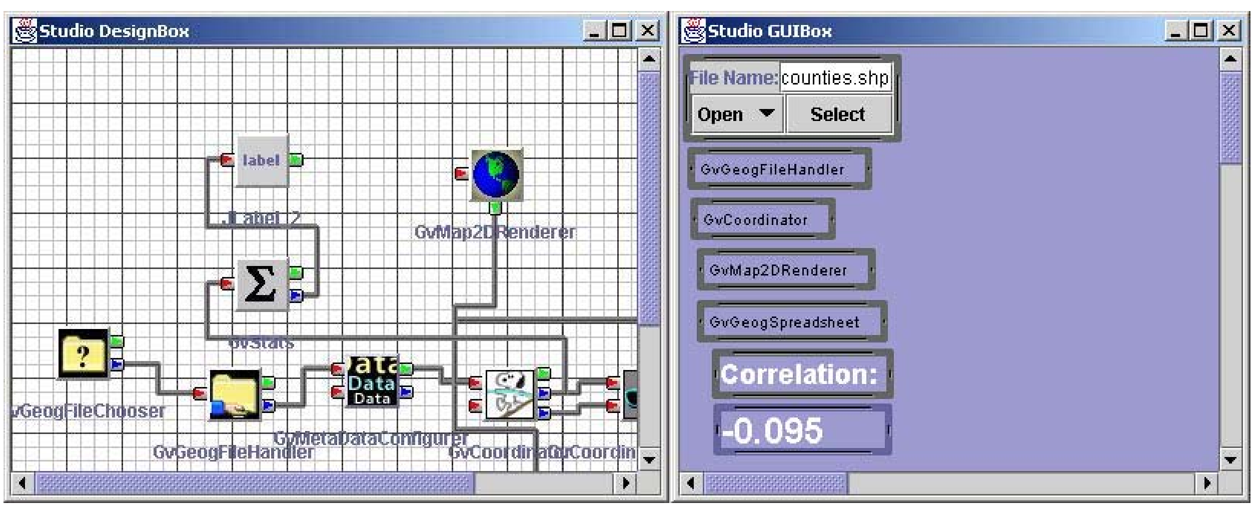
An appealing property of a PCP is that correlation between variables on adjacent axes is depicted visually (by the extent to which lines cross) (Inselberg, 1985). However, if there are thousands of lines connecting two axes, the relationship may be obscured. As discussed above, the ability to classify data depicted in the PCP and to selectively highlight (or repress) subsets of the data make our implementation of the PCP useable for larger data sets. Below, the patterns of lines for the counties with particularly high and low percentages of growth are obscured in the first PCP (left), but clearer in the second (right – in which three intermediate classes are turned off).



In the PCP at right, the crossing of the lines indicate a negative relationship between percentage population change for counties between 1980 and 1990 (PER_80_90) and percentage of population identifying as Hispanic (HISPANIC90). High change (the classes in green) corresponds with low percent Hispanic and the reverse. Similarly, there appears to be a negative relationship between percent change overall (PER_80_90) and change in the percentage of population identifying as Hispanic (HISP8090).

The surprising nature of this relationship suggests that the next step in analysis should be to check the accuracy of the data. We do this first visually my mapping the data on separate maps. Below, a map of the percentage change in population between 1980 and 1990, and a map of proportion of Hispanics in 1990, both conform to well-known distributions. To statistically confirm that the relationship we suspect actually exists, we can add functionality to a *Studio* design at run-time. In the second figure below, a statistical bean and a label bean have been added to the design. With these additions, the user can set the display properties for the label, and the resulting statistics are displayed. In this case, the correlation between the proportion of Hispanics in 1990 in the 100 counties with the highest population growth and the population growth in those counties is shown to be –0.095 which is a weak, but negative relationship.





As we would expect, the relationship between population growth and percentage of Hispanics for the U.S. as a whole, expressed as a correlation coefficient, is positive, 0.118 (although not strong). Similarly, the correlation coefficient between population growth and growth in the Hispanic proportion of the total is also positive at 0.187. However, if we examine the 100 counties with the highest and lowest growth, the picture changes dramatically to being a weak or negative relationship. For the 100 counties with the highest growth, the correlation coefficient of overall population growth with proportion Hispanic in 1990 is (–

0.095), and for the 100 counties with the lowest population growth it is (–0.345). The relationship between the change in percentage of Hispanics in the county and population growth for the 100 counties with the fastest growing proportion of Hispanics is positive but very weak at 0.036, while for the 100 counties with the largest shrinkage in proportion of Hispanics the relationship between population growth and change in the proportion of Hispanics is negative at –0.323. The reversal of the national trend in the extreme cases could be due to a number of factors. One such factor could be that Hispanic immigrants have been migrating to cities in the "rustbelt" with declining populations. Another factor is that there is a strong relationship between wealth, as measured by median housing values and population growth in counties (0.45). People from Hispanic backgrounds may be less likely to self-identify as Hispanic as they integrate into wealthier counties with different dominant cultural values. These demographic trends will be further explored in reference to other socio-economic data sets to explain these relationships.

GeoVISTA *Studio* is being disseminated through use of Java Web Start. This mechanism will make it possible for users to download the software once (through a standard web browser) and automatically retrieve software updates whenever the program is launched (on a machine with an active web connection). See www.geovista.psu.edu for more information.

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Web-Based Collaborative Tools for Geospatial Data Exploration

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Federal government agencies have collected large and highly complex federal statistical summaries and geo-reference data. Methods and tools for identifying patterns and uncovering multivariate relationships in the complex datasets have drawn attention in multiple fields. The approach we present here extends from and integrates perspectives from multiple fields, including exploratory data analysis (EDA), geovisualization, information visualization, and data mining. Important components of our research are supported by a NSF Digital Government grant (#99883451). Other support comes from a National Cancer Institute (NCI) contract. Our DG research is now being extended to develop comprehensive multivariate analysis methods and tools, through a grant from NCI (CA95949).

Over the past year, (in addition to enhancement of existing tools), new multivariate analysis and visualization tools and functionalities added include: (a) feature selection and multivariate clustering tools for identifying interesting subspaces from high dimensional datasets, (b) a custom parallel coordinate plot (PCP) application, which supports the analysis requirements of NCI, (c) extensions of ColorBrewer for bivariate mapping, and (d) integration of GeoVISTA *Studio* and GeoTools, an open source Java library for developing OpenGIS solutions to geospatial data access, analysis, and presentation tasks.

The feature selection and multivariate clustering tools support work that develops a human-centered, component-based, exploratory spatial data analysis environment for discovering patterns in large and high-dimensional data, e.g., various census data, public health data, etc. The implemented system includes a suite of computational and visual components, each of which focuses on a specific task or step in the overall data exploration process and together they can communicate with each other and collaboratively address complex problems. Specifically, this part of our suite of methods and tools includes: (1) an interactive feature selection method for identifying interesting subsets of variables, (2) an interactive, hierarchical clustering method for searching multivariate clusters, and (3) a set of coordinated visual and computational components centered around the above two methods to facilitate an visually-enabled, efficient, effective, human-led exploration of multivariate spatial patterns. Figure 1 shows a snapshot of the

