Supporting Map-based Geocollaboration Through Natural Interfaces to Large-Screen Displays

Alan M. MacEachren
GeoVISTA Center
Department of Geography
Penn State University
maceachren@psu.edu

Guoray Cai
GeoVISTA Center
College of Information Science and Technology
Penn State University
cai@ist.psu.edu

Issac Brewer
GeoVISTA Center
Department of Geography
School of Information Science and Technology
Penn State University
ixb117@psu.edu

Jin Chen
GeoVISTA Center
Department of Geography
Penn State University
jxc93@psu.edu

This paper is a revision and extension of MacEachren, A. M., Brewer, I., Cai, G., & Chen, J. 2003, Visually-Enabled Geocollaboration to Support Data Exploration and Decision-Making. International Cartographic Conference, Durban, South Africa, pp. 394-401. An earlier version was presented at the International Advanced Workshop on Virtual Geographic Environments and Geocollaboration, The Chinese University of Hong Kong, December 15-16, 2003 and appeared on the workshop's CD ROM. We thank the organizers of that workshop and the ICA for permission to publish this revised and extended version here.

Groups usually carry out science and decision-making activities involving geographic information. However, current mapping and related geospatial technologies are not group-friendly, and attempts to extend (or reinvent) technologies for group use have been largely ad hoc. Elsewhere, we have developed a comprehensive conceptual approach to geocollaboration that provides a framework for both studying collaborative work with geospatial information (and technologies) and the development of new technologies designed to support group work. We are applying that approach to a range of prototype systems that support same- and different-place as well as same- and different-time group activities.

Our focus in this paper is on same-time, same-place group work environments that enable that work through use of large-screen displays supporting natural, human-system dialogue and multi-user interaction. Two environments are described and compared. Both make use of hand gestures as a mechanism for specifying display locations. One adopts a combined wall map/white board metaphor while the other adopts a drafting table metaphor. We focus on crisis management as a typical use case.

Keywords: large-screen display, multi-modal map, HCI, interaction metaphors, geocollaboration

INTRODUCTION

Visual displays of geospatial information in the form of maps and images have long served as enabling devices for group work. For example, scientists and industry analysts carrying out data exploration tasks often work collaboratively around large paper maps (e.g., when developing a national ecoregion map or identifying promising locations for oil or mineral exploration). Urban and regional planners also 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 discus-

Initial submission, February 15, 2005; revised submission, May 11, 2005; final acceptance, May 15, 2005

sion at subsequent public meetings. Military strategists use large paper maps in similar ways to plan the distribution of supplies and to coordinate actions. Similarly, teams involved in crisis management use large maps to carry out situational assessment, plan logistics, and guide performance of damage response activities.

The above, traditional situations 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 and 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.

"As an activity, we consider geocollaboration to be group work about geographic scale problems facilitated by geospatial information and information technologies."

Although geographic information technologies have advanced rapidly over the past decade, they still generally impede rather than facilitate geocollaboration. Desktop displays are designed for individual use. In addition, interfaces to GISystems and related technologies remain complex and difficult to learn and use – despite repeated calls for more natural, easy to use systems (Mark, 1999; Mark & Gould, 1991; Muntz *et al*., 2003). Recent advances in display hardware and interface devices are making it possible to merge: (1) the advantages of large format representations that facilitate group work, (2) advances in methods and mechanisms for individual and group interaction with information displays, and (3) progress in natural, multimodal interface technologies that require less prior training and less conscious attention during use than is needed for standard mouse-keyboard interfaces. Some examples of initial steps in this direction are discussed in (Cohen and McGee, 2004; Hopkins *et al*., 2001; Sharma et al., 2003). This union of recent advances into group work methods and tools is likely to have a substantial impact on group productivity. Beyond simply increasing the speed and productivity of work, dynamic, large-format displays having natural interfaces designed specifically to support group work have the potential to dramatically (and qualitatively) change the manner of group work with geospatial data by creating fundamentally new types of geocollaboration. Easy to use large displays can dramatically shorten the time it takes now to get a large format map in front of a team that needs it to make a decision. More importantly, once the team is working with the map, the map can be updated in response to requests from the team members for more or different information or in response to rules for providing new information that helps the team maintain its situational awareness.

This paper provides a new perspective on large format maps as an object of and support for group work. This perspective derives from two ongoing projects that develop map-based methods and tools to support 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. The overall approach integrates perspectives from cognitive science (particularly distributed cognition), semiotics (particularly the mechanisms through which representations are devices for sharing meaning), and usability studies (particularly cognitive systems engineering). For details of the overall conceptual approach and of its instantiation in a series of multimodal prototypes, see: (MacEachren and Brewer, 2004; MacEachren *et al*., 2005). Here, we focus on comparing alternative metaphors for support of group work with large screen displays and on some of the key display design decisions that underlie the natural, multi-user interfaces we have implemented.

". . . we focus on comparing alternative metaphors for support of group work with large screen displays and on some of the key display 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: DAVE_G (Dialogue Assisted Virtual Environment for Geoinformation) and HI-SPACE (Human Information Workspace). Both make use of large displays and natural interaction to enable same-time, same-place group work with geospatial information. The HI-SPACE environment, developed by May (May, 1999), supports joint use of exploratory geovisualization tools, while DAVE_G, developed by our research team, is directed toward crisis response facilitated by GIS. Section 4 focuses on crisis management as an application context within which both natural, easy-to use interfaces and large-screen map-based displays to geospatial information are needed. Here, we also report on selected findings from our empirical study of geospatial information and technology use within crisis management, specifically those findings related to large-screen, map-based displays. Section 5 provides discussion of ongoing challenges in mapping to support geocollaboration.

"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."

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.* (Florence *et al.*, 1996), for example, proposed (but did not implement) the *GIS wallboard*, an electronic white board envisioned to support sketch-based gestures (of the sort implemented for smaller, tablet devices by Oviatt (1997) and Egenhofer (1997)). In the precursor to our multiuser 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 (Kettebekov *et al.*, 2000; Kettebekov and Sharma, 1999) and extended the system to support a crisis response scenario used to test robustness of the interface methods (Kettebekov *et al.*, 2000).

Large screen, group work environments can be based upon at least three different metaphors: wall map/white board, drafting table/light table, and real world. Work with each is outlined below.

White board/wall map

"... wall-mounted maps are useful in presenting briefings in contexts such as a public planning meeting or emergency operations center."

