Extending Distributed GIS to Support Geo-Collaborative Crisis Management

Guoray Cai

School of Information Sciences and Technology, Pennsylvania State University, University Park, PA 16802
E-mail: cai@ist.psu.edu

Abstract
Crises are often complex, geographical scale problems that require professionals to work in teams while dealing with a large amount of geographic information for decision making. However, current geospatial technologies do not directly support group entities working with geographic information–they impede rather than facilitate human-human collaborations and communication. Towards the goal of making GIS "collaboration-friendly," this paper explores the potentials of extending distributed GIS with groupware and intelligent communication agents to support geo-collaborative crisis management by teams. Members of such a team are often geographically distributed and play different roles. In addition to the architectural choice, special attention was given to the computational approach to enable collaborative geographic information dialogues in spatial decision-making contexts. Collaboration requires representation and reasoning on a team mental model, which must be constructed from dialogue contexts and shared knowledge. An implementation of an intelligent, multimodal, multi-user geographic information environment, called GCCM_Connect, is presented as a proof-of-concept for the proposed architecture.

Keywords
geo-collaboration, distributed GIS, groupware, crisis management

I. INTRODUCTION

"*Most of the science and decision making involved in geo-information is the product of collaborative teams. Current geospatial technologies are a limiting factor because they do not provide any direct support for group efforts.*" — **IT Roadmap to a Geospatial Future**. National Academy of Sciences (Muntz et al., 2003)

Geographic information is increasingly used to address complex social and environmental problems such as managing crises, creating new environmental policies, or planning urban growth. In such applications, individual knowledge and skills are no longer adequate. Professionals and scientists must work in teams to take advantage of their collective intelligence and their complementary skills. Meanwhile, dealing with complex geographic-oriented problems requires compilation of a large number of spatial data sources for integrated analysis and visualization. Recent developments in distributed computing, geographic information science, and computer-supported-cooperative-work (CSCW) suggest that maps and geographic information systems (GIS) are likely to take on a new role in facilitating human-human collaborations and communication (MacEachren, 2000). Despite such potential of geographic information, current geographic information technologies are mostly design for use by individuals. When a work group needs to deal with geographic information, group members often resort to phones and paper maps for communication and collaboration, even though they have access to GIS and mapping tools. This is not surprising because existing GIS do not direct support multi-user applications, or they only do so to the extent that many people can access the same data as if each was the only user (Churcher and Churcher, 1999). For collaborative decision making, it is important for participants to be able to browse, annotate, query, and visualize geographic data with full awareness of each other's action and collaboratively act on their common goals.

The central theme of this paper is to develop computer support for groups working with geographic information, commonly known as *geo-collaboration*. Geo-collaboration is a special type of collaborative activities that involve a committed effort on the part of two or more people to collectively frame and address a task that requires the use of geospatial information (MacEachren and Brewer, 2004). Geospatial information enables tightly coordinated work by providing contexts and details about the event itself, its causes, participating agents, and situations. The potential for maps and related geospatial technologies to be the media for collaborative activities among distributed agencies and teams have been discussed (MacEachren, 2000, 2001; Muntz et al., 2003; MacEachren and Brewer, 2004), but feasible technological infrastructure and tools are not yet widely available. There are two main barriers in supporting geo-collaboration. First, we know very little about how teams work with geographic information through GIS and other related technologies. Second, there has been a lack of technological advances in achieving feasible solutions to mediate geo-collaboration in the computing environment. To deal with the former barrier, we should direct research effort toward understanding the role of maps in different application domains where geo-collaboration is the norm. In addressing the later (technological) barrier, future development of geographic information technologies must explicitly model collaborative activities, distributed users, and semantics of

1082-4006/05/1101-4$5.00

geographic data sources.

