Collaborative Geographic Visualization: Enabling shared understanding of environmental processes

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ABSTRACT

Most work with geospatial data, whether for scientific analysis, urban and environmental planning, or business decision making is carried out by groups. In contrast, geographic visualization environments and related geographic information technologies have been built and assessed only for use by individuals. In this paper, we describe a prototype same-time/different-place collaborative geovisualization environment. Next, we outline an approach to understanding use and usability and present results of interviews with domain experts about the ways in which collaborative geovisualization might enable group work at a distance. Finally, we present goals for futher research.

1 INTRODUCTION

Recent conceptual and technical developments in Geographic Information Science (GIScience) (e.g., (Kraak and MacEachren 1999, Mark 1999)), and in information technology (e.g., (Brown et al. 1999, Flanagan et al. 1997)), suggest that we are on the cusp of a substantial increase in the role of maps, images, and computer graphics as mediators of collaboration – in a range of contexts including environmental and urban planning, resource management, scientific inquiry, and education. Many potential scientific, educational, and decision-making applications for geovisualization, specifically, involve small groups working together on a problem solution; yet, existing tools support use only by individuals. The prototype geovisualization environment we report on here is designed to support same-time/same-place as well as same-time/different-place collaboration among scientists as they explore complex spatio-temporal information. Such environments have potential application to regional and local planning/decision-making, scientific research conducted by distributed inter/intradisciplinary teams, and web-based education.

We consider collaborative geovisualization to involve a committed effort on the part of two or more people to use geovisualization tools to collectively frame and address a task involving geospatial information. Our approach draws upon a diverse multidisciplinary literature dealing with group (multi-participant) work and visualization. See, for example: Roschelle and Teasley 1995, Snowdon and Jää-Aro 1997, Schönhage, and Eliëns 1998, Brodlie et al. 1998, Greenhalgh and Benford 1999, Horrocks, et al 1999. For research on group work with geospatial data specifically, see: Armstrong 1993, MacEachren in press-a, MacEachren in press-b, Nyerges 1999. Somewhat surprisingly (considering that GISystems use visual, map-based interfaces), attention to the role of visual displays as mediators for geospatial collaboration has been limited (see Armstrong and Densham 1995, for one initial effort).

Our focus here is on geovisualization to mediate and enhance collaborative knowledge construction among environmental scientists. The prototype described below is designed to facilitate collaboration among users who are exploring time series of climatic (or similar environmental) data through shared dynamic (animated and interactive) displays. We expect that many of the collaborative visualization issues raised in this context will be common to a range of information visualization applications.

We begin, below, with an overview of the initial collaborative prototype developed. Then, we discuss human-centered design for different place collaborative visualization environments and present results of a user task analysis that uses our prototype to prompt discussion. We conclude with brief comments on future directions based on these results.

2 AN INITIAL PROTOTYPE

The initial prototype collaborative geovisualization environment allows multiple users to view and manipulate multivariate climatic data simultaneously and, thus, to share knowledge as they identify space-time patterns and processes (figure 1). A map view allows collaborators to manipulate a 3-D depiction of precipitation and temperature as it varies with terrain. Users are able to control parameters of a time series animation as well as the color scheme used to represent the data. The latter controls allow users to focus the group's attention on particular data ranges.

The prototype is constructed from a set of Java/Java3D tools. These include:

- VisAD, a Java class library for interactive and collaborative visualization of numerical data developed by Bill Hibbard, see: www.ssec.wisc.edu/~billh/visad.html.
- DEMViewer, a Java digital elevation model viewer for ArcGrid ASCII export files, developed by Ugo Taddei, see: www.geogr.uni-jena.de/~p6taug/demviewer/demv.html.
- Our own extensions for data queries, time referencing, and networking.