The environments mentioned above all adopt a wall map or white board metaphor. A white board metaphor implies a display that is initially blank, with the primary functionality being the ability to write/draw on the display using different colored pens and to erase selectively. A wall map metaphor implies a display that initially contains a map, perhaps with the ability to point out features of interest and to move between different map views (by rolling up one map and pulling down another). As McGee and colleagues have demonstrated in their study of military personnel using large paper maps in a field command center environment, paper wall-size maps affixed to a cork board or other mounting device also afford the flexible representation of events and plans through use of push pins, markers, and other tools (McGee *et al.*, 2000).

Beyond their use in strategic planning, large, wall-mounted maps are useful in presenting briefings in contexts such as a public planning meeting or emergency operations center. In these cases, it is common that one or two individuals take a lead role in presenting information and steering a group discussion. As one of us observed during a hurricane briefing at a regional Emergency Operations Center (EOC), large screen displays are used currently, but they rely on keyboard-mouse interaction. This limits the potential of a map-based display to support effective question and answer interaction between the EOC chief and other personnel.

An electronic wall map/white board interface of the kind envisioned here affords the actions of walking up and pointing, drawing or writing, switching among views, and then giving way to another actor. This metaphor can also support asynchronous use in contexts such as public planning in which a map is on display for an extended period of time and the public is encouraged to add annotations that communicate their opinions about topics of debate, for example, about the proposed location of a highway.

"An electronic wall map/white board interface of the kind envisioned here affords the actions of walking up and pointing, drawing or writing, switching among views, and then giving way to another actor."

Drafting table/light table

The second metaphor considered here is the drafting/light table. A drafting table affords group activity around (rather than in front of) a large map on which collaborators might sketch their ideas. This format is typical of work by military and emergency management personnel in field command centers 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 (2001) as well as Arias, Fischer and colleagues (Arias *et al.,* 2000; Fischer, 2001) have implemented large, table-like group work displays supporting map-based planning activities. The latter research team, in their Envisionment and Discovery Collaboratory (EDC), 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.

Arias and colleagues (2000) adopted a user-centered, participatory design approach to assess and evolve the EDC. Specifically, they worked closely with planners and interested citizens focused on community development issues in Boulder, Colorado. They report on four key insights arrived at as they developed and refined the EDC: (a) representing multiple perspectives on a problem is essential, (b) systems must support "learning as a shared, collaborative activity—particularly in the context of bridging these multiple perspectives," (c) EDC, and related environments, have the potential to support democratic and social processes, and (d) to be successful, systems should support interaction and reflection.

In some contexts, such as crisis response and military planning, large paper maps retain a distinct advantage in their combination of high resolution and portability—even in comparison to physically augmented virtual spaces such as the EDC described above. As noted in the previous section, McGee and colleagues (McGee *et al*., 2002; McGee *et al*., 2000; McGee *et al*., 2001) have studied military planners working with such maps (in both wall mounted and table top situations). Based on this research, they proposed an approach to augmenting paper maps through digital Post-it© notes (physical notes for which the position and content of the note 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 failures or power outages occurred.

"In some contexts, such as crisis response and military planning, large paper maps retain a distinct advantage in their combination of high resolution and portability—even in comparison to physically augmented virtual spaces . . ."

Real world

A third metaphor used in group work environments is an activity space in which a real world (or virtual) space represents a geographic space. Activity spaces (e.g., conference rooms, computer laboratories, etc.) afford entering and behaving within them; immersive environments for group work attempt to support the same behaviors. Neves and colleagues (Neves *et al*., 1997) 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 database). Their implementation supported only one user at a time. However, (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 (Johnson et al., 1999). 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: (MacEachren and Brewer, 2004; MacEachren *et al*., 1999; Wheless *et al*., 1996). Recently, Armstrong (2001) 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.

Within the category of adopting a real world metaphor for group work environments, there has also been recent progress toward collaborative technologies that support augmenting real-world space with virtual information (Billinghurst and Kato, 2002). One geospatial example is a system designed to support collaboration in outdoor navigation and information targeted at tourists exploring a city (Reitmayr and Schmalstieg, 2004). The environment augments the world with waypoints (in the form of information icons) that one user can leave for others to follow. Information icons provide shared information about cultural-historical attractions (superimposed on real world objects). Another intriguing system is one developed to support archeological prospecting (Nigay *et al*., 2002). This environment integrates a head-mounted display (HMD) and a tablet computer to create an environment in which users can see both the world and the digital environment; the latter also includes a view of the world generated from a video camera on the HMD. Users can select real world objects displayed on the tablet screen by clicking, creating a version of what the authors term "clickable reality". They also propose a system that supports gestures in the real world (e.g., pointing at a building) as a way to select an object in the virtual scene. The latter kind of interaction has been described in a recent National Research Council Report as "point-and-click real world" functionality (National Research Council, 2003).

"Within the category of adopting a real world metaphor for group work environments, there has also been recent progress toward collaborative technologies that support augmenting real-world space with virtual information."

NATURAL, MAP-BASED INTERACTION WITH GEOSPATIAL INFORMATION

Here, we discuss two geocollaborative system development efforts, emphasizing the role of the map-based, large-screen display as a primary interface component in each. The first system uses a vertical display that functions like an electronic white board/wall map. The second system uses a horizontal display that functions much like a traditional drafting table that multiple participants in a group activity can gather around. 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.

DAVE_G – Dialogue-Assisted Visual Environment for Geoinformation

As noted above, our DAVE_G project uses an electronic white board/wall map metaphor and puts emphasis on making interaction with the map seem "natural." DAVE_G is designed to be natural in two ways. First, users indicate what they are interested in through natural speech-gesture signification. Second, the map is interactively constructed through human-computer dialogues to ensure its relevance to the user's information needs.

DAVE_G has gone through multiple generations and we have detailed the system architecture and natural dialogue processor elsewhere (Cai *et al*., 2005b; MacEachren *et al*., 2005; Rauschert *et al*., 2002). Here we describe the system briefly, emphasizing its use of maps to mediate human-system and human-human collaboration and setting the stage for comparing experiences using the two metaphors (white board/wall map in this case and drafting table below).

"To deal with the challenge of support for natural human system dialogue, an intelligent dialogue agent is employed to process ill structured, incomplete, and sometimes incorrect requests, and to facilitate task-oriented interactions and collaborations."

Development of our initial DAVE_G prototype (figure 1) was made tractable by narrowing the potential application domain from collaborative work generally to collaborative work with geospatial data in the context of crisis management. To deal with the challenge of supporting natural human signification of the user's information needs, 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 challenge of support for natural human system dialogue, an intelligent dialogue agent is employed to process ill structured, incomplete, and sometimes incorrect requests, and to facilitate task-oriented interactions and collaborations.