Toward the goal of supporting geo-collaboration, this paper advances the research agenda of distributed GIS in two aspects: (1) *identify necessary extensions of distributed GIS that meet the need of IT support for geo-collaboration*; and (2) *propose the architecture and a framework to develop distributed GIS for distributed collaborative applications*. Although distributed GIS has the great potential to be a technology core for map-mediated group work with geographic information, it has been traditionally regarded as a technology about sharing geographic data and GIS processing power across organizations and users. This paper is the first to propose geo-collaboration as a new frontier of research and development in distributed GIS. Challenges on integrating groupware support, workflow models, and mixed-initiative dialogue systems are identified. The main result of this work is an architectural specification for geo-collaborative applications. This specification is feasible and flexible in a web-service-based open network environment. We initially place our discussion in the context of geo-collaborative crisis management, and focus on map-mediated real-time collaborations among a geographically distributed team.

II. A MOTIVATING EXAMPLE: GEO-COLLABORATIVE CRISIS MANAGEMENT

The research effort reported here was motivated by the need to support geo-collaborative activities for emergency and crisis management. Crisis events, like the 9/11 attack in the U.S. and the recent tsunami devastation in South Asia, have dramatic impacts on human society, economy and natural environment. Crisis management (involving immediate response, recovery, mitigation, and preparedness) relies upon geospatial information to depict geographic distribution of events, their causes, affected people and infrastructure, and available resources. Maps and images play a key role in pre-event assessment of risk and vulnerability as well as response during the event and subsequent recovery efforts. The potential roles of GIS in providing information to crisis managers have been detailed repeatedly (Mondschein, 1994; Kumar et al., 1999), but recent field studies showed that GIS is rarely utilized in real-time crisis response (Zerger, 2002; Zerger and Smith, 2003). The reasons for the lack of widespread utilization of GIS in crisis management activities can be attributed to limited data and software interoperability, lack of mechanisms for immediate integration of real time geospatial data, and difficulties in using human-computer interfaces. However, a deeper reason, as revealed by our recent survey and field observations in hurricane response teams, is perhaps that the collaborative nature of crisis management activities is not supported by traditional GIS.

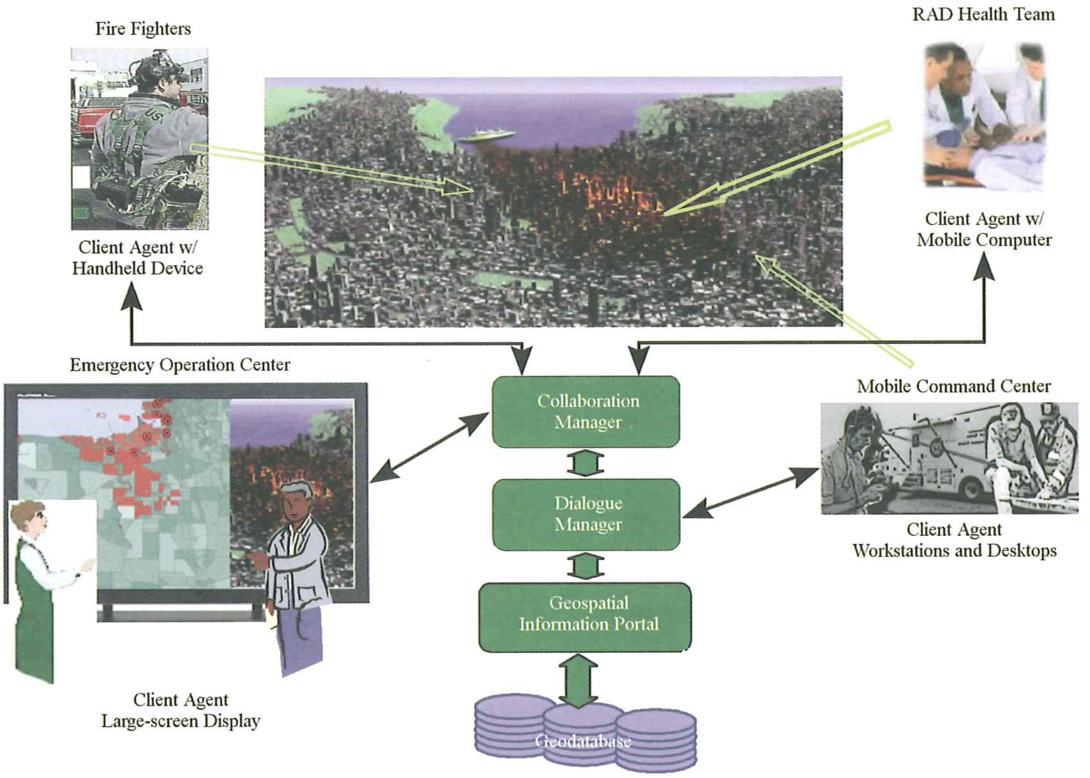
Crisis management requires multiple individuals and organizations sharing information, expertise, and resources to support rapid assessment and decision-making. For example, the response effort for the 9/11 attacks involved hundreds of federal, state and local agencies, and private organizations covering different domains of knowledge, jurisdictions, and with different levels of decision-power (Cahan and Ball, 2002). Figure 1 describes a sample scenario of crisis situation after a radioactive release. During a crisis event like this, one or more emergency operation centers (EOC) work in cooperation with teams of field responders. The EOC(s) communicate with teams about the situation and coordinate actions. Making spatial decisions on resource allocation, dispatching, and prescribing medical treatments requires collecting and sharing geographical intelligence through collaborative efforts among multiple, distributed agencies and task groups. As a common representation of geographic knowledge, maps encourage efficient communication of knowledge, perceptions, judgment, and actions. In this sense, crisis management can be conceptualized as a type of geo-collaborative activities.