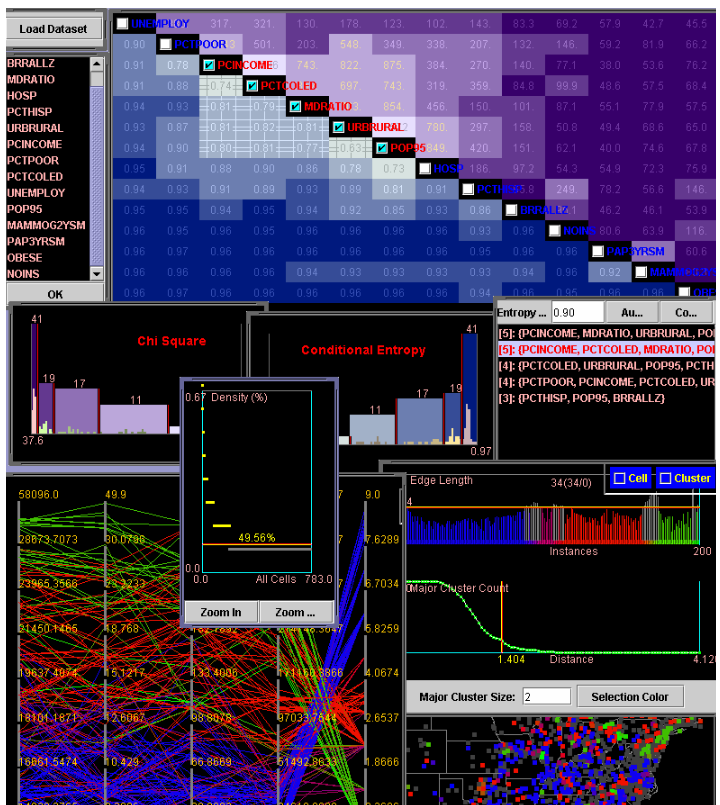

Figure 1: Integrated feature selection and multivariate clustering tools (Guo, 2003)

integrated system. A normal cycle within the iterative exploration process can be: loading data, cleaning the data, interactively selecting interesting subsets of variables for further analysis, identifying hierarchical clusters of the data (using selected variables), interactively exploring and interpreting those clusters, visualizing the clusters in a map and examining the spatial distribution of discovered multivariate spatial relationships.

New parallel coordinate plot (PCP) and time series analysis components were implemented under the contract with NCI and packaged as a stand-alone application that includes a scatterplot and bivariate map. This application is designed for NCI data analysis needs, which include temporal data analysis, interactive data range setup, box plot analysis on each variable, and others. The application's PCP supports display of multiple variables at the same time by mapping an n-dimensional dataset to a two-dimensional space where variables are listed as parallel axes, and each observation is visualized as a polyline, connecting the points on axes, which are the observation's values on those axes.

Color schemes play a critical role in displaying the patterns within multivariate data in geovisualization environments. An extension to univariate color schemes, ColorBrewer, has been developed to represent bivariate data. A set of scheme choices for each two-variable combination is implemented, such as sequential-qualitative or diverging-diverging. The schemes are constructed by sampling the surface of geometric objects within CIE L* a* b* color space, a perceptually scaled 3D color space. Two tools, the Color scheme design board and the Color scheme coordinator, are implemented in GeoVISTA *Studio*. The Color scheme design board is aimed at advanced users who would like to explore the parameters of bivariate color schemes and/or to design custom schemes. The ColorBrewer stores the information about recommended color schemes and can communicate with client components in GeoVISTA *Studio* to apply the color schemes.

Two key architectural changes have been made to the GeoVISTA *Studio* environment, which is the backbone platform that the research uses to integrate various components. The first is the development of 'invisible' adapters, which automatically translate data structures between different components and thus greatly ease the process of integrating components into an analysis environment. The second adds the ability to attach notes (or metadata) to *Studio* designs and thus help non-developer users (e.g., epidemiologists) understand the use and purpose of the design. The research also supported experimentation and re-engineering of interfaces that conforms to standard GIS and database data formats, including Open GIS Consortium standards for describing data and describing the visual appearance of maps and displays.

The applications described above follow a component based software design standard; they are implemented as independent but coordinated Java beans. These components are "coordinator-aware" and make use a coordinator bean to communicate with each other, as well as other existing tools, such as maps, matrices, spread sheets, etc. The concept of dynamic coordination, supported by these independent components, is implemented as data sharing, selections, classifications and focusing, and enables a dynamic and comprehensive multivariate analysis of geospatial data.

The source code of these tools, along with GeoVISTA *Studio* is available through SorceForge. Stand-alone applications have been distributed to collaborating agencies and some applications are available as Java Applets, at www.geovista.psu.edu. All of the multivariate analysis tools and applets developed by our group will be demonstrated at the System Demonstration session during the dg.o2004 conference.

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VISUALLY-ENABLED GEOCOLLABORATION TO SUPPORT DATA EXPLORATION & DECISION-MAKING

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Abstract:

Current mapping and related geospatial technologies are not designed to support group work and we have a limited theoretical or practical basis from which to extend (or reinvent) technologies for group use of geospatial information. To address the challenge of supporting group work with geospatial information, we have developed a comprehensive conceptual approach to *geocollaboration* and are applying that approach to a range of prototype systems that support both same- and different-place group activities.

Our focus in this paper is on same-time, same-place group work environments that mediate distributed thinking and decision-making through use of large-screen displays supporting multi-user, natural interaction. Two environments will be described and compared. Both make use of hand gestures as a mechanism for specifying display locations. One adopts a white board metaphor while the other adopts a drafting table metaphor. We also consider two use cases: group data exploration (by scientists and analysts) and group decision-making (by crisis managers and planners).

1 INTRODUCTION

Visual displays of geospatial information in the form of maps and images have long served as enabling devices for group work. Urban and regional planners, for example, often gather around large paper maps to discuss master plans or specific development choices and these same large format maps are used as the object of discussion at subsequent public meetings. Similarly, teams involved in crisis management use large maps in both situation-assessment and response activities and earth scientist (e.g., geologists, ecologist) often work collaboratively on development of map categories and on planning for field research activities. These are rudimentary examples of what we label *geocollaboration.* As an activity, we consider geocollaboration to be group work about geographic scale problems facilitated by geospatial information technologies. As a field of research, we consider geocollaboration to be the study of these group activities, together with the development of methods and tools to facilitate them.

Recent technological advances in display hardware and multimodal interfaces are making it possible to merge the advantages of large format representations that facilitate group work with those of dynamic, interactive displays (applied over the past decade to desktop mapping and GIS applications designed for individual use). This merger is likely to have a substantial impact on group productivity. In addition, dynamic, large-format displays having natural interfaces designed specifically to support group work have the potential to dramatically (and qualitatively) change the way groups work with geospatial data, thus to create fundamentally new kinds of geocollaboration.

This paper provides an update on two ongoing projects to develop methods and tools that support visually-enabled geocollaboration – among humans and between human and computer agents. The research builds on a human-centered conceptual approach to both design of geocollaboration environments and evaluation of environment usability. For details, see: [3, 4]. The overall approach integrates perspectives from cognitive science (particularly distributed cognition), semiotics (particularly the mechanisms through with representations are devices for sharing meaning), and usability studies (particularly cognitive systems engineering). Here, we focus on different metaphors for support of group work with large screen display and on some of the key design decisions that underlie the natural, multi-user interfaces we have implemented.

We begin below (in section 2) with a brief overview of recent research on large-screen, map-based displays and their use in facilitating group work. In section 3, we describe and compare two environments that we are developing. Both make use of large displays and natural interaction to enable same-time, same-place group work with geospatial information. One environment supports joint use of exploratory geovisualization tools. The second is directed toward crisis response facilitated by GIS. Section 4 provides discussion and plans for future research.

2 BACKGROUND

The advantages of large format maps as group situation-assessment and decision-making tools have prompted multiple authors to consider the potential of dynamic, large-format, map-based displays for group work with geospatial information. Florence, et. al [5], for example, proposed (but did not implement) the *GIS wallboard*, an electronic white board envisioned to support sketch-based gestures (of the sort implemented by Oviatt [6] and Egenhofer [7] for tablet displays). In the precursor to our multiuser Dialogue-Assisted Visual Environment for Geoinformation (DAVE_G) system (discussed in section 3) our colleague Rajeev Sharma and his research team successfully implemented a natural multimodal (speech-gesture) interface to a large screen dynamic map [8, 9] and extended the system to support a crisis response scenario used to test robustness of the interface methods [10].

The environments above all adopt a white board (or wall map) metaphor. This kind of interface is likely to be useful in a context such as a public planning meeting or emergency operations center briefing in which one or two individuals take a lead role in presenting information and steering a group discussion. This kind of interface (like the traditional white board or black board) affords the action of walking up and drawing or writing, then giving way to another actor.