DAVE_G is based on the interaction framework initially developed in *iMap* (Sharma *et al*., 1999) and enhanced in XISM (Kettebekov *et al*., 2000; Kettebekov and Sharma, 1999; Sharma *et al*., 2003). We have added substantial extensions to support human-system collaboration (through addition of a human-system collaboration manager) as well as to support multiple user interaction (by duplicating modules for speech and ges-

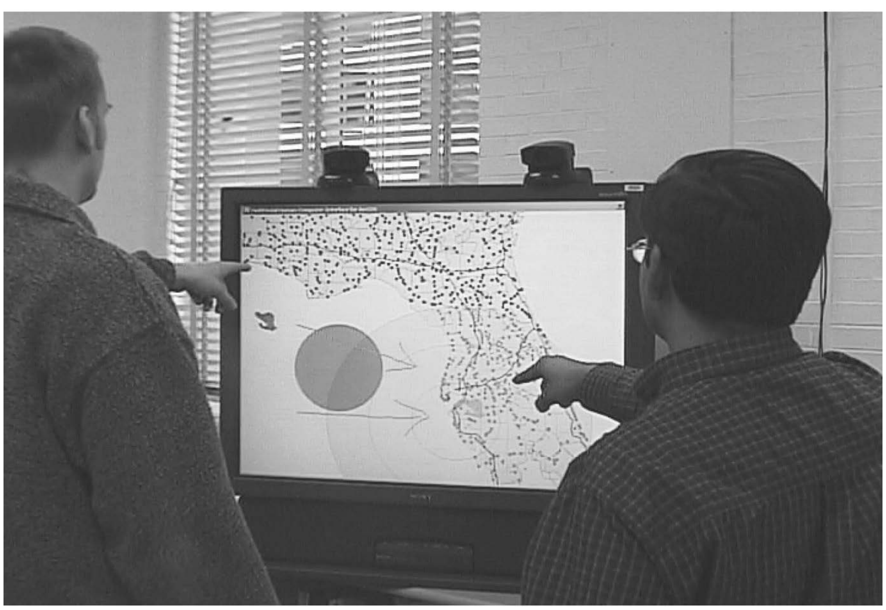

Figure 1. Two-person, gesture-speech interface to DAVE_G. Demonstration of a collaboration scenario focused on analyzing potential hurricane impacts. Figure reproduced from (Rauschert *et al*., 2002).

ture recognition for each additional participant). To capture and process speech, DAVE_G utilizes a speaker dependent voice recognition engine (ViaVoice from IBM) that allows fairly 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. The grammar constrains the available vocabulary but retains flexibility in the formulation of speech commands.

"Hand gestures are captured using computer vision-based techniques. By capturing hand gestures, the system keeps track of the user's spatial interest and spatial attention."

Hand gestures are captured using computer vision-based techniques. By capturing hand gestures, the system keeps 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 module have to be associated with co-occurring gestures observed by the gesture recognition module. Currently, DAVE_G can understand speech/gesture requests for most commonly used map display functions such as "show a map of the population within Pennsylvania", "zoom here{gesture}", "highlight these{gesture} features", "make a one-mile buffer around these {gesture} features", and more. It can also support more complex requests such as "Dave, show me the areas that will flood," an ambiguous request to which it will respond with a prompt such as "I have flooding data for Tropical Storms and Category 1 through 5 Hurricanes, which would you like to see?".

The user-system dialogue segments, as illustrated above, are mediated by DAVE_G's GeoDialogue subsystem (Cai *et al*., 2005b). GeoDialogue implements specific mechanisms to enable natural communications assisted by visual displays. DAVE_G's 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. The system can initiate dialogues anytime to request missing information for the specification of GIS queries. This dialogue-assisted human-GIS interaction approach is designed to deal with the complexity of specifying spatial information needs in crisis management (and other) applications of GIS, which often requires the synthesis of inputs from multiple people in several iterations in order to construct a fully specified and executable GIS query.

HI-SPACE

"GeoDialogue implements specific mechanisms to enable natural communications assisted by visual displays."

The HI-SPACE environment, like DAVE_G, implements a gesture-based interface developed by Richard May (May, 1999). As noted above, the HI-SPACE environment offers a drafting table (light table) metaphor that allows users to gather around a shared display and to interact with the display using gestures and placement of physical objects on the virtual map (figure 2). Our experimental unit is on loan from the Pacific Northwest National Laboratory. In its current form, the interface relies on gesture alone (i.e., it does not support speech input).

One of May's initial goals when developing the HI-SPACE environment was to promote more natural interaction among groups of users as well as between each user and the display. We have implemented modest extensions to HI-SPACE that focus on support for maps and exploratory visualization tools in the display.

The three most important features of the HI-SPACE environment in relation to group use of maps and related visualization tools are its: *hori-*