We envision a multimodal, dialogue-enabled *Geo-Collaborative Crisis Management* environment. It integrates two sets of related technologies to meet the needs: large screen displays for face-to-face group work in Emergency Operation Centers (EOCs) and portable devices for mobile field personnel. In an EOC, large screen displays coupled with natural, multimodal interfaces can support dialogue and allow users to: (a) display and interact intuitively with geospatial and non-geospatial information–while users may not need in-depth GIS training; (b) visualize and discuss the situation, make decisions, represent those decisions in some kind of visible forms, and quickly revise decisions while no paper maps may need to be printed out; (c) use the system as a portal to remote sites and collaborators; (d) store decision processes for later retrieval for training and performance review. Out in the field, teams of the first responders (police, fire, medical) make on-site assessment, evacuate people, and respond to various events while keeping in touch through mobile phones or wearable computers. Besides dealing with the dispersed location of and the diversity of devices, another major research thrust is to extend distributed GIS so that they facilitate dialogues among involved crisis management personnel (regardless of where they are) as well as dialogues between humans and information devices (through multimodal, dialogue-enabled interfaces). The bottom part of Figure 1 presents a sample dialogue that reveals the nature of dialogue-assisted human-system-human communication and collaboration during a crisis.

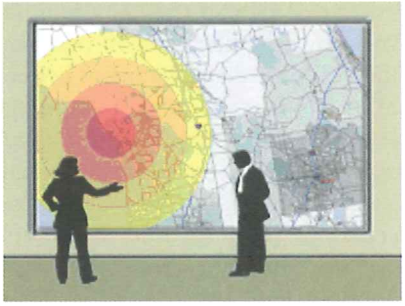
Crisis management imposes demanding requirements on information technology support in terms of data storage, computing infrastructure, interoperability, modeling capabilities, and mobility (Scherlis et al., 1999).

- From the *data perspective*, much of the data, information, and knowledge that underpin critical decisions for emergency preparedness, response, recovery, and mitigation are geospatial in nature (Muntz et al., 2003). Crisis events happen in certain geographical context and

A Scenario: The Crystal River nuclear power plant has notified officials that an accident occurred, resulting in a potential radioactive particulate release within 9 hours. Response professionals with a range of expertise, working together to determine the impact area, order and carry out evacuations, and deploy RAD health teams to identify 'hot zones' in the residential and agricultural areas. Based on available information, immediate decisions must be made about where and how to evacuate or quarantine residents, establishing decontamination checkpoints, deploying rescue and health teams, ordering in-place shelters, and prioritizing situations. As field personnel are deployed, a Mobile Command Center is established and coordinates the activity of this distributed taskforce. Collaboration among participants is mediated by a distributed GIS which communicates with a range of devices and is capable of supporting knowledge work with geospatial information.