In order to create a collaborative environment, it was necessary to build a mechanism to support communication

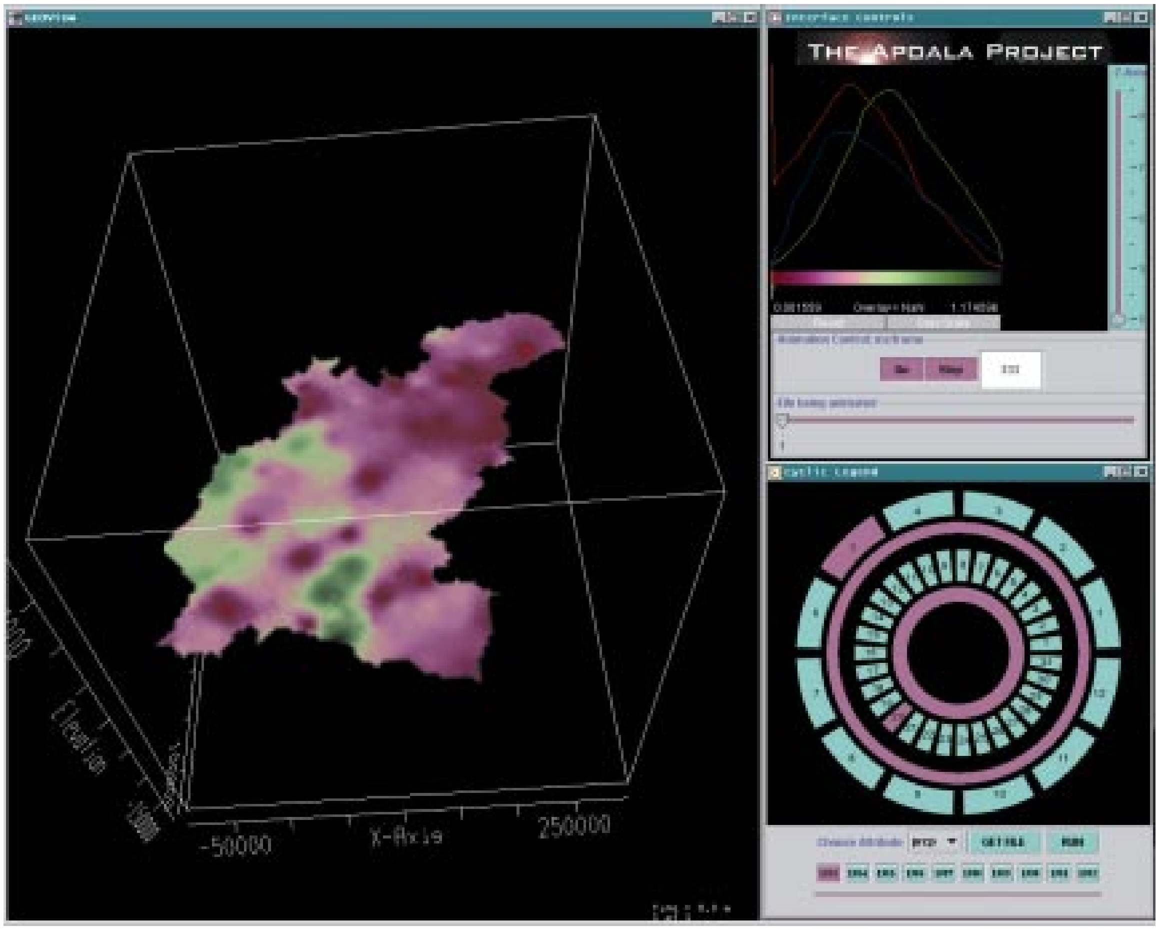

Figure 1 Prototype collaborative geovisualization environment, one user's view.

among different computers. The mechanism developed, TalkServer, is a JAVA application for communicating user-initiated events among networked collaborative applications. It was written by Hadi Abdo of the Visualization Group in the Penn State Center of Academic Computing. TalkServer listens on a predetermined port of a server for new connections from client applications. 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 that indicate changes that will affect other clients in the collaborative session, the messages are relayed to the TalkServer. TalkServer then requests that all TSTs update their corresponding clients accordingly. Our current implementation does not yet include a method to keep animations synchronized as they run on different machines. Any action to stop, step, or restart the animation, however, re-synchronizes the views.