An alternative metaphor is the drafting/work table. This metaphor affords group activity around (rather than in front of) the map display (creating an environment similar to one with a large map on a drafting table). This format is typical of work by military and emergency management personnel in the field or urban planners in the office (where they may conduct extended work prior to its presentation with a wall display at a public meeting). Hopkins and colleagues [11] as well as Arias, Fischer and colleagues [12, 13] have implemented large, table-like group work displays to map-based planning activities. The later group has merged virtual and physical space in a system that allows users to create a shared model of a planning problem by manipulating 3D physical objects that provide a "language" for interacting with a computer simulation.

In some contexts, such as military planning and crisis response, large paper maps retain a distinct advantage in their combination of high resolution and portability. McGee [14, 15] has studied military planners working with such maps. Based on this research, he proposed an approach to augmenting paper maps through digital Post-it notes (physical notes for which the position and content could be sensed by the system). The goal was to create a robust system that did not require users to learn new work routines and that would continue to work even when technological or power failures occurred.

A third metaphor used in group work environments is activity (or geographic) space itself. Activity spaces afford entering and behaving within them; and that is what immersive environments for group work attempt to support. Neves and colleagues [16] developed an immersive virtual workspace based on a GIS room metaphor (a room in which maps can be mounted on the wall or placed on a digitizing tablet for encoding in the system). They implemented the environment only individual users but, conceptually, the metaphor could support multiple users. One of the first collaborative, immersive environments using a geographic space as the underlying metaphor is the *Round Earth Project*, developed to enable children's learning about the shape and size of the earth [17]. While that effort focuses on same-place collaboration, there have been several Cave and ImmersaDesk-based demonstration projects that support collaboration within 3D, geographic-scale environments representing real and modeled spatio-temporal processes, see: [3, 18, 19]. Recently, Armstrong [20] identified teleimmersive environments (different-place, collaborative, immersive environments that rely on high performance computing and distributed geo-processing) as a grand challenge to the research communities in geographic and information sciences.

3 NATURAL, MAP-BASED INTERACTION WITH GEOSPATIAL INFORMATION

Here, we discuss two geocollaborative system development efforts, emphasizing the role of maps as a primary interface component in each. The first system uses a horizontal display that functions much like traditional drafting tables that multiple participants in a group activity can gather around. The second system uses a vertical display that functions more like an electronic white board. Both differ from most other large screen environments in their use of hand gestures in place of mouse, pen, or wand as a primary interface method for specifying display location.

3.1 HI-SPACE

The HI-SPACE (Human Information Workspace) environment offers a platform for enabling groups of analysts to interact with each other and with geospatial data in new ways, remedying some of the inefficiencies involved in group use of visualization tools on traditional displays. This prototype, collaborative virtual environment (CVE) is an experimental, hands-free, untethered, enhanced reality system developed by Richard May [1]. The goal of developing this HI-SPACE environment was to promote more natural interaction between groups of users and modern computing displays.

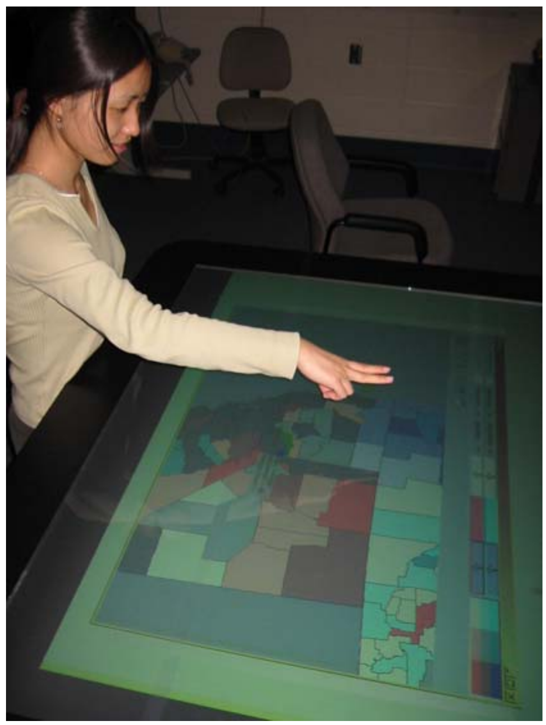

Figure 1. Gesture interface to the HI-SPACE Table. Demonstration of collaboration with interactive map component in GeoVISTA *Studio*. HI-SPACE *Table developed by Richard May[1], on loan to the GeoVISTA Center from the Pacific Northwest National Laboratory.*

HI-SPACE has specific attributes that have the potential to significantly alter collaborative interaction for decision making, exploration and command and control situations. First, the size of the display enables groups of individuals to work in a comfortable round-table fashion, rather than dispersed on separate personal computers or clustered around smaller, vertical displays. Second, untethered gesture recognition (not requiring a data glove or other device) allows group members to use natural forms of communication to share ideas (such as pointing to indicate emphasis). Third, the table supports phicon (physical object) recognition so that users can utilize real world objects on the display as they would on a traditional table or desk top to augment and enhance collaborative discussions. Each of these features is discussed below, and the context in which these functionalities have an impact for users of geospatial information is considered.

Data gloves, head mounted displays, data wands, and other tools for interacting with virtual data have not been widely adopted by practitioners. There is, thus, a need for untethered interaction that reflects the natural interaction among collaborators, the surrounding environment, and the CVE. The HI-SPACE environment has the potential to comfortably support 3-6 simultaneous collaborators using relatively natural (untethered) gestures and the software provides an individual cursor icon for each of the participants. This form of interaction is likely to improve group communication through eye contact, gaze, and the ability of each person to experiment with their individual cursor.

Our work addresses this need by building on the neural network gesture recognition developed by May [1]. Currently, the HI-SPACE table can track the hand position and identify individual gesture poses (e.g. two fingers extended). Modern Operating Systems (OS) are designed to support interaction with single users. That means there is only one mouse available for interaction between a user and a computer. In order to support *geocollaboration*, in which multiple users work concurrently on a single platform (computer), multiple mice or channels are needed in single computer. Our extensions to the HI-SPACE environment address this issue.

Here, we introduce, briefly, how these extensions to HI-SPACE support interactions between multiple users and a Java application platform. Understanding multi-user interaction requires a brief discussion of how a single user interacts with a Java application. As shown in figure 2, a mouse click is translated by the operating system into an OS-level event. The event is sent to the Java Virtual Machine (JVM) where it is translated into a JVM mouse event. Java applications actually respond to JVM (rather than OS) events. In order to enable multiple-users interaction, we can generate virtual mouse events, either OS-level or JVM-level, for each user.

HI-SPACE collects interactive information from multiple users by capturing user gestures. Different gestures indicate different mouse behaviors. For example, we have implemented two simple actions: stretching out one finger indicates a mouse move action and using two fingers indicates a mouse press action. The gestures of each user are translated into virtual mouse events which are fed into the OS, sequentially, thus, the establishing a direct link between the users and the computer through HI-SPACE. In practice, as JVM mouse events are generated they are recognized, processed, and fed to the Java Virtual Machine. Figure 2 shows how this procedure works.

Integrating HI-SPACE with a Java application is relatively easy. From the perspective of the JVM, the mouse events generated by HI-SPACE are not different from those generated by the real mouse. Thus a Java application responds to HI-SPACE events in the same way as it does to real mouse events. This means, theoretically, we do not have to change the Java application except by attaching an adapter to accept HI-SPACE events.

Concurrent users of HI-SPACE are not limited to same-place work; they can be in distributed places. For distributed users, virtual mouse information can be transmitted via the network. Priorities for virtual mouse events can be established so that interference among users' operation can be avoided.