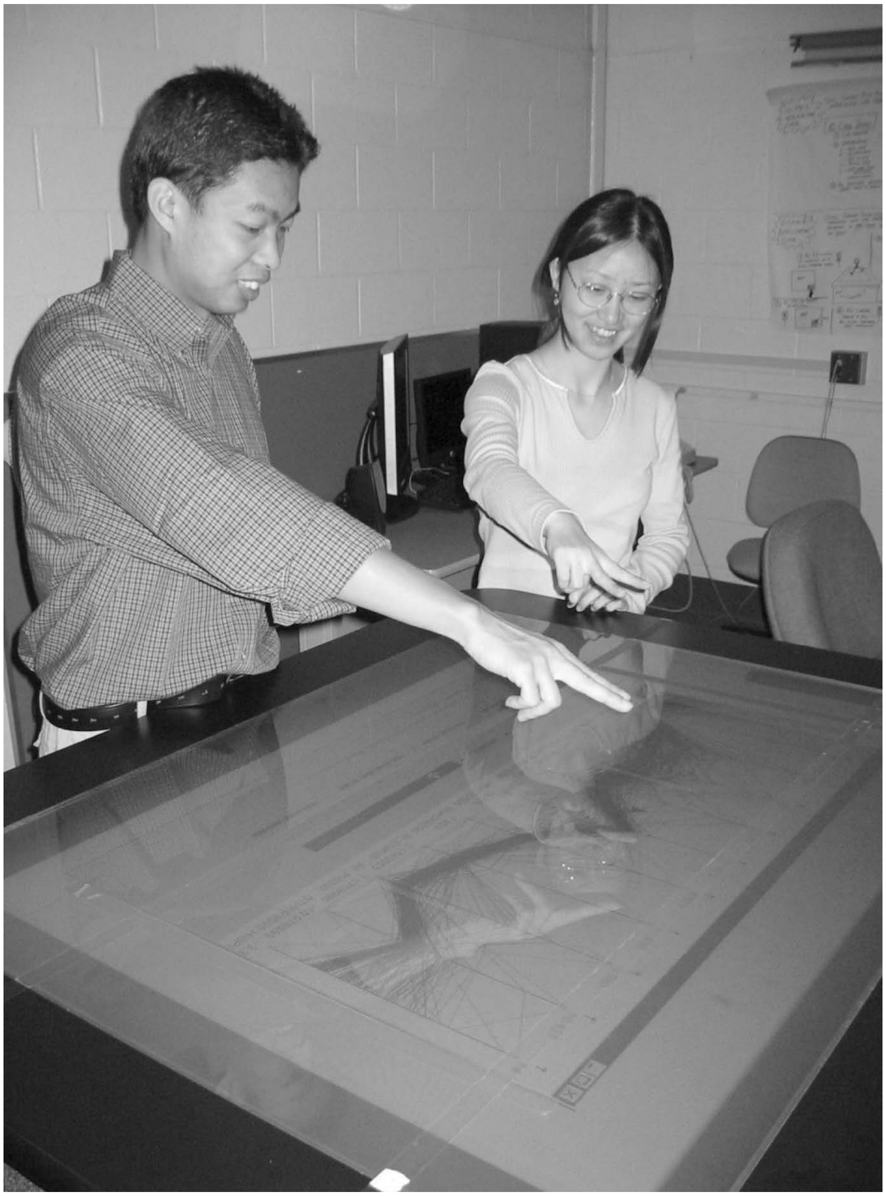

Figure 2. Gesture interface to the HI-SPACE Table. Demonstration of collaboration with interactive map component in GeoVISTA Studio. *HI-SPACE* Table developed by Richard May (May, 1999), on loan to the GeoVISTA Center from the Pacific Northwest National Laboratory.

zontal display surface, *support for multiple cursors,* and *untethered gestures*. The combination of these features enables natural forms of group communication through eye contact, gaze, and the ability of each person to interact with a map or other visualization tools through their individual cursors. Next, we provide a few more details on the implementation of these features.

Desktop metaphor

The size and horizontal orientation of the HI-SPACE display enables groups of individuals to work in a comfortable round-table fashion, rather than being dispersed on separate personal computers or clustered in front of vertical displays (where shifting attention between the display and collaborators requires more substantial head and eye movement). Besides

"The size and horizontal orientation of the HI-SPACE display enables groups of individuals to work in a comfortable round-table fashion . . ."

viewing and sharing visual information, users can also place real world objects on the HI-SPACE table display as they would on a traditional table or desktop to augment and enhance collaborative discussions. Unlike a traditional tabletop and paper map, however, the placed objects (called phicons) are recognized by the camera system and become part of the display. For example, when a user places an object on the display, the object's attributes are determined by matching its shape (or symbols on its surface) to possible kinds of object; e.g., in an epidemiological context, a circular object placed on a map could be interpreted as the centroid of a public health region for which aggregate statistical summaries are then calculated. At this point in our work, we have not implemented the tools to take full advantage of this HI-SPACE functionality, but the developers of HI-SPACE have demonstrated the potential in a computer game application (Cowell *et al*., 2004).

". . . when a user places an object on the display, the object's attributes are determined by matching its shape (or symbols on its surface) to possible kinds of object . . ."

Multiple cursors

In order to support *geocollaboration*, in which multiple users work concurrently on a single platform (computer), a mechanism is required for multiple users to interact with the display. Myers, et al (Myers *et al.*, 2004) discussed three options for addressing this problem: (1) forcing users to take turns with one cursor, (2) having multiple simulated cursors; or (3) building applications that have an independent cursor inside the application that supports multiple customizable cursors. Our extensions to the HI-SPACE environment address this issue through the third option.

Our implementation is designed to support use of HI-SPACE with Java applications. Understanding multi-user interaction, thus, requires a brief discussion of how a single user interacts with a Java application. As shown in figure 3, 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 events (rather than OS events). In order to enable multiple-user interaction, virtual mouse events for each user can be generated at either the OS-level or JVM-level. In our application they are generated at the JVM level.

Gesture-based interaction

"HI-SPACE supports untethered gesture recognition . . . allowing group members to use relatively natural forms of communication to share ideas . . ."

HI-SPACE supports untethered gesture recognition (not requiring a data glove or other device), allowing group members to use relatively natural forms of communication to share ideas (such as pointing to indicate emphasis). HI-SPACE is like DAVE_G in relying on video capture of gesture to support user interaction. It differs from DAVE_G in using a ceiling mounted, non-active camera that recognizes hand position and gesture as an absence of signal from a set of vertically oriented, infrared emitters in the HI-SPACE's base. This method of gesture capture supports relatively precise recognition of hand signals.

Our extensions to HI-SPACE support recognition of multiple distinct gestures that can signify different mouse behaviors. For example, 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 that are fed into the OS, sequentially. This establishes a direct link between the users and the computer through the HI-SPACE display. In practice, as JVM mouse events are generated they are recognized, processed, and fed to the Java Virtual Machine. Figure 3 shows how this procedure works.