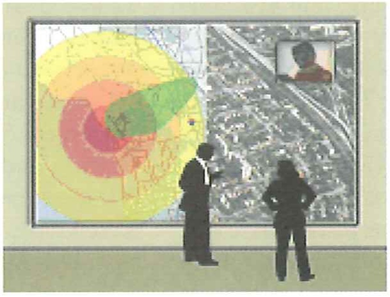


Jill: "We have a situation at Crystal River Nuclear plant. They're warning of a radioactive particulate release requiring evacuation."
Jim: "Show me the 10, 20, 30, and 40 mile EPZ zones around the plant (*gestures to location*)."
GC: (The system displays 4 buffered rings around the region in question).



Jill: "Alright, prevailing winds are generally here (*gestures SW to NW*), what are current wind conditions? Create a plume model over this region." (*circle gesture indicating area*).
GC: (the system creates the radiation plume model and displays it over the region)
Jim: "With those projected wind speeds, it's going to hit the Ocala metropolitan region with a wind shift threatening Gainesville."

Jill: "We need to decide whether to evacuate, in-place shelter, or quarantine the region. Give me population stats inside the plume and the latest satellite imagery for this city" (*gestures at Ocala*).



Jim: "Our protective action recommendations are to evacuate within a 30 mile EPZ. (*Indicates 3rd ring, system removes 4th*). The imagery indicates construction here (*points*).
GC: (highlights corresponding areas on map and imagery).
Jim: Show me evacuation routes here (*points to map*), and total population in the new construction areas." (*points to imagery*).
Jill: "System, sound the sirens and relay the evacuation zones to EAS radio; all remaining areas will have to in-place shelter."

The Evacuation Proceeds: Mobile command units are sent to the area for radiation sampling
Jill: "OK, display decontamination checkpoints near here (*points*) and contact the field teams."

RAD team 1: "How many people require in-place quarantine here?" (*points at 3 regions on PDA*).
GC: (About 18,000)
Jim: "Ok, order them to close windows and shut off air conditioning intakes. RAD-1, send me your readings as soon as you can."
Jill: "RAD-2 is in charge of agricultural response. We might have to quarantine age areas in the plume. Relay all beef and dairy farms data to RAD2–we have to know if those animals have been contaminated."
RAD team 2: "EOC, we also need to know the locations of the food processors, vegetable farms, and plant nurseries in the region" (*points to a region*)

Figure 1. GeoCollaborative crisis management

their effects are mostly geographically distributed and location-dependent. Crises management requires an extraordinary quantity of resources, such as search and rescue teams, medial assistance, food, and shelter. These resources are highly diverse and geographically dispersed as well. Emergency managers need tools to quickly identify, collect, and integrate crucial information about the rapid development of the situation.

- From the *information retrieval perspective*, there are three major constraints on human use of geographical information in crisis response: *immediacy*, *relevancy* and *sharing* (Cai et al., 2005). The simultaneous presence of all three demanding requirements in crisis response applications creates a unique system design problem.
- From the *mission and activity perspective*, the underlying technology must support team work with geographic information. Crisis management teams are often formed dynamically in an ad-hoc manner according to the situation. A team may work together at the same-or-different time and at the same-or-different places (Ellis et al., 1991; Armstrong, 1993). Some members may be constantly on the move, while others stay in relatively stable environments. Members may be equipped with a diverse range of devices that need to communicate with each other reliably. Irrespective of the team configuration, technology support should facilitate information flows among team members. Map-mediated geocollaboration goes beyond simple sharing of geographic information, and should include workspace awareness and activity awareness to enable coordination and cooperation. Communications and interactions may take place among crisis responders, between crisis responders and computer systems, or between crisis responders and citizens.