Specifically, our work is focusing on the development of a coordinator or arbitrator that helps determine which user has control of the system at any given time, while storing other related events into a queue for later processing. Long term efforts are aimed at merging voice recognition software to identify the person who is in control of the collaborative discussion, and subsequently provide that individual with highest priority for interaction.

May [1] envisioned a HI-SPACE environment that would minimize attention shifting from data work to collaborative work by providing seamless interaction between collaborators and the information through the use of physical objects, or phicons. His plan was to merge the workstation

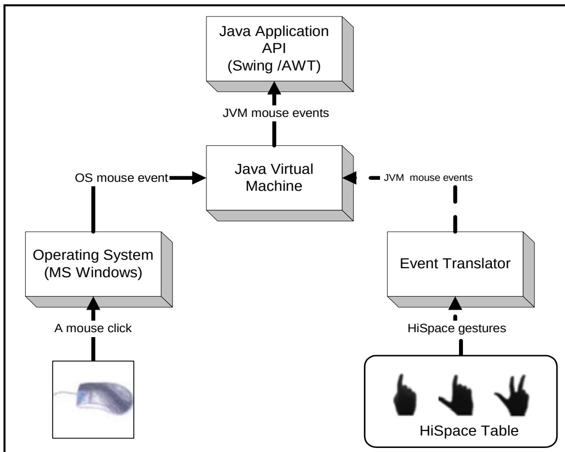

Figure 2. Implementation strategy for supporting multiple participants, using gesture to initiate mouse events.

and the typical desk environment together into a seamless coupling of shared information. For example, if a collaborator were to place pen at a location on the table to indicate something, but then get distracted by a discussion with a fellow collaborator, the table should recognize the pen as a place holder that assists in guiding the discussion away from the tangent and back to its original focus. To this end, we are exploring the use of pens, erasers, markers, magnifying glasses and other physical objects that can be used to not only facilitate human-human collaboration, but also be recognized by the HI-SPACE display for interaction with the underlying geospatial data.

We are also building on this base to provide complex gesture support that does not require individual hand poses, but instead, uses the gestures that come naturally when indicating information on the table top display. Our approach to natural interaction with geographic applications is also expanding from a gesture-only approach to the inclusion of voice commands. We are in the process of adding simple voice commands that complement and augment gesture commands to create a flexible, easy to learn, and easy to use interface. Both natural, free-hand gesture interpretation and its integration with speech input are central components of DAVE_G (described below).

3.2 DAVE_G – Dialogue-Assisted Visual Environment for Geoinformation

Development of our initial DAVE_G prototype has been made tractable by narrowing the potential application domain from collaborative work generally to support for collaborative work on geospatial data in crisis management. To accommodate the need for a large format map as a shared context for collaborations among different domain experts, DAVE_G (figure 3) uses a large screen display where maps are served from geographical information servers, and users can stand freely in front of the display (implementing a white board metaphor). In order to make the collaborative decision-making more effective, DAVE_G addresses two challenging problems commonly found in the traditional use of geographical information in emergency management centers. First, there is a need to relieve emergency managers from the burden of having to use keyboard and mouse to formulate well-structured commands. Here, we offer the ability to interact with the system using natural modalities (spoken language and natural gestures). Second, emergency managers should be able to interact directly with geographical information instead of interacting with a GIS operator who can be a bottleneck to (rather than facilitator of) communication in a collaborative work environment. To deal with the first challenge, DAVE_G uses microphones and active cameras to capture spoken language and natural gestures as direct input that drives the system's response on the map display. To deal with the second challenge, an intelligent dialogue agent is employed to process ill-structured, incomplete, and sometimes incorrect requests, and to facilitate task-oriented, extended interactions and collaborations. For a detailed explanation of the architecture for our initial DAVE_G prototype see [2].

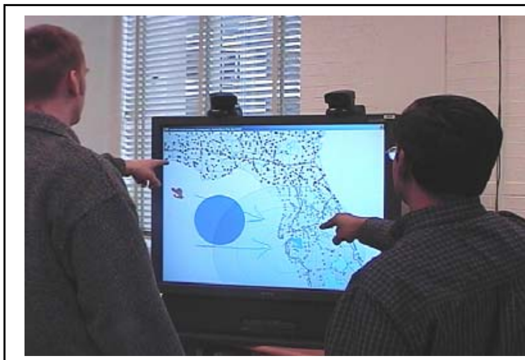

Figure 3. Two-person, gesture-speech interface to DAVE_G. Demonstration of a collaboration scenario focused on analyzing potential hurricane impacts. *figure reproduced from* [2].

DAVE_G is based on the interaction framework initially developed in *iMap* [21] XISM [8, 9, 22]. We have added substantial extensions to support multiple user interaction (by duplicating modules for speech and gesture recognition for each additional participant) as well as human-system collaboration (through addition of a human collaboration manager). To capture and process speech, DAVE_G utilizes a speaker dependent voice recognition engine (ViaVoice from IBM) that allows reliable speech acquisition after a short speaker training procedure. The set of all possible utterances is defined in a context free grammar with embedded annotations. This constrains the available vocabulary but retains flexibility in the formulation of speech commands.

Hand gestures are captured using computer vision-based techniques, and are used to keep track of the user's spatial interest and spatial attention. For reliable recognition of hand gestures, a number of vision-related components (face detection, palm detection, head and hand tracking) are engineered to cooperate together under tight resource constraints. The results of speech recognition and gesture recognition each provide partial information for intended actions. To achieve a complete and coherent understanding of a user's request, verbal utterances from the speech recognition have to be associated with co-occurring gestures observed by the gesture recognition process. Currently, DAVE_G can understand speech/gesture requests for most commonly used map display functions such as "show a map of population within Pennsylvania", "zoom here{gesture}", "highlight these{gesture} features", "make a one-mile buffer around these features", and more.

In DAVE_G, dialogue is neither user-led nor system-led, but rather is a mixed-initiative process controlled by both the system and the users in collaboration. It allows complex information needs to be incrementally specified by the user while the system can initiate dialogues anytime to request missing information for the specification of GIS query commands. This is important since the specification of required spatial information can be quite complex, and the input from multiple people in several steps might be needed to successfully complete a single GIS query. Therefore, the HCI can not require the user to issue predefined commands, but needs to be flexible and intelligent enough to allow the user to specify requested information incompletely and in collaboration with other users and the system.

Information requests are provided to the system in fragments of spoken utterances and gestures that can not be understood without taking into account the shared context established by previous discussions (interactions). Furthermore, information requests that come from different users may be incoherent, or even conflicting with each other, and such problems must be handled carefully to avoid 'breakdowns' in the collaboration process. The dialogue manager in DAVE_G is able to understand and guide the user through the process of querying the system for information and acts to verify and clarify the dialog with the user when there is missing information or recognition errors. To provide such behavior, the dialog manager requires a deep understanding regarding the current discourse context and task progress, and also must maintain a model of users in terms of their intention, attention and information pool. To handle complex human-GIS-human dialogues in geocollaborative use of map information, DAVE_G uses the SharedPlan theory [23] to guide the development of a model of rational behavior in group spatial decision making. It models the map-mediated geocollaborative environment as a system of multiple agents that plan and act cooperatively.

3.3 Discussion

Our approach to designing, developing, and creating multimodal systems is yielding promising results. For example, lessons learned about work domains, work tasks, collaboration, and technological challenges from work in the HI-SPACE environment often carry over to work on the DAVE_G system (or the reverse). This robust, simultaneous development cycle has yielded new insights not only into the nature of collaboration with geospatial information, but also into the design of complex systems themselves.

4 CONCLUSIONS

The two system development efforts discussed above are part of a larger effort to develop a theoretical framework that supports the design, implementation, assessment, and application of technologies to support geocollaboration as well as the study of geocollaboration as a process. Technology-enabled geocollaboration is a relatively new domain of research and practice. As such, there are many unanswered questions and the platforms detailed above provide an opportunity to investigate a subset of them. Specifically, we are focusing on: the impact of different metaphors to enable collaboration in different problem domains and with different kinds of geoinformation technologies, alternative methods for making interfaces more natural (and whether this does, in fact, make them easier to use), and how visual displays enable (or might enable) human-system and human-human dialogue and joint work.