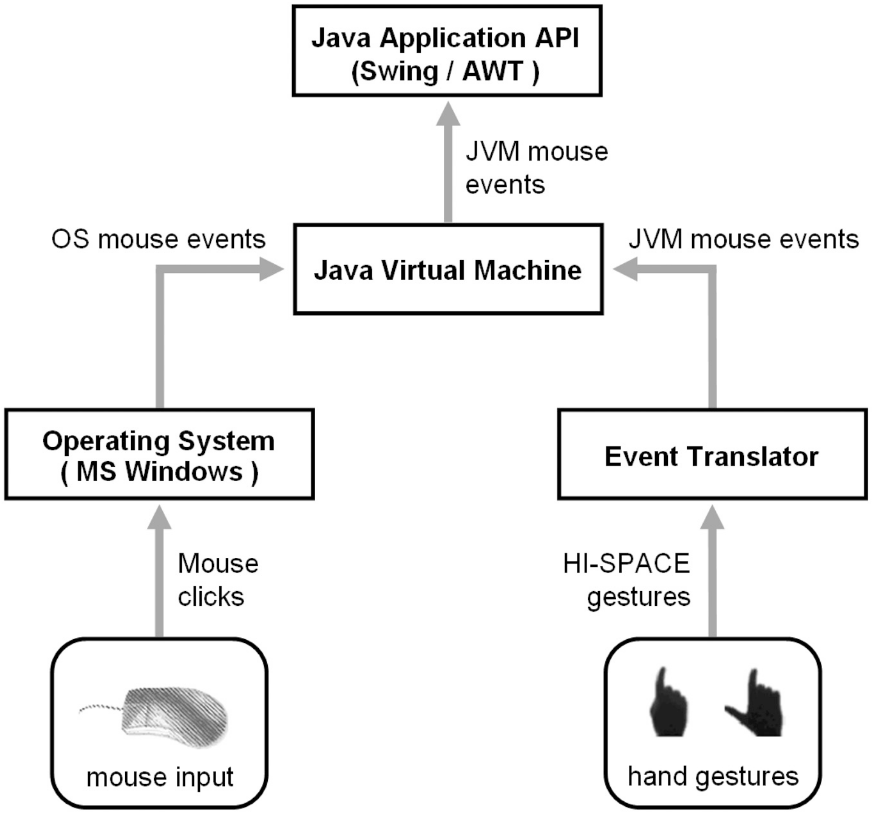

Figure 3. Implementation strategy for supporting multiple participants, using hand gestures to initiate mouse events.

Comparison and Contrast

In this section, we compare and contrast DAVE_G and HI-SPACE, drawing upon experiences gained through iteratively testing and refining the interfaces. Both DAVE_G and HI-SPACE allow a small team of collaborators to be co-located comfortably around a common large-screen display device. The large display is designed to provide a shared visual workspace (Whittaker *et al*., 1993), supports situation awareness (Endsley, 1995), and enables smooth transition between individual and collaborative actions in mixed focus collaboration (Gutwin & Greenberg, 2002). HI-SPACE enables groups of individuals to work in a round-table fashion, while DAVE_G allows multiple individuals to be clustered in front of vertical displays. Like the use of a drafting table, HI-SPACE seems to be a better fit for small team decision-making where participants are relatively equal partners in decisions. In comparison, the use of DAVE_G, like the use of wall-mounted maps, is more suited to briefings and asynchronous updating of a shared view onto evolving situations.

"HI-SPACE enables groups of individuals to work in a round-table fashion, while DAVE_G allows multiple individuals to be clustered in front of vertical displays."

Beyond their use of large-screen display, DAVE_G and HI-SPACE both allow collaborators to use natural forms of communication to interact with the visual display and to share ideas with others. We believe that support for this natural, collaborative exchange will result in significant savings in time to complete key tasks because the nature of communication and the process of work remains consistent as collaborators shift between individual and collaborative activities and between interaction with the system and with each other (Dourish & Belotti, 1992).

As shown in Figure 1, DAVE_G simultaneously captures the hand gestures of multiple users and represents them visually on the display as gesture icons. HI-SPACE implements the same function as multiple cursors, each representing a user's hand location. Such a design feature can enrich support of small-team geocollaboration because individual activities on the visual workspace are immediately visible to other members of the team, enhancing the ability of the team to maintain activity awareness (Carroll *et al.*, 2003).

"As a step toward developing geospatial information technologies that support group work in crisis management, we have conducted a range of task analysis activities focused on understanding the process of teamwork in crisis management and emphasizing how geospatial information and technologies are used."

A key feature of both HI-SPACE and DAVE_G is that they allow users to add objects to the visual display to augment and enhance collaborative discussions. The HI-SPACE table supports phicon recognition where users can place and manipulate physical objects on the display to signify the real-world entities under discussion. The complement to phicons available in DAVE_G is an ability to point to any location and ask the system to place a marker from the system's knowledge base at that location. Examples from the crisis management application domain discussed in detail below include user positioning of HAZMAT incident site markers, emergency shelters, roadblocks, or other point objects on the virtual map. We have implemented, used, and assessed this functionality; for discussion of the assessment, see: (Fuhrmann *et al*., 2005).

CONSIDERING THE CONTEXT OF CRISIS MANAGEMENT

To make near-term progress toward natural interfaces to large-screen map-based display, we have focused attention on one application domain, crisis management. This domain is likely to benefit considerably from both large screen display and natural interfaces that allow users to focus on the problem at hand (rather than how to use the system).

As a step toward developing geospatial information technologies that support group work in crisis management, we have conducted a range of task analysis activities focused on understanding the process of teamwork in crisis management and emphasizing how geospatial information and technologies are used. For discussion of the methodology and detailed results from this task analysis work, see: (Brewer, 2002; Brewer, 2005). Here we highlight selected findings and conclusions from these activities that relate specifically to large-screen, map-based display.

". . . typical computer support for crisis management teams consists of multiple desktop computers, often clustered by emergency response function or by the participating government agency. This fragmented workspace discourages tightly coordinated decision-making. "

Our task analysis work has involved off-site study of the training materials and operations plans used to prepare personnel for and guide work in crisis management activities plus on-site visits to multiple EOCs as well as observation of multiple training exercises. One finding of these activities is that typical computer support for crisis management teams consists of multiple desktop computers, often clustered by emergency response function or by the participating government agency. This fragmented workspace discourages tightly coordinated decision-making. There is a trend toward installation of large-screen displays in EOCs, but thus far they are used mostly for broadcasting updates, rather than for enabling group work.

Excerpts from an interview with the Florida Hurricane Program Manager are particularly relevant to consideration of the ways in which easy-to-use, large-format display might enable effective work in an EOC. This manager indicated that a constraint on the utility of maps in time critical situations had been the time it took to print the large maps needed to support group discussion. Also, in the planning rooms, it was sometimes difficult to clearly see the printed maps. The manager noted, specifically that:

If you have a great big map, and everyone can reasonably, clearly see it, and you're standing up there saying, these are the places where our assets are deployed. These are the areas where we need to send them into. It's much easier to do that with a map than it is to say, well, wait a minute, how close is Alachua to Brevard County. A lot of things become self-evident.

The manager went on to indicate that they were working to get large flat screen TVs in the planning and conference rooms where most of the decisions were being made. That would allow them to show the real-time displays of the multiple mapping technologies used in planning (GIS, HURREVAC, Satellite Imagery, etc).

To me, words are almost useless in a high stress, immediate decision-making contexts. Whatever we can do to map it out and make it easy for people to digest is by far the way to go.

". . . the maps were critical for making decisions because they helped eliminate speculative discussions of how close one area was to another."