The above requirements for system support highlight the importance of research issues in distributed GIS, and at the same time, impose challenges and new research questions that help moving distributed GIS beyond its current state.

III. DISTRIBUTED GIS AND GROUP WORK WITH GEOSPATIAL INFORMATION: THE LITERATURE

Our current work lies at the intersection and cross-fertilization of distributed GIS technologies and the field of computer-supported cooperative work (CSCW). This section will review relevant literature and major advances in both areas and their integration.

A. Architecture and technologies for distributed GIS

Following Peng and Tsou (2003), distributed GIS is defined as *geographic information services provided though the Internet (both wired and wireless network) and allow people to access geographic information, spatial analytical tools, and GIS-based web services without owning a GIS and data.* It is the driving force of a wide range of on-line geospatial applications such as digital libraries (Buttenfield and Goodchild, 1996; Smith, 1996), digital governments (www.whitehouse.gov/omb/egov/), on-line mapping (e.g., MapQuest and Yahoo!Map), data clearinghouses (e.g., FGDC's data clearinghouse, http://clearinghouse3.fgdc.gov) and the USGS National Map Seamless Data Distribution System (http://seamless.usgs.gov).

Distributed GIS is simply GIS technology that is built and deployed using distributed computing technology and the standards of the Internet. The primary functions of distributed GIS have been the sharing of geographic data and GIS processing tools across organizations and among developers, owners, and users. Three levels of sharing can be identified: (1) online archive, search, and download; (2) interactive map servers and mobile navigation services that commonly include the display, zoom-in/out, query of spatial information; and (3) on-line GIS modeling and spatial analysis. The recent emergence of geospatial portal technologies (Maguire and Longley, 2005; Tait, 2005) has made the access to distributed geographical information services much simpler by service discovery tools.

The architecture of a distributed GIS depends on the purposes of the application. For Web-based interactive mapping applications, a 3-tier client-server architecture is a popular choice. The first tier is called "the client tier" which supports the user to make requests and to view geospatial data. The second tier is the middleware tier that includes the Web Server and the Server Connectors to bridge the communication between clients and the map servers. The third tier is the data storage tier that includes the map server and the database server. The three-tier software architecture of web-based GIS provides customizable functions for different mapping applications and scalable implementation of different hardware configurations. With the advent of web services as a new paradigm for distributed application development, future generation of distributed GIS will allow users to dynamically create task-oriented clients utilizing interoperable services (Albrecht, 1997). Application developers will have the flexibility to select services based on the requirements of the end-user by choosing the service implementations that are best suited to the task at hand. In addition, developers of applications for the traditional non-GIS users can select the set of functionalities without implementing the full GIS capability.

Figure 2 shows a service-oriented view of distributed GIS architecture. At the bottom, the geographic data management component of a distributed GIS supports the active use and maintenance of geographic data. This capability allows both internal and external organizations to access the latest data while allowing the content to be actively managed and maintained. Geographic data and processing functionalities are then packaged into GIS web services that are published to the Internet. Clients may consume GIS web services by dynamically assembling multiple GIS web services to fit the need of a variety of client applications. The aggregation of GIS web services can even be performed in real-time if the