Supporting group work with geospatial information is a challenging task. Maps have played a substantial role in collaborative activities for centuries, but cartographers seem to have given little thought to the design of maps (or map-based interactive displays) to specifically support group work. Similarly, while there has been considerable attention given to group spatial decision support [24-26], only limited attention has been given to visually-enabled group work. We view this gap in our knowledge and understanding as a substantial opportunity for cartography to make an impact on GIScience and information science more generally and on the application of that science in a range of contexts for which group work with geospatial information is critical. We encourage cartographers to this engage this opportunity.

Acknowledgments

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GEOVISUALIZATION TO MEDIATE COLLABORATIVE WORK: Tools To Support Different-Place Knowledge Construction and Decision-Making

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Abstract: *In this paper, we focus on extending geovisualization methods and tools to support the work of groups. More specifically, we consider the role of map-based displays in facilitating collaboration in the context of geospatial knowledge construction and decision-making activities. Emphasis is given to those situations in which collaborators are interacting at a distance from one another. Rapid advances in electronic communication technologies that make collaboration at a distance both practical and expected will exacerbate the single-user limitations of existing tools and approaches. Particular emphasis is given here to the role of visual display as a mediator between individuals who apply different perspectives to a problem and the role of information visualization methods in providing both participants and system designers with important feedback about the process of collaboration. After providing a conceptual overview and brief background, we describe components of two collaborative geovisualization prototypes.*

1 Introduction

Extending geovisualization tools and approaches to meet the needs of collaborative work is a substantial challenge. This challenge will require new perspectives on old problems of geospatial information manipulation and cartographic representation as well as attention to new problems related to how groups work. The approach to collaborative geovisualization taken by our research group integrates perspectives from cartography (and geographic information science), cognitive science, human-computer interaction, computer-supported cooperative work, and semiotics. In this work, we are beginning to address the full range of space-time collaborative situations that can involve group work in the same or different places and at the same or different times.

Here, we focus specifically on the design of visual representations that facilitate *different-place* collaboration, both same time and different time. We give particular attention to the ways in which dynamic visual representations can be used in these contexts to facilitate shared understanding. Through discussion of a pair of early prototypes, two separate but related problems are considered. *First*, we address the ways in which visual representations can be used to mediate among participants, supporting collaborative knowledge construction and providing a vehicle to negotiate among perspectives. *Second*, we propose and discuss methods by which collaborating participants and their interaction with the system can be visually represented. These representations are designed to facilitate both coordinated work among groups of users and our own subsequent visual analysis of that work as we conduct experiments designed to refine the tools.

In the next section, we highlight relevant research focused on collaborative visualization, collaborative virtual environments, and visual support for group work. This is followed, in section 3, with an overview of two collaborative prototypes, through which we are beginning to address the pair of problems outlined above (how to visually mediate understanding and how to represent participants in different-place group work). The paper concludes (in section 4) with a discussion of planned follow-up work.

2 Background

There have been only a few efforts thus far to develop collaborative geovisualization environments that enable different place group work. Thus, it is necessary to draw upon a range of related efforts in other domains in order to construct a base from which to develop, implement, and assess such environments. In this section, we outline selected components of this work. See recent overviews for a more comprehensive review (Nyerges, 1999; MacEachren, 2000; MacEachren, in press).

2.1 Collaborative Visualization

Collaborative visualization involves committed, synergistic efforts among multiple participants using visual displays to frame and address tasks (Brewer et al., 2000). Wood, et al (1997) propose that the ideal collaborative visualization systems should support both instructor-driven collaborations and the interaction of multiple independent participants. For the later, they suggest that the environment should support data exchange, shared control, dynamic interaction, ease of learning, and shared application mode.

Whether instructor-driven or for independent participants, the likely application that collaborative visualization tools can be expected to support include a range from exploration and analysis of scientific data through decision support to education and training. Collaborative visualization tools have been developed for use in a variety of fields in which geospatial data are important, including environmental management (Rhyne, 1998) oceanographic and meteorological studies (Pang and Fernandez, 1995) and hazards research (Padula and Rinaldi, 1999). In order to support dynamic, asynchrounous and syncrounous collaboration, research has begun to focus on the identification and design of interface features required for effective scientific collaboration (Watson, 2001).

2.2 Collaboration in Virtual Environments

Collaborative Virtual Environments (CVEs) have the potential to improve distributed collaborative work significantly, by making work at a distance more natural. CVEs have been developed for a range of applications, including: visualization of seismic data by collocated individuals (Lin et al., 1998); development of collaborative geocomputational tools for battlefield analysis (Jones et al., 1998); and earth/space science education (Roussos et al., 1999). Almost all CVEs rely upon visual displays as a mediator among participants and create “spaces” within which participants interact and many focus on applications using geospatial data; thus work on CVEs provides a base from which to develop collaborative geovisualization environments. One of the identified barriers to successful CVE implementation is our limited understanding of how people interact with objects, and with each other, in virtual displays. Hindmarsh, et al (2000) address one component of this problem through a comparison of the ways in which participants make use of mediating visual objects in a discussion. When collaborators are in the same location, they often use gestures directed to display objects to facilitate discussion, however, when collaborators are in different locations, they must develop alternatives (e.g., verbal expression) which are often less successful and can interfere with dialogue focused on the questions atr hand. A related barrier to CVE success is that the nature of social interaction within CVEs differs from that of real (face-to-face) interaction. Tromp, et al (1998) explored the characteristics of initial meetings in CVEs, and how such interactions relate to everyday social interaction.

2.3 Visual Support for Group Work

Hindmarsh et al. (2000) suggests that the use of high quality graphical visual depictions of real and imagined scenes could become the typical every day work medium for distributed interaction among experts. The role of visual displays in providing support for group work, however, has received only limited research attention thus far (see (Armstrong and Densham, 1995), for one initial effort using geospatial information).

Perhaps the best-tested collaborative system mediated by visual displays is the UARC/SPARC collaboratory project (Olson and Olson, 2000). The collaboratory allows users to organize their data streams into hundreds of individualized displays –3D visual renderings and virtual realty rooms - that are then shared (both synchronously and asynchronously) with other collaborators. While the UARC/SPARC collaboratory supports collaborative visualization, its developers have not yet examined the cognitive or social impacts of such visualizations on the collaborative process. Recent efforts to improve our understanding of the interaction between cognition and graphical representations have focused on collaborative learning (Suthers, 1999) and on the design of graphical user interfaces for data visualization (Ma, 1999).

3 Prototype Development and Implementation

In this section, we describe two prototypes. The first is designed to support different-place analysis of environmental processes and human-environment interaction (and to facilitate requirements analysis for subsequent systems). The second is designed to support representation of participant behaviors in a different-place collaborative session (and assessment of those behaviors).

3.1 Visual Support for Work at a Distance

The prototype described in this section was developed as an extension to a single user geovisualization environment. The extension was implemented as a first step toward a suite of collaborative geovisualization and geocollaboratory tools being developed as part of the Human-Environment Regional Observatory (HERO) project's Intelligent Networking Environment (HEROINE). The focus for this prototype is on supporting both same time–same place and same time–different place collaboration among scientists as they explore complex spatiotemporal data.

3.1.1 Components and integration

The prototype is implemented in Java/Java3D, specifically using VisAD, a Java (2D/3D) class library for interactive and collaborative visualization and analysis of numerical data.[1] We also make use of DEMViewer, a VisAD compatible digital elevation model viewer for ArcGrid ASCII export files.[2] The initial (pre-collaborative) application was built to support the needs of two research teams from whom we obtained data for use in testing the application. The first data set is drawn from a much larger climate data set for the Susquehanna River Basin of Pennsylvania, New York, and Maryland (figure 1) -- specifically daily maximum temperature, minimum temperature and precipitation for the time period of 1983-1993. The second includes monthly precipitation data for Greece from 1901-1995.