Continuing on this theme, the manager suggested that large format maps (printed or digital) allow the directors to ask questions such as "why are you recommending that we evacuate starting at 7 o'clock in the morning?" and the hurricane program manager could show the map depicting the evacuation timings. Highlighting the importance of large maps during disaster planning and response, (as noted above) the participant indicated that part of the reason maps were not used more frequently in decision making contexts in the past was the length of time it took to have them plotted. He indicated that the maps were critical for making decisions because they helped eliminate speculative discussions of how close one area was to another. To help overcome the time required to plot maps, the GIS team had begun to develop an easier to use interface to allow decision makers and response personnel real-time access to the geospatial information.

Based on our analysis of the process of work in crisis management and the current and potential use of geospatial technologies to support that process, we have developed some general working hypotheses about natural, large-screen interfaces for crisis management activities with geospatial information. These include:

- The white-board/wall map metaphor (thus a large, vertical display) is most appropriate for briefings to large groups (e.g., in an Emergency Operations Center or at a planning meeting). Here, natural gesture combined with speech should be effective – since displays are typically both large and elevated for viewing. Thus, natural pointing and other gestures (of the sort you would use to draw someone's attention to a location on a wall map) are appropriate.
- In our efforts to implement interfaces that can be experimented with in real-world situations, we have found that there is a trade off between robustness of performance and naturalness of gesture-based interaction. In order for natural, free hand gesture-based displays to support coordinated group work (thus to go beyond the case of one individual presenting results of work to a group), we believe that they must achieve a high level of naturalness. Thus, users should not have to think about interacting with a computer display (as they do when moving a cursor across the screen with either a mouse movement or hand gesture). Instead, they should be able to focus on interacting with the information represented (as they can (at least in a limited way) in DAVE_G when they say "highlight the segment of Interstate from here to here" and accompany this request with

". . . there is a trade off between robustness of performance and naturalness of gesture-based interaction."

a composite gesture that points roughly at the beginning and ending intersection intended. This functionality, however, has proved difficult to support when the system is intended to be used by many different individuals. Thus, to achieve reasonably low error rates in system interpretation of user requests, it has been necessary to limit the system to using a *hand as a mouse* metaphor in which gestures are used to guide a screen cursor (rather than the more natural *free-hand gesture* metaphor where the purpose of gesture is determined by context).

"For groups ranging from two to perhaps a dozen individuals, we anticipate that hand-held, PDA based interfaces will be an effective interface device."

- Due to the challenges of making free-hand gesture interfaces both natural and robust for a range of users, we believe that a sketch-based interface will have advantages (in the near term, perhaps the next 2-3 years) over the free-hand gesture-based displays we have experimented with. While there are sketch-based wall mountable displays available commercially, the displays tend to be modest in size and probably will not support more than 2-3 people working at one time. For groups ranging from two to perhaps a dozen individuals, we anticipate that hand-held, PDA based interfaces will be an effective interface device. With a linked PDA, users beyond practical pointing distance can add annotations and draw the attention of others to objects or places they are discussing. We have begun to experiment with the option of sketch-based interfaces to maps that use hand-held devices to control large-screen displays. Specifically, we have used tablet computers rather than PDAs because the available resolution allows essentially the same information to be displayed on the hand held device and on the large screen. This makes feature selection and annotation more practical that that with a PDA on which only a subset or schematic representation of the large screen display content is possible.
- The tabletop metaphor (thus a HI-SPACE like display) will be appropriate for situation rooms, mobile command centers, planning department offices and other applications in which small teams of people collaborate intensively. We expect the use of phicons to be particularly effective as a device for supporting human-human dialogue and idea generation in this context. Since more complex work will be done in situation rooms and mobile command centers than in a public briefing, we expect that a *gesture language* may have advantages over more natural, free hand gestures and that voice input that is command-like (rather than natural) may prove to be efficient for immediate information access.

"While sketch-based interfaces, a gesture language, and limitations on voice input have potential advantages . . . support for natural gesture and language in combination has the potential . . . to enable both human-human display-supported dialogue and mixed-initiative human-system dialogue . . ."

- While sketch-based interfaces, a gesture language, and limitations on voice input have potential advantages (particularly in the short term), support for natural gesture and language in combination (as implemented partially in DAVE_G) has the potential (particularly in the long term) to enable both human-human display-supported dialogue and mixed-initiative human-system dialogue (where the system anticipates users needs). Empirical comparison of these approaches is needed as is consideration of how they might be productively integrated.

DISCUSSION

At this stage of our work, we have implemented the two prototypes detailed above and we have also implemented a speech-pen tablet interface that supports collaboration between individuals in an EOC and in the field, see: (Cai et al., 2005a). We have applied the prototypes to a series of realistic crisis management scenarios derived from our field work with crisis management personnel in contexts that range from hurricane response at the state level, through regional response to major chemical spills, to local emergency response. Initial progress makes it clear that achieving more natural interfaces to GISystems will depend upon being able to recognize and adapt to the context of use. This will, in turn, require strategies for modeling context, which is a very challenging research problem in its own right.

Based on our experiences with large-screen group displays and support for natural modes of interaction, we are developing more comprehensive strategies to support natural, group interaction with and through "smart" maps. A key component in our approach is to recognize that, in natural human dialogue and related collaborative activities, visual input serves at least three distinct roles (MacEachren and Brewer, 2004). *First*, visual displays (maps, images, diagrams) often represent the objects of attention – thus, they represent what the group work is about or directed to. *Second*, visual displays serve as a medium and resource for human thinking; they can support structuring of arguments and negotiation among alternatives. *Third*, visual displays can be used to provide workplace awareness, to help a user keep track of what others are doing, and of the process of activity over time. The GeoDialogue subsystem, now implemented as part of DAVE_G, includes specific mechanisms to maximize the above roles of visual displays (Cai *et al*., 2005b). In this environment, our user modeling subsystem keeps track of the mental states of collaboration and knowledge sharing and guides the process of display generation.

"Initial progress makes it clear that achieving more natural interfaces to GISystems will depend upon being able to recognize and adapt to the context of use."

Maps (or other visual displays) in our GeoDialogue subsystem are not pre-determined by the system, but instead are constructed through coordinated user-system interaction. This approach differs, fundamentally, from traditional GISystem uses of maps. The map, in a dialogue-based system, is a core component of a human-system (or human-human) dialogue process (rather than being a simple information source). The goal is that maps act as dynamic facilitators to thinking and communication. In addition the map, as an externalized representation of human thinking, should 'listen' to users and share initiative with the user as appropriate. Thus, the process of generating and using map displays to address problems must be mixed-initiative. Our most recent additions to DAVE_G demonstrate the potential of mixed-initiative human-system dialogue (Cai *et al*., 2005b).