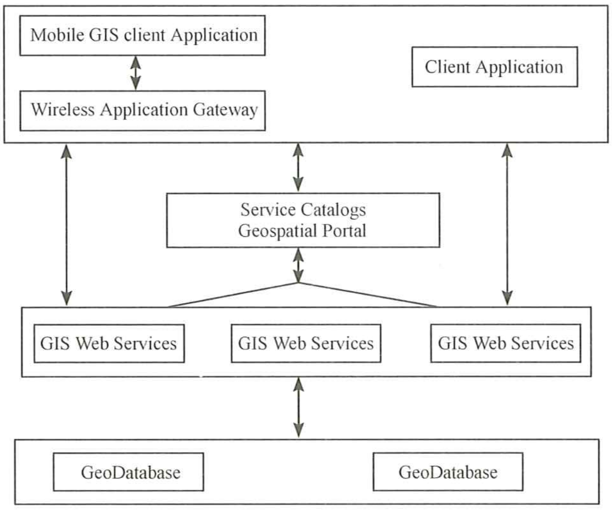


Figure 2. Service-oriented distributed GIS architecture

component services are properly marked up using a language similar to the Distributed GIS Component Markup Language (DGCML) (Preston et al., 2003).

Web services have become the industry standard for allowing technology to interoperate across programming languages, platforms and operating systems. Generic web service standards, such as eXtensible Markup Language (XML), Simple Object Access Protocol (SOAP), and Web Services Description Language (WSDL), are utilized by GIS vendors to support the deployment of geographic web services. Geographic web services publish geographic contents and functionalities. The geographic industry has published geographic web services standards, which serve as additional layer on top of some of those generic standards. The Open GIS Consortium (OGC) envisions that geospatial data and geoprocessing resources will be fully integrated into mainstream computing and information infrastructure.

In order to facilitate the vision of achieving interoperable data and services, OGC has developed specifications for its central technology themes of sharing geospatial information and providing geospatial services. The first and foremost of these is the *Geographic Markup Language* (GML). GML is an open standard for marking up geospatial information and making it easy to transfer spatial data between distributed, heterogeneous applications and platforms. GML is based on the XML schema and provide a language for the modeling, transport and storage of geographic information, including both the spatial and aspatial properties of the geographic features. It also allows descriptions of geospatial application schemas for specialized domains and information communities. The second set of OGC's specifications is on geospatial domain-specific web services, such as Web Map Service (WMS), Web Feature Service (WFS), and Coordinate Transformation Service (CTS).

There have been many successful applications of distributed GIS. Mobile GIS (Montoya, 2003; Wang et al., 2004) or field-based GIS (Zingler et al., 1999; Pundt and Brinkkotter-Runde, 2000) have been heavily used in field data collation. These systems use wireless communication systems, mobile computers, and positioning systems to provide the capabilities to access, process, and display geospatial information in the field (Nusser et al., 2003; Casademont et al., 2004). Due to the limited computational power on mobile computers, it is impractical to run a full GIS on the device. Instead, mobile GIS commonly take advantage of geographic information services available from the Internet. Others have applied distributed GIS in delivering statistical information (Andrienko et al., 1999), public participation (Al-Kodmany, 2001; Carver et al. ,2001; Peng, 2001), and decision-making (Kingston et al., 2000).

B. Group work with geographic information

Putting people to work in groups is the common approach to deal with problems that are ill-structured, multi-disciplinary, or with multiple stakeholders. Maps and GIS, with their abilities to formally encode spatial phenomena and their interdependencies, are inherently well suited to facilitate collaboration among participants in thinking and decision-making on the geographic-scale issues (MacEachren, 2000). In the spatial decision-making context, cartography and GIS have been used by groups in two types of applications: (1) spatial decision making by experts (Group-SDSS) (Armstrong, Densham, 1995; Densham, et al., 1995; Jankowski, et al., 1997), and (2) public participation in policy decisions (PP-GIS) (Obermeyer, 1998; Kingston et al., 2000; Carver et al., 2001; Peng, 2001). Among the most interesting group-support methods are:

- Shared GIS workspace (or shared graphics "What-You-See-Is-What-I-See") (Armstrong, 1994)
- Group summary mapping (showing group consistency and consensus) (Armstrong and Densham, 1995)
- Argumentation map (Rinner, 2001)
- Allow group members to directly interact with, and change the map representation, and propagate such changes to other members (Shiffer,1998; Rogers et al., 2002; MacEachren et al., 2005)
- Real-time conferencing in GIS (like GroupArc (Churcher and Churcher, 1999))
- Allow members to sketch and annotate on private or public map displays (Churcher and Churcher, 1999; Singh, 1999; Rauschert et al., 2002)

For the purpose of this paper on supporting real-time geo-collaboration for distributed crisis management team, we limit our interest to the role of GIS in same-time different-place collaborations, or real-time distributed collaborations. Two most interesting systems in this category are *GroupArc* and *TouchanNavigate*.

