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

Alan M. MacEachren, Isaac Brewer and Erik Steiner
GeoVISTA Center, Department of Geography, 302 Walker
Penn State University, USA
Fax: 814-863-7943; email: alan@geog.psu.edu

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.[i] We also make use of DEMViewer, a VisAD compatible digital elevation model viewer for ArcGrid ASCII export files.[ii] 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. 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).

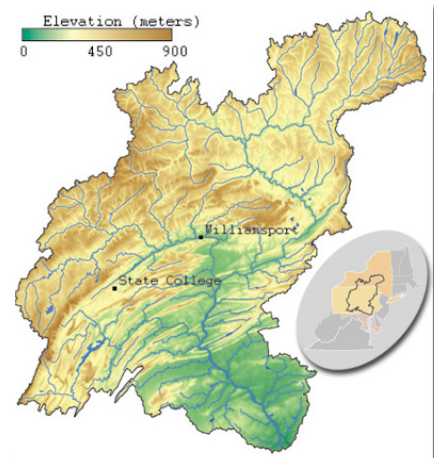

figure 1. Susquehanna R. study area

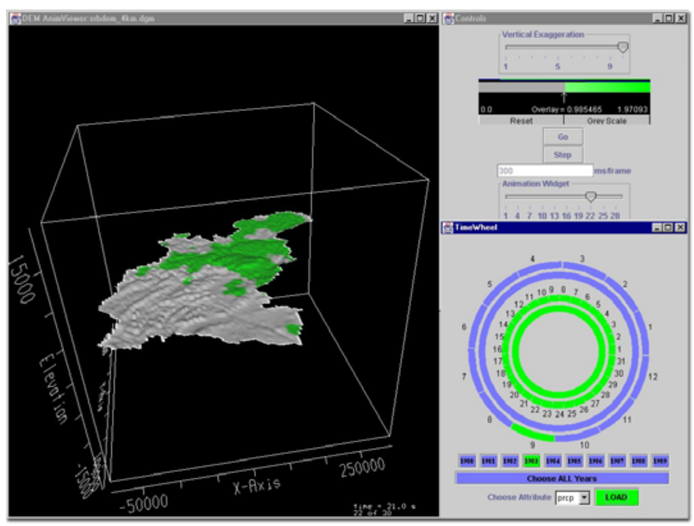

figure 2. Initial pre-collaborative application. The environment is being used to explore precipitation events (draped on terrain). All days for one month (Sept.) for one year (1984) are selected using the temporal controls. Color scheme controls allow "focusing" on a subset of high values (depicted 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.[iii] 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

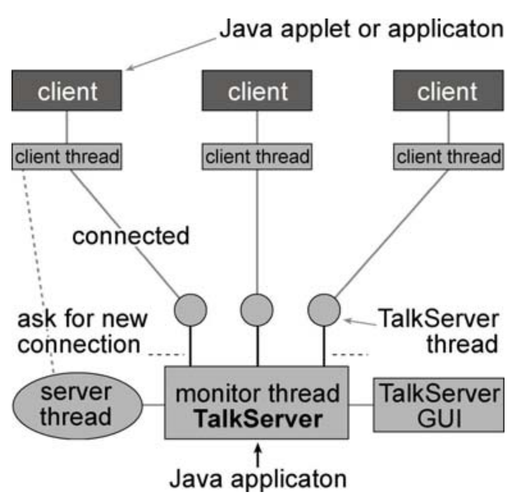

figure 3. TalkServer communication manager.

TalkServer. TalkServer then requests that all TSTs update their corresponding clients accordingly.

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

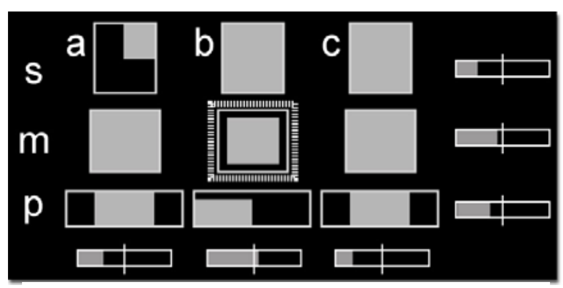

figure 4. Prototype watcher display.

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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References

Armstrong, M.P. and Densham, P.J., 1995. Cartographic support for collaborative spatial decision-making, Auto Carto 12, Vol. 4, Charlotte, NC, Feb. 27 - March 2, 1995, pp. 49-58.