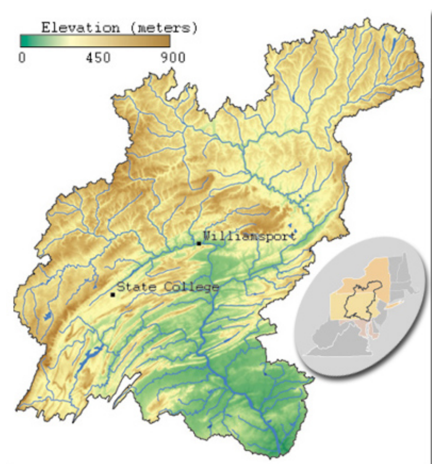

figure 1. Susquehanna R. study area

Both groups were concerned with understanding environmental change and with using that understanding to support integrated regional assessments. The initial version of the prototype focused on support for temporal database queries and interactive animation (Kraak et al., 1997), through which relationships between terrain and climate patterns can be explored. We implemented support for linear and cyclic temporal database queries, with queries accessing a database implemented in POET, an object-oriented database (figure 2).

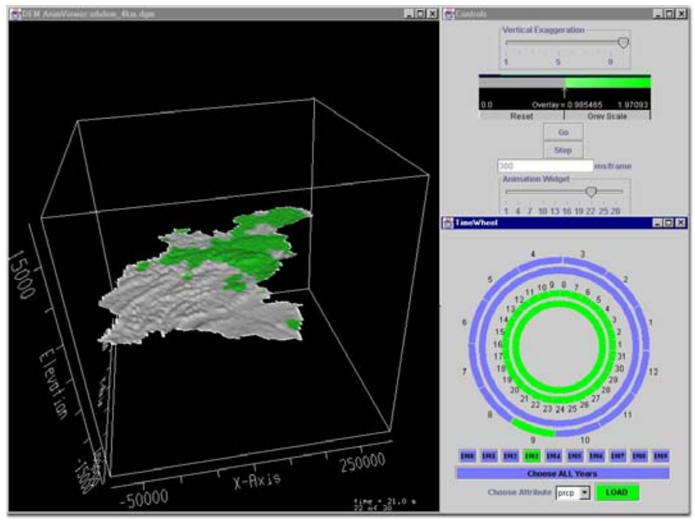

figure 2. Initial pre-collaborative application. The environment is being used to explore precipitation events (draped on terrain). All days for one month (Sept.) for one year (1984) are selected using the temporal controls. Color scheme controls allow "focusing" on a subset of high values (depicted on the map display). Other controls allow the user to play or stop an animation, to move to particular times in the series and to manipulate the vertical scaling for the terrain representation.

3.1.2 Support for different place collaboration

A primary objective of the HERO/HEROINE project is to facilitate coordinated and collaborative research directed to understanding and predicting the implications of global environmental change for people and places at a regional level. For representation of geospatial information in this and related contexts, visualization has the potential to provide a display "space" (frame of reference) within which ideas about geographic space and place can be shared. More specifically, visual displays can be used collaboratively to: (1) facilitate common understanding of geographic context; (2) enable integration of georeferenced data generated by different sources; (3) facilitate spatial (and temporal) comparisons of perspectives; (4) link perspectives about pattern and process across scales; (5) clarify spatial (and temporal) components of an argument; (6) summarize multiple points of view.

As a first step toward a collaborative geovisualization environment to support these aims, we leveraged the prototype described above to produce an initial, limited same time—different place application that we used as a proof of concept and prompt for discussing design of more comprehensive collaborative tools. The collaborative geovisualization environment developed allows multiple users to view and manipulate changing climatic data simultaneously and thus to share knowledge as they identify drainage basin scale patterns and processes. The animated view window allows users to manipulate the 3-D depiction in all directions. Users can also zoom in and out from all angles. Linked desktops for multiple users are synchronized when the GO button is pressed. Performance is adequate when using comparable computers for short time span; however, the prototype does not include methods to ensure that animations remain synchronized.

Turning the single-user geovisualization application (figure 2) into a different place collaborative tool required a mechanism for managing communication between remotely located computers. A number of alternatives exist for accomplishing this (some of which are discussed in (Jem, 1998)). We opted for an implementation in which each connected computer ran its own local copy of the application and had a local copy of the database. This "heavy client" implementation requires that any changes to the application or database be distributed to all collaborating clients prior to a collaborative session (resulting in the potential for incompatibilities if a change is made at only one location). The primary advantage of this implementation, of course, is that network traffic is minimized (only event instructions are transmitted), thus eliminating the need for high bandwidth communication channels.

The specific event-synchronization mechanism developed, TalkServer, is a JAVA application for communicating user-initiated events among networked collaborative applications.[3] TalkServer listens on a predetermined port of a server for new connections from client applications (figure 3). For each new socket connection detected, TalkServer creates a TalkServerThread (TST) to communicate with the connected client application. When a TST receives subsequent messages from its client application indicating system wide changes in the collaborative session, the messages are relayed to the TalkServer. TalkServer then requests that all TSTs update their corresponding clients accordingly.

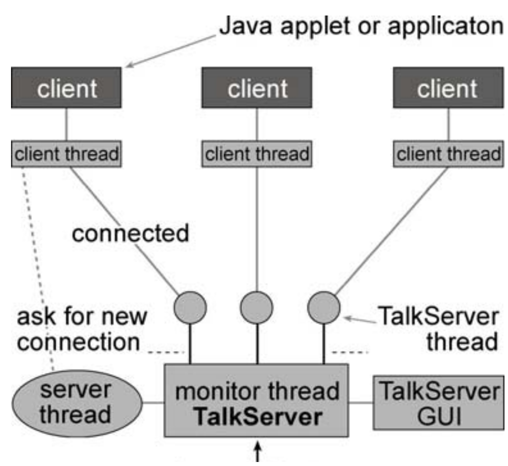

figure 3. TalkServer communication manager.

While the initial prototype is limited in functionality, it has been used effectively as a prompt for discussion with potential users, as part of the human-centered approach we are taking toward design and implementation of collaborative systems. Results of initial work with these users (based upon in-depth interviews) are reported elsewhere (Brewer et al., 2000). To summarize the findings from that study, five system characteristics (not present in the prototype) were identified as important for supporting different place collaboration: (1) facilitating dialogue – ability to talk/chat while viewing and interacting with tools; (2) group member behaviors – ability to know what others were doing; (3) drawing the group's attention – ability to indicate objects, places, and regions and to alert others to the indications; (4) private work – ability to work ideas out individually before sharing them with others; (5) asynchronous collaboration – ability to save and share sessions and to initiate new analysis from any point.

3.2 Representing Participant Behaviors

We have begun to address the second and fifth of the desired collaborative system characteristics listed above. Specifically, we are experimenting with designs for a "watcher" window that depicts users and actions schematically. The goal is to provide collaborators with a small, dynamic, visual summary of key aspects of a collaborative session. Among the things that collaborators are likely to want information about are: who is currently controlling the display, which windows are active, and which collaborators have shared views of the data.

An initial design for a watcher window to provide this and other information is shown in figure 4. The schematic display is designed to accompany a multi-window analysis environment, thus needs to be both small and simple, so that it does not obscure the display or require much time to interpret. The watcher window shown represents use of tools for exploration of multivariate geospatial statistical information using dynamically linked components (a map, scatterplot, and parallel coordinate plot). The watcher window has not yet been integrated with a collaborative version of the data analysis tools it is designed to accompany, but we have implemented a rapid prototype to illustrate how the tool will work (available at: http://hero.geog.psu.edu/collaboratory/watcher.htm

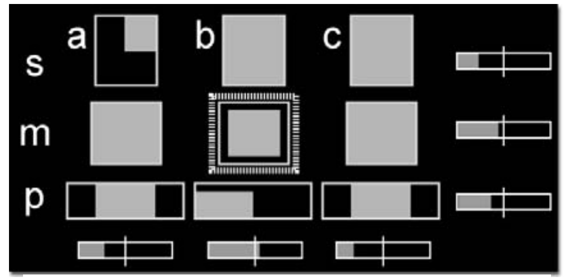

figure 4. Prototype watcher display.