Another extension of our current work on DAVE_G and HI-SPACE is to enable geographically distributed teams to engage in geocollaborative activities. For distributed users, support for workspace awareness and activity awareness is much harder (than with co-located users) due to the lack of visual clues to monitor task and collaboration states. The strategies for coordinating among distributed users include (1) transmitting and prioritizing virtual mouse events received over the network so that multiple users' operations can be processed without interfering with one another and (2) supporting collaboration through a variety of display and interface technologies where a mix of DAVE_G, HI-SPACE, and Tablet PC-based pen-voice interfaces communicate through a collaboration agent. Extensions to the coordination mechanisms in our GeoDialogue subsystem now allow us to effectively simulate geocollaborative crisis management scenarios where individual users in the field (working with a tablet displays) can interact with a group of users in an office or command center using the HI-SPACE display or DAVE_G (Cai *et al*., 2005a).

"Overall, supporting group work with geospatial information is a challenging task, whether that work is same-place or different-place."

Overall, supporting group work with geospatial information is a challenging task, whether that work is same-place or different-place. Our broad goals in the research reported here (and in a series of complementary recent papers) are: (1) to develop a theoretical framework that supports the design, implementation, assessment, and application of technologies that support map-based geocollaboration and (2) to apply that framework to both the study of map-based geocollaboration as a process and the development of information technologies that support geocollaboration.

"Technology-enabled geocollaboration is a relatively new domain of research and practice."

Technology-enabled geocollaboration is a relatively new domain of research and practice. As such, there are many unanswered questions and the software/hardware environments detailed above provide an opportunity to investigate a subset of them. Specifically, we plan to build upon the work detailed above by 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), support for multi-lingual and multi-cultural users, and understanding how map-based (and other) visual displays enable (or might enable) human-system and human-human dialogue and joint work.

"Maps, of course, have played a substantial role in collaborative activities for centuries, but cartographers . . . seem to have given little thought to the design of maps . . . to specifically support group work."

Maps, of course, have played a substantial role in collaborative activities for centuries, but cartographers (and others) seem to have given little thought to the design of maps (or map-based interactive displays) to specifically support group work. Our own work thus far has also given limited attention to map design for group work tools. However, we see design of maps to enable group work as an important challenge for cartographers to address as collaborative maps move into the main stream with environments such as Toucan Navigate, a commercial, web-based collaborative mapping environment (Schafer *et al.*, in press). Similarly, while there has been considerable attention given to group spatial decision support (Armstrong, 1994; Jankowski and Nyerges, 2001; Nyerges and Jankowski, 1997), only limited attention has been given to maps and other visual displays as devices to 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 and other GIScientists to this engage this opportunity.

ACKNOWLEDGMENTS

This material is based upon work supported by the National Science Foundation under Grants No. BCS-0113030, EIA-0306845, on a NIMA-NURI grant funded by the U.S. Geological Survey, and on support to Brewer from the Intelligence Community Post Doctoral Research Fellowship Program. Many colleagues have contributed to development of these ideas; in particular we would like to acknowledge Rajeev Sharma, Ingmar Rauschert, Levent Boelli, Sven Fuhrmann, Benyah Shaparenko, Hongmei Wang, Richard May and Dennis McQuerry.

REFERENCES

Arias, E., Eden, H., Fischer, G., Gorman, A. and Scharff, E., 2000. Transcending the individual human mind - creating shared understanding through collaborative design. *ACM Transactions on Computer-Human Interaction,* **7**:1, 84 - 113.

Armstrong, M. P., 1994. Requirements for the development of GIS-based group decision-support systems. *Journal of the American Society for Information Science,* **45**:9, 669-677.

Armstrong, M. P., 2001. The Four Way Intersection of Geospatial Information and Information Technology. *White paper prepared for NRC/CSTB*

Workshop on Intersections between Geospatial Information and Information Technology, September 19.

Billinghurst, M. and Kato, H., 2002. Collaborative augmented reality. *Commun. ACM,* **45**:7, 64-70.

Cai, G., MacEachren, A. M., Brewer, I., McNeese, M., Sharma, R. and Fuhrmann, S., 2005a. Map-Mediated GeoCollaborative Crisis Management. *IEEE ISI-2005: IEEE International Conference on Intelligence and Security Informatics, May 19-20,* Atlanta, Georgia.

Cai, G., Wang, H., MacEachren, A. M. and Fuhrmann, S., 2005b. Natural Conversational Interfaces to Geospatial Databases. *Transactions in GIS,* **9**:2, 199-211.

Carroll, J. M., Neale, D. C., Isenhour, P. L., Rosson, M. B. and McCrickard, D. S., 2003. Notification and awareness: synchronizing task-oriented collaborative activity. *International Journal of Human-Computer Studies,* **58**:5, 605-632.

Cohen, P. R. and McGee, D. R., 2004. Tangible multimodal interfaces for safety-critical applications. *Communications of the ACM,* **47**:1, 41-46.

Cowell, A. J., May, R. and Cramer, N., 2004. The human-information workspace (HI-Space): Ambient table top entertainment, *Entertainment Computing - Icec* (V3166, 101-107).

Dourish, P. and Belotti, V., 1992. Awareness and coordination in shared workspaces*. Proceedings of the 1992 ACM Conference on Computer Supported Cooperative Work*, New York, 107-115.

Egenhofer, M. J., 1997. Query processing in spatial-query-by-sketch. *Journal of Visual Languages and Computing,* **8**:4, 403-424.

Endsley, M. R., 1995. Toward a theory of situational awareness in dynamic systems. *Human Factors,* **37**:1, 32-64.

Fischer, G., 2001. Articulating the task at hand by making information relevant to it. Human-Computer Interaction (Special issue on context-aware computing), 16, 243-256.

Florence, J., Hornsby, K. and Egenhofer, M. J., 1996. The GIS wallboard: interactions with spatial information on large-scale displays. In Kraak, M.J. and Molenaar, M. (Eds.), *International Symposium on Spatial Data Handling* (V7, 449-463). Delft, The Netherlands: Taylor and Francis.

Fuhrmann, S., Cox, A. and MacEachren, A., 2005. Gesture and Speech-Based Maps to Support Use of GIS for Crisis Management: First User Studies*. AutoCarto 2005*, Las Vegas, NV, March 18-23.

Gutwin, C. and Greenberg, S., 2002. A descriptive framework of workspace awareness for real-time groupware. *Computer Supported Cooperative Work (CSCW),* **11**, 411-444.

Hopkins, L. D., Ramanathan, R. and George, R. V., 2001. *Interface for a Planning Workbench*. Department of Urban and Regional Planning, University of Illinois at Urbana-Champaign. Available: http://www.rehearsal.uiuc.edu/DesignWorkSpace/ [Nov. 4, 2001].