One of our foci in the prototype is on temporal query and display tools designed to help users explore both linear and cyclic components of information (figure 2). The Java implementation developed for this prototype extends from our previous work on controls for temporal aspects of spatio-temporal visualization environments (Edsall et al. 1997, MacEachren et al. 1999). Here, we implement a cyclical legend that supports queries at different temporal scales. In the example, the legend is set to select 4 years, 4 months, and 11 days each month. The time-line tool supports selection of consecutive and non-consecutive times. We are extending the hierarchically structured time line in two ways. First we are implementing support for multi scale selection (e.g. by year, season, month, day). Second, we have developed and are implementing methods for graphically constructing temporal averages across selected temporal ranges.

The temporal (and other) query tools are linked to an object-oriented database that supports complex range queries on space, time, and attribute. The database implements the data representation component of the "Pyramid" data model developed by other research team members (Mennis et al. in press).

The environment described is evolving. We have recently adapted the environment for display in an ImmersaDesk using an inexpensive game controller to interact with the 3D display. Over the next few months we anticipate completing the following additional extensions:

- Build more robust links to our database implementation;

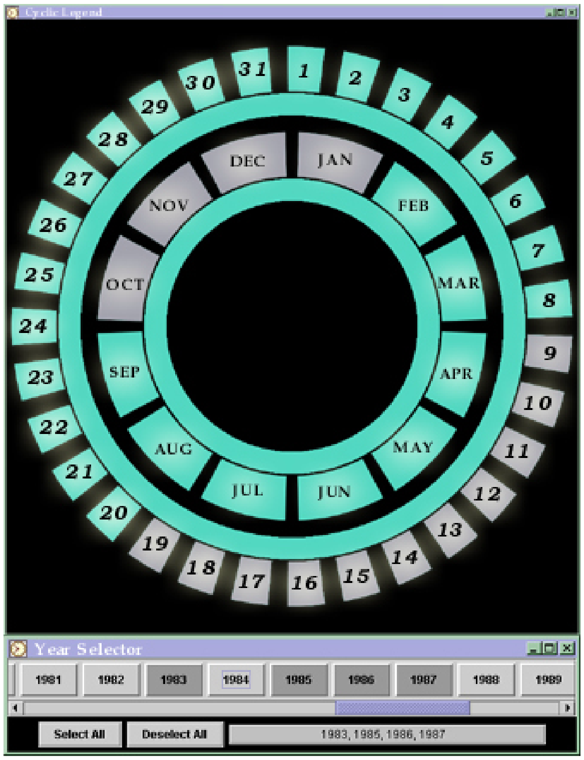

Figure 2 Cyclic and linear temporal query controls

- Develop more flexible and complete interaction -- e.g., improved color scheme selection and focusing tools;
- Add the time scale and temporal averaging tools described to allow users to apply moving averages and create composite weeks, months, or years;
- Experiment with more than two collaborators;
- Compare same and different place collaboration.

3 HUMAN-CENTERED DESIGN

One goal for our research is to design an effective and flexible system that can support group work on environmental science research mediated through dynamic geovisualization displays. We are addressing this goal using a four-step human-centered system design process, modeled on that proposed by Gabbard et al. (1999) for development and evaluation of virtual environments. The steps they delineate are: (1) user task analysis, (2) expert guidelines-based evaluation, (3) formative user-centered evaluation, (4) summative comparative evaluation. This multistage evaluation process helps refine the system and its components and reveals usability concerns early in the system design process, so that such problems can be eliminated prior to resource intensive, formal user testing.

We have begun to adapt this multistage approach for use with collaborative visualization environments. Here, we present the first stage, a user task analysis that will serve as a blueprint for prototype refinement and a benchmark for subsequent formal evaluation. Specifically, we use semi-structured interviews with environmental science domain experts to explore their current and potential use of maps and dynamic visual displays in research collaborations. First, we discuss the interview process. Next we present results.