Each row in the watcher display represents use of one of the three data exploration components (labeled, s, m, p) by individuals (labeled a, b, and c) who are participating in a collaborative session. Shading in each window icon indicates the portion of the full display currently in view for a particular individual. The bold outline indicates the participant who is currently controlling the displays and which display window they are interacting with. The gauges at the bottom of each column fill (over time) to indicate session time during which each participant has been in control. The gauges to the right indicate which views into the data have attracted the most attention. These gauges provide useful information to participants about the session as it proceeds and are intended for use in post-session analysis of the collaborative process. Our work on session capture methods (to enable asynchronous collaboration and usability analysis) is detailed in another paper presented at this meeting (Haug et al., in press).

There are many additional aspects of a collaborative session that users might want information about (e.g., which variables are displayed in each view, the specific locations within a display that a participant indicates as being of interest, etc.). A trade-off must be made between availability of information and complexity of the display. Related questions involve determining (or controlling) when the watcher window is visible, how to include it in the display without distracting from the primary object of attention, and in what circumstances (if any) a separate watcher window is preferable to embedding group activity information directly into the data display directly.

4 Discussion and Next Steps

Our multi-disciplinary approach to the design of collaborative geovisualization environments has the potential to aid in the production of a unique, distributed geovisualization system. In following a human-centered systems approach and developing system components based upon computer supported cooperative work, group systems, and visualization research, we have laid the foundations for conceptual guidelines for developing collaborative geovisualization systems. Based upon experiences in building and assessing the collaborative geovisualization environment described above, we are currently working on two follow-up projects. One focuses on more complex kinds of synchronous collaborative geovisualization, the other on lightweight web tools to support both synchronous and asynchronous work with geospatial data.

The first follow up involves extending GeoVISTA *Studio*, a Java-based visual programming environment for geovisualization and geocomputation, to support same time—different place work. *Studio* allows JavaBeans to be combined easily into applets and applications. Part of our work to develop *Studio* has focused on multi-parameter coordination among components instantiated in different windows of a multi-window display (MacEachren et al., 2001). We are currently extending this approach to support coordination among linked components on different computers.

The second follow-up project builds upon our experience using Macromedia Flash to experiment with information visualization methods for representing individuals and their use of collaborative tools. Here we are working to add capabilities to interactive linked web maps and graphics that support synchronous multiuser manipulation of displays and capture of interactive sessions so that they can be shared, asynchronously, with others.

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[1] VisAD was developed by Bill Hibbard, Space Science and Engineering Center University of Wisconsin, Madison. It can be obtained from: www.ssec.wisc.edu/~billh/visad.html.
[2] DEMViewer was developed by Ugo Taddei, Department of Geoinformatics, Geohydrology and Modelling, Institute of Geography, University of Jena, Germany www.geogr.uni-jena.de/~p6taug/demviewer/demv.html
[3] TalkServer was developed by Hadi Abdo as part of his Masters Thesis in Computer Science and Engineering at Penn State University.

GeoCollaborative Crisis Management (GCCM)

Building better systems through advanced technology and deep understanding of technology-enabled group work

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The need to develop information science and technology to support crisis management has never been more apparent. Federal, state, and local government agencies must develop coordinated strategies and adopt advanced and usable technologies to prepare for and cope with crises in contexts ranging from natural disasters to homeland security.

Crisis management is considered here to include both strategic assessment (work to prepare for and avert crises) and emergency response (activities designed to minimize loss of life and property). G*eospatial information* plays a key role in both activities, providing context and details about the event itself, its causes, the people and infrastructure affected, and resources available to respond. Crisis management also requires close coordination among individuals and groups of individuals who need to collaboratively derive information from geospatial data and use that information in coordinated ways. *Current geospatial information technologies, however, fail to support group work and have typically been designed without scientific understanding of how groups (or groups of groups) work in crisis management to collect, process, and use geospatial information*.

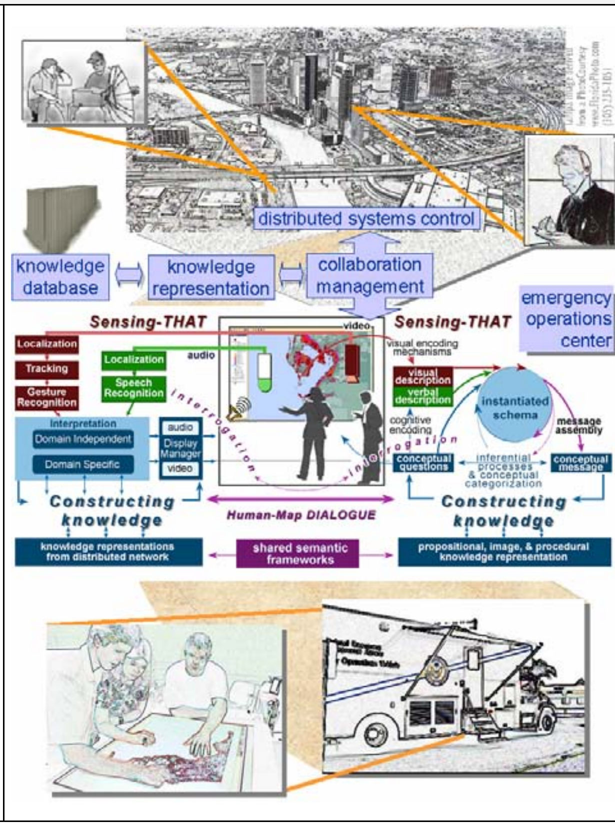
Our research addresses both of these problems in an integrated way, within the context of real world crisis management activities. The research is focused on parallel, integrated advances for two fundamental components of *GeoCollaborative Crisis Management* (GCCM): (1) developing a deep understanding of group work with geospatial information and technology and (2) developing advanced geospatial technology to support both same-place and distributed, dialogue-enabled, collaborative crisis management activities. The research is advancing both theory and technological practice required to make geospatial information technology more effective for command and control, situation assessment, and crisis response activities.

Agency collaborators include units focused directly on crisis management for natural hazards (chemical, biological, meteorological) and on homeland security as well as units that supply the geospatial information to meet their needs. Federal partners include the EPA (four units), HHS-Agency for Toxic Substances and Disease Registry, NIMA, USGS, NASA (Earth Science Applications Division), Air Force Research Laboratory, Wright Patterson Air Force Base, and the Federal Geographic Data Committee. State partners are the PA-DEP, the Port Authority of NY & NJ, Operations & Emergency Management, and the Florida Emergency Management Agency. Our industry partner, *Advanced Interface Technologies, Inc.* (AIT) will collaborate on technology implementation portions of the research.

Our research is addressing collaborative geoinformation use and technologies to enable all stages of crisis management (mitigation, preparedness, response, and recovery, with an emphasis on preparedness and response. The approach we take is a human-centered one that builds on theories of distributed cognition, emphasizes development of intelligent adaptive systems, applies robust Cognitive Systems Engineering (CSE) methods, and takes a Living Laboratory perspective. Our vision for next generation distributed GCCM is characterized in the Scenario and figure below.

A Scenario: Imagine a crisis management center with Center Director Jill White and chief logistics manager Jim Smith, in front of the large-screen display provided by the agency's *GeoCollaborative Crisis Management (GCCM) system*.