Jankowski, P. and Nyerges, T., 2001. *Geographic Information Systems for Group Decision Making: Towards a participatory, geographic information science*. New York: Taylor & Francis.

Johnson, A., Moher, T., Ohlsson, S. and Gillingham, M., 1999. The round earth project - Collaborative VR for conceptual learning. *IEEE Computer Graphics and Applications,* **Nov/Dec**, 60-69.

Kettebekov, S., Krahnstöver, N., Leas, M., Polat, E., Raju, H., Schapira, E. and Sharma, R., 2000. i2Map: Crisis Management using a Multimodal Interface. *ARL Federate Laboratory 4th Annual Symposium*, College Park, MD, March.

Kettebekov, S. and Sharma, R., 1999. Toward multimodal interpretation in a natural speech/gesture interface. *Proceedings, International Conference on Information Intelligence and Systems*, 328 -335.

MacEachren, A. M. and Brewer, I., 2004. Developing a conceptual framework for visually-enabled geocollaboration. *International Journal of Geographical Information Science,* **18**:1, 1-34.

MacEachren, A. M., Cai, G., Sharma, R., Brewer, I. and Rauschert, I., 2005. Enabling collaborative geoinformation access and decision-making through a natural, multimodal interface. *International Journal of Geographical Information Science,* **19**:3, 293-317.

MacEachren, A. M., Edsall, R., Haug, D., Baxter, R., Otto, G., Masters, R., Fuhrmann, S. and Qian, L., 1999. Virtual environments for geographic visualization: Potential and challenges. *Proceedings of the ACM Workshop on New Paradigms in Information Visualization and Manipulation*, Kansas City, KS, Nov. 6 (also at: www.geovista.psu.edu/publications/NPIVM99/ammNPIVM.pdf), 35-40.

Mark, D. (Ed.), 1999. *NSF Workshop Report -- Geographic Information Science: Critical Issues in an Emerging Cross-disciplinary Research Domain*. Washington, DC: NSF.

Mark, D. M. and Gould, M. D., 1991. Interacting with geographic information: A commentary. *Photogrammetric Engineering & Remote Sensing,* **57**:11, 1427-1430.

May, R. A., 1999. *HI-SPACE: A Next Generation Workspace Environment.* Unpublished Unpublished Masters Thesis, Washington State University, Pullman, WA.

McGee, D. R., Cohen, P. R., Wesson, R. M. and Horman, S., 2002. Comparing paper and tangible, multimodal tools. *Proceedings of the SIGCHI conference on Human factors in computing systems: Changing our world, changing ourselves*, Minneapolis, Minnesota, USA, 407 - 414.

McGee, D. R., Cohen, P. R. and Wu, L., 2000. Something from nothing: Augmenting a paper based work practice via multimodal interaction. *Pro-*

ceedings of the ACM Designing Augmented Reality Environments DARE 2000, Helsinor, Denmark, April 12-14, 71-80.

McGee, D. R., Pavel, M. and Cohen, P. R., 2001. Context shifts: extending the meaning of physical objects with language. *Human-Computer Interaction (Special issue on context-aware computing),* **16**, 351-362.

Muntz, R. R., Barclay, T., Dozier, J., Faloutsos, C., MacEachren, A. M., Martin, J. L., Pancake, C. M. and Satyanarayanan, M., 2003. *IT Roadmap to a Geospatial Future, report of the Committee on Intersections Between Geospatial Information and Information Technology*. Washington, DC: National Academies Press.

Myers, B. A., Nichols, J., Wobbrock, J. O. and Miller, R. C., 2004. Taking Handheld Devices to the Next Level. *Computer,* **37**:12, 36-43.

National Research Council, 2003. *IT Roadmap to a Geospatial Future, report of the Committee on Intersections Between Geospatial Information and Information Technology*. Washington, DC: National Academies Press.

Neves, N., Silva, J., Goncalves, P., Muchaxo, J., Silva, J. M. and Camara, A., 1997. Cognitive spaces and metaphors: A solution for interacting with spatial data. *Computers and Geosciences,* **23**:4, 483-488.

Nigay, L., Salembier, P., Marchand, T., Renevier, P. and Pasqualetti, L. I. E., 2002. Mobile and Collaborative Augmented Reality : A Scenario based design approach. *Mobile Human-Computer Interaction, 4th International Symposium, Mobile HCI, Lecture Notes in Computer Science Springer*, Pisa, Italy, September 18-20.

Nyerges, T. L. and Jankowski, P., 1997. Enhanced adaptive structuration theory: A theory of GIS-supported collaborative decision making. *Geographical Systems,* **4**:3, 225-259.

Oviatt, S. L., 1997. Multimodal Interactive Maps: Designing for Human Performance. *Human-Computer Interaction,* **12**:1-2, 93-129.

Rauschert, I., Agrawal, P., Fuhrmann, S., Brewer, I., Wang, H., Sharma, R., Cai, G. and MacEachren, A., 2002. Designing a human-centered, multimodal GIS interface to support emergency management. *ACM GIS'02, 10th ACM Symposium on Advances in Geographic Information Systems*, Washington, DC, USA, November, 119-124.

Reitmayr, G. and Schmalstieg, D., 2004. Collaborative Augmented Reality for Outdoor Navigation and Information Browsing. Proceedings of the Symposium on Location Based Services and Telecartography, Geowissenschaftliche Mitteilungen Nr. 66.

Schafer, W. A., Ganoe, C. H., Coch, G. and Xiao, L., in press. Designing the Next Generation of Distributed, Geocollaborative Tools. *Cartographic and Geographic Information Science*.

Sharma, R., Poddar, I., Ozyildiz, E., Kettebekov, S., Kim, H. and Huang, T. S., 1999. Toward Interpretation of Natural Speech/Gesture: Spatial Planning on a Virtual Map. *Proceedings of ARL Advanced Displays Annual Symposium*, Adelphi, MD, February, 35-39.

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

Wheless, G. H., Lascara, C. M., Valle-Levinson, A., Brutzman, D. P., Hibbard, W. L., Paul, B. and Sherman, W., 1996. The Chesapeake Bay Virtual Ecosystem: Initial results from the prototypical system. *International Journal of Supercomputer Applications and High Performance Computing,* **10**:2-3, 199-210.

Whittaker, S., Geelhoed, E. and Robinson, E., 1993. Shared workspaces: how do they work and when are they useful? *International Journal of Man-Machine Studies,* **39**:5, 813-842.