Brewer, I., MacEachren, A.M., Abdo, H., Gundrum, J. and Otto, G., 2000. Collaborative Geographic Visualization: Enabling shared understanding of environmental processes, IEEE Information Visualization Symposium. Salt Lake City Utah, Oct. 9-10, 2000, pp. 137-141.

Haug, D., MacEachren, A.M. and Hardisty, F., in press. The challenge of analyzing geovisualization tool use: Taking a visual approach, 20th ICA Conference. Beijing, August 6-10, 2001.

Hindmarsh, J., Fraser, M., Heath, C., Benford, S. and Greenhalgh, C., 2000. Object-focused interaction in collaborative virtual environments. ACM Transactions on Computer-Human Interaction, 3(4): 477-509.

Jem, M., 1998. "Thin" vs. "fat" visualization client, Proc., Computer Graphics International. 772 -788.

Jones, P., Hayes, C., Wilkins, D., Bargar, R., Sniezek, J., Asaro, P., Mengshoel, O., Kessler, D., Lucenti, M., Choi, I., Tu, N. and Schlabach, M., 1998. CoRAVEN: Modelling and Design of a Multimedia Intelligent Infrastructure for Collaborative Intelligence Analysis, Proc. IEEE International Conference on Systems, Man, and Cybernetics, San Diego CA, Oct 1998, 914 -919.

Kraak, M.-J., Edsall, R. and MacEachren, A.M., 1997. Cartographic animation and legends for temporal maps: Exploration and or interaction, 18th International Cartographic Conference. ICA, Stockholm, June 23-27, 1997, pp. 253-262.

Lin, C., Loffin, R.B. and Stark, T., 1998. Virtual reality for geosciences visualization, Proc. of Computer Human Interaction. pp. 196-201.

Ma, K.-L., 1999. Image graphs - A novel approach to visual data exploration, IEEE, 81-88, 513.

MacEachren, A.M., 2000. Cartography and GIS: facilitating collaboration. Progress in Human Geography, 24(3): 445-456.

MacEachren, A.M., in press. Cartography and GIS: Extending collaborative tools to support virtual teams. Progress in Human Geography.

MacEachren, A.M., Wheeler, M., Hardisty, F., Mark Gahegan, Dai, X., Guo, D. and Takatsuka, M., 2001. Supporting visual integration and analysis of geospatially-referenced statistics through web-deployable, cross-platform tools, Proc, dg.o.2001, Los Angeles, CA, May 21-23.

Nyerges, T., 1999. Progress in spatial decision making using geographic information systems. In: M. Craglia and H. Onsrud (Editors), Geographic Information Research: Trans-Atlantic Perspetives. Taylor & Francis, London, 129-142.

Olson, G.M. and Olson, J.S., 2000. Distance Matters. Human-Computer Interaction, 15: 139-78.

Padula, M. and Rinaldi, G.R., 1999. Mission critical web applications: A seismological case. Interactions, July-August: 52-66.

Pang, A. and Fernandez, D., 1995. REINAS instrumentation and visualization, Proc., OCEANS '95. San Diego, Oct. 9-15, 1892-1899.

Rhyne, T.-M., 1998. Case study #1: Collaborative Geographic Visualization, Course Notes: ACM SIGGRAPH '98, #35. ACM, Orlando, www.education.siggraph.org/~rhyne/vis-tut/gisvis-tut/casegisvis.html.

Roussos, M., Johnson, A., Moher, T., Leigh, J., Vasilakis, C. and Barnes, C., 1999. Learning and building together in an immersive virtual world. Presence, 8(3): 247-263.

Suthers, D., 1999. Representational support for collaborative inquiry, Proc. 32nd HI Inter. Conference on System Sciences, Maui, HI, Jan. 5-8.

Tromp, J., Bullock, A., Steed, A., Sadagic, A., Slater, M. and Frécon, E., 1998. Small group behavior experiments in the Coven Project. IEEE CG & Applications, Nov/Dec: 53-63.

Watson, V.R., 2001. Supporting Scientific Analysis within Collaborative Problem Solving Environments, HICSS-34, Maui, Hawaii, Jan 3-6.

Wood, J., Wright, H. and Brodlie, K., 1997. Collaborative Visualization, Proc., IEEE Information Visualization '97. IEEEComputer Society, Pheoniz, Oct. 19-24, 1997, pp. 253-259.

[i] 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.

[ii] 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

[iii] TalkServer was developed by Hadi Abdo as part of his Masters Thesis in Computer Science and Engineering at Penn State University.