The Crystal River nuclear power plant has notified officials that an accident occurred, resulting in a potential radioactive particulate release within 9 hours. Response professionals with a range of expertise, work to determine the impact area, order and carry out evacuations, and deploy RAD health teams to identify 'hot zones' in residential and agricultural areas. Based on available information, immediate decisions must be made about where and how to evacuate or quarantine residents, establishing decontamination checkpoints, deploying rescue and RAD health teams, ordering in-place sheltering, and prioritizing situations. As field personnel deploy, the command Center focuses on coordination of the distributed activity among many participants who are using a range of devices and who have a wide range of geospatial information needs. At right, we represent the multimodal, dialogue-enabled *GeoCollaborative Crisis Management* methods and technologies we envision, and to which our research is targeted. The central portion of the figure depicts models of the complementary system/human knowledge construction processes and components of the proposed dialogue-enabled links between them.



The research is focusing on two problem domains relevant to achieving the above vision:

- Group work in Emergency Operations Centers (EOCs) around large screen, GIS-enabled displays using multimodal, gesture-speech interfaces.
- Distributed teams – some of whom use mobile devices in the field linked to others using desktop or large-screen displays in the EOC or in mobile field stations.

Specific research questions being addressed include:

- **Distributed cognition**: How can we facilitate distributed cognition in GCCM? What role can external, visual, manipulable representations play in distributed cognition for teams?
- **Visually-enabled group work**: What are the impacts of visual-mediation tools on group work with geospatial information and how can these tools be enhanced?
- **Multimodal interfaces**: What role can multimodal interfaces play in GCCM command centers? How can multimodal interfaces support work of distributed, mobile teams?
- **Dialogue management**: How can technology enable human-computer-human mixed initiative dialogues for GCCM activities?
- **Intelligent adaptive systems**: How can intelligent geo-appliances enable user-computational power in the real world? How can we support robust, human—agent, shared mental models providing context for mutual adaptation in a changing environment?
- **Time-critical decision support**: How should geocollaborative devices be designed to facilitate user-centric, distributed team use in stressful crisis management environments?

GeoCollaborative Crisis Management: Using Maps to Mediate EOC–Mobile Team Collaboration

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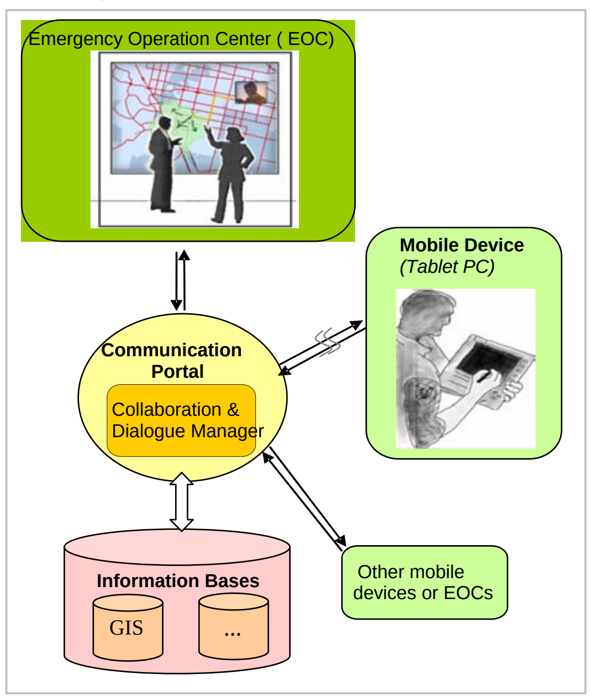
Managing large scale and distributed crisis events is a national priority; and it is a priority that presents information technology challenges to the responsible government agencies. Geographical information systems (with their ability to map out evolving crisis events, affected human and infrastructure assets, as well as actions taken and resources applied) have been indispensable in all stages of crisis management. Their use, however, has been mostly confined to single users within single agencies. The potential for maps and related geospatial technologies to be the media for collaborative activities among distributed agencies and teams have been discussed [1-4], but feasible technological infrastructure and tools are not yet available. An interdisciplinary team from Penn State University (comprised of GIScientists, information Scientists and computer scientists), currently funded by the NSF/DG program, have joined efforts with collaborators from federal, state, and local agencies to develop an approach to and technology to support "GeoCollaborative Crisis Management" (NSF-EIA-0306845). The dual goals of this project are: (1) *to understand the roles of geographical information distributed crisis management activities*; and (2) *to develop enabling geospatial information technologies and human-computer systems to facilitate geocollaborative crisis management*. This demonstration presents initial progress towards supporting geocollaborative activities, focusing on one type of collaboration involving crisis managers in the field coordinating with those in an emergency operation center (EOC).

The architecture that underlies the demo system is sketched in the figure below. Here we assume that the EOC is equipped with a large-screen display together with microphones and cameras to capture human speech and free-hand gestures and support human-system dialogue. The EOC coordinates with hand-held device clients (e.g., a Tablet PC) that support user-tool dialogue with natural speech and pen-based gestures. All communications are through XML-based web service protocols. Mobile devices use wireless connections, while the EOC system(s) use high-speed network connections.



Central features of this system are its abilities to (1) *understand and act on natural multimodal requests for geographical information from crisis managers*, (2) *allow each member to work with geospatial information individually or collaboratively with others*, (3) *manage mixed-initiative dialogues for cooperative decision-making*, and (4) *access existing data and services from an enterprise spatial (and non-spatial) informational infrastructure.* The "Collaboration & Dialogue Manager" component is an intelligent agent that mediates the collaborative discourses among humans and devices, and acts on database access and information display on user's behalf.

Our demonstration is based on the following hypothetical scenario for a typical crisis event:

Scenario*: A category 4 hurricane has struck the south east part of Florida, potentially causing flooding that affects a number of counties along the coastal area. While evacuation alerts have been sent out to affected communities, state and local emergency management forces must make sure that all residents evacuate in time and (if needed) find shelter in designated facilities.*

While he was searching a residential area in Palm Beach county, Matt (a member of the first responder team) found a group of people who need assistance getting to a shelter. These people are elderly and some have serious health care needs.

In the EOC, a manager, Sue, and her assistant, Dave, have access to a large-screen display which shows the overall situation in the whole flooded region. They get reports from multiple sources (sensors, satellite, 911 phone calls, field reports) and have the responsibility to help field team.

Matt: Sue, I need help evacuating a group of people in Palm Beach county. { *a map is shared that shows the general area of Palm Beach county*}

Sue: Could you identify your location on the map please?

Matt: I am here {*gesture on the map screen. A marker is placed on the map*}.

Sue: What is the condition there?

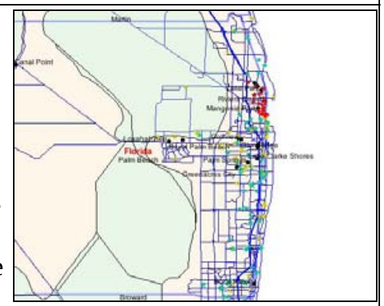
Matt: There are 12 elderly people and some of them have serious chronic health problems.

Sue: OK, we'll get back to you in a moment.

Matt: Thanks!

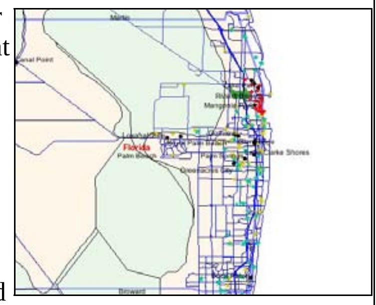
{*Sue and her EOC team quickly compile a map showing information about Assisted Living facilities, their specialty and capacity. Then they selected a few candidate facilities that will fulfill the need and have enough capacity. The candidate facilities are highlighted and the map is shared with Matt}*

Sue: Matt, there are several facilities that we can let you use. Which one looks practical?



Matt: {gesture on one highlighted facility} show me details about this facility

System: This is Center Region Retirement Center. It has 70 beds, and two nurses.



Matt: That sounds perfect … Let's take these folks there.

Sue: Great! I will send you an emergency vehicle ASAP.

{*Dave brings up a map showing real-time location of emergency vehicles. After a few phone conversations, he finds two willing to take on the task. Dave shares a map with the drivers, showing the location of pick-up and location of drop-off. Dispatch complete*}

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