3.1 Interviews with domain experts

Six domain experts were interviewed. All are potential users of the collaborative environment described above. The interviews were designed to sketch a picture of multidisciplinary environmental science collaborations and the current and potential role of geovisualization as a mediator for those collaborations. The expert participants are geographers with a research emphasis in environmental science (either climatology or hydrology) and who are active participants in multidisciplinary projects. Three are faculty and three are their senior graduate students. None had used the prototype previously. Four participants were interviewed individually with one pair interviewed together.

Hour long interview sessions were organized around an interview guide that included four sections and a series of potential questions used to prompt discussion. The goal was to obtain insights from the participants about the aspects of research collaborations that might be facilitated by geovisualization tools and about the kinds of visualization tools that might be needed. Thus, the prepared interview guide was not allowed to dictate the focus of the interview (simply to steer it) and most interviews addressed a subset of the potential questions, sometimes delving into unanticipated topics.

Section one: Before viewing the prototype, each participant was asked to discuss their typical research collaborations. Specific attention was directed to the role of maps, images, and dynamic visual displays in facilitating aspects of that collaboration and to the kinds of maps that are (or might be) used (e.g., static versus animated, grid cell versus polygon, large versus small scale).

Section two: Next, the prototype geovisualization environment was demonstrated and used to help focus discussion on specific issues. Participants were prompted to discuss the ways in which dynamic maps could be used to mediate discussion during research collaborations. Issues raised specifically in our prompts included: drawing attention, joint control, shared views, and usefulness of maps within and between disciplines.

Section three: The third section of the interview focused on group size. Specifically, participants were prompted to speculate on characteristics of computer displays that support or impede use by groups of different size. Issues raised were alterations to the desktop environment that might be needed for use by larger groups and the relative merits of large wall displays versus large table-top displays.

Section four: Finally, the ability of the prototype to support collaboration by individuals working on different computers (perhaps in different research labs) was demonstrated on side-by-side machines. This demonstration was used to prompt discussion of how being separated in location might influence the nature of collaboration with, or mediated by, a display.

3.2 Results

Section one: Prior to viewing the prototype, when prompted to discuss the ways maps have facilitated collaboration or might do so, most participants mentioned the role of maps in providing a context within which scientific discussion takes place. One participant suggested they we "can't communicate (spatial characteristics) without a map." Most saw map displays as mediators for different data sources and scales of analysis. One participant pointed to the role of map displays as vehicles for posing 'what-if' questions and three noted the role of maps in representing temporal information (in time series analysis, query by season, smoothing over time, or finding cycles and trends). Across the group, there was general consistency in a focus on map displays that are multivariate, multiscale, and that depict change over time.

Section two: Comments on five issues are summarized:

- After seeing the prototype and being asked to comment on aspects of the dynamic display relevant for successful collaboration, most attention was focused on the ability to interactively change the data variables being displayed or to control characteristics of the time series display (e.g., changing the pace of an animation). The ability to focus on specific data ranges was also cited as a way to share understanding of observed features.
- Most participants used gestures (pointing circling, etc.) to draw our attention to features and felt that tools that facilitate "drawing attention" were crucial. Suggestions included: the mouse pointer for indicating locations, drawing tools for highlighting features, support for zooming and focusing, and separate windows within which each user can control emphasis.
- A common theme across users was that maps help to provide a context for sharing ideas across disciplines and that general reference information (boundaries, roads, etc.) provide the framework for that context.
- When asked about the advantages or disadvantages of providing joint interface controls, most participants recognized a possible need to do so, but also noted the potential for resulting conflict. Solutions included a turn-based approach and separate windows for each user. Two participants explicitly expressed the idea that having a single person in control would be best.
- Some differences in map/display use across disciplines were noted. Among the more important were the different spatial and temporal scales that disciplines emphasize and the need for collaborative environments to support methods to relate those scales. In addition, one participant noted that physical scientists treat maps as a component in process modeling while social scientists consider maps to be presentational devices.

Section three: When asked about scaling up to larger groups, one participant advocated using linked desktop machines for each individual user and suggested that a large (wall) screen would be useful only if group members each had a desktop machine linked to it. Most other participants assumed a larger screen would be used and focused on the advantages and disadvantages of shared control. The need to zoom in and out to deal with visual acuity ranges was also noted. Other issues considered were the need to distinguish (visually on the display) among users interacting at any one time. Color coding of user representations was proposed. When asked whether a wallboard-like display or a workbench-like display was preferable, most users favored the workbench orientation due to the ease with which multiple users can gather around and the sense of active participation it generates.

Section four: Five issues were raised in relation to support for work at different locations:

- Facilitating dialogue - For dialogue, all but one participant favored voice (with telephone considered less convenient than digital audio). The other participant preferred voice translated to text displayed in an unobtrusive window. Minicams were also proposed.
- Group member behaviors - The ability to know what others were doing, not just the outcome of actions, was raised by most participants. The lack of this feature in the prototype may have prompted this observation. Color coding of the representation for each user was suggested by a pair of participants as a way to recognize who is taking what actions. Two other participants suggested a split screen with windows for each user as an alternative (or complement) to this. The need to represent actions of multiple users simultaneously was also raised (specifically in relation to the time wheel query control – with the suggestion that it be rendered in 3D with one layer for each user). Another important issue noted by one participant is that, in many geographic applications (e.g., regional planning), it is important to know not only who each group member is, but also where they are from.
- Drawing the group's attention - The most common suggestions were to use the mouse (again, color coded for users) or to include electronic whiteboard drawing tools that allow each user to circle or otherwise annotate features. One participant considered the ability to save selected displays to be important and another suggested that making it possible to flash a region or object on and off might be necessary to draw the groups' attention.
- Private work - When asked about the need for a private workspace (not seen by the group), all participants responded that this aspect was important.
- Asynchronous collaboration - Only four of the participants were asked about asynchronous collaboration. All suggested the need for some form of activity logging and the ability to replay the log. Two, however, pointed out that they would not want to view everything that a collaborator had done, thus some tool to annotate or otherwise highlight the most important parts of an analysis session would be needed.

3.3 Discussion

Results of interviews highlighted questions that require subsequent research. These include how to: (1) support joint control of displays by multiple users, (2) represent users and their behaviors, and (3) integrate verbal with visual communication for different-place collaboration.

The task analysis presented here represents the first stage in a longer term effort to develop a human-centered collaborative geovisualization environment. Our prototype is designed to support tasks that users currently cannot undertake, collaborating at a distance with, and about, dynamic visual displays. Thus, standard user task analysis is not appropriate. We found that a modified task analysis, using an initial prototype to prompt discussion, was an effective way to generate input needed to support design decisions. We are now working on a second stage prototype and will use progressively more focused assessment methods for refinement.

4 CONCLUSIONS

The project reported here is complemented by our related effort to develop, assess and refine a conceptual framework for collaborative geovisualization (MacEachren and Brewer submitted). Our goal is to use this framework to structure a systematic program of research focused on understanding the interrelationships among cognitive, social, and technological aspects of geovisualization-facilitated collaboration. An anticipated product of the overall research program (that links the conceptual framework with design, implementation, and assessment of prototypes) is a theory of geocollaboration that supports prediction (and testing of predictions) about the applicability of different collaborative geovisualization tools in different application contexts.

Based on our work thus far, we have identified the following research challenges that must be met to make effective collaborative geovisualization possible, to:

- develop a theoretical understanding of the cognitive and social aspects of both local and remote collaboration mediated through display objects in a geospatial context;
- assess the advantages and disadvantages of extending methods of interactive geographic and information visualization methods (developed for single users) to collaborative settings versus designing new methods to meet unique characteristics of group work;
- examine the role of different kinds of visual representations (realistic versus abstract, animated versus static) in geocollaborative settings.

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