GroupARC (Churcher and Churcher, 1996; Churcher and Churcher, 1999) is a lightweight geographic information browsing and annotation tool that allows group interaction and discussion of spatial problems. It was developed by connecting a groupware (GroupKit (Roseman and Greenberg, 1992)) with a conventional GIS(ARC-INFO). GroupARC provide chat room and electronic whiteboard functions for viewing and discussing geographic data. Participants' viewing areas are color-coded for awareness. Users can point at a specific feature, annotate with free-hand sketches, manipulate the scrolling bar, or perform simple queries, and the results of such actions are shared with others. Each participating user needs to have a copy of GroupARC running, and one of them is required to have access to a conventional GIS (see Figure 3). This configuration is quite cumbersome and limited, as will be discussed in the next section in more detail.

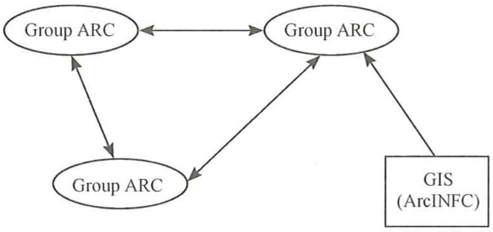


Figure 3. GroupARC architecture

Toucan Navigate (www.infopatterns.net) is a commercial product that implements the 'virtual map room' functions, featuring collaborative geo-visualization and editing. Toucan Navigate is based on a groupware toolkit, Groove (www.groove.net), with the add-on of a lightweight geographic visualization tool. It does not require a GIS to operate. Toucan Navigate follows the model of file sharing and relay in virtual office applications. When a user makes changes on the collaborative visual workspace, the changes are disseminated to other users by a relay server. With GPS on the clients, it also supports location awareness for mobile team applications (see Figure 4).

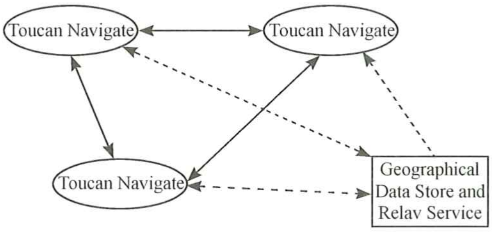


Figure 4. Toucan Navigate architecture

Common to the two systems (as reviewed above) is that they treat GIS data and functions lightly, and implemented collaborative GIS as an add-on to generic groupware tools. These development decisions were mainly due to the lack of a technology solution to make GIS functions available to members of the collaborative session without having to run a version of GIS on each client. This architecture issue will be revisited. In the next section, we will propose an alternative approach where distributed GIS is extended with collaborative functions.

IV. EXTENDING DISTRIBUTED GIS FOR COLLABORATIVE APPLICATIONS: AN ARCHITECTURE

In order to design a system that supports collaborative work with geographic information, it is necessary to integrate functions that were currently scattered across workflow systems, groupware, and GIS. Churcher and Churcher (1999) delineated two alternative routes to achieve this goal:
(1) Incorporating groupware functions within traditional GIS
(2) Extending existing groupware with necessary GIS functions.

They argued that the second approach is preferable, since it does not require a GIS for every participant to join collaborative sessions (but the first approach does). We argue here that the above two approaches are equally bad strategies for geo-collaborative applications. The dependencies of geo-collaborative software on either a groupware system or a GIS would likely to create nightmare in terms of deployment, maintenance, and adaptation in the future. We believe that a geo-collaborative application is likely to need a small subset of functions from GIS and groupware, but what constitute this subset is dependent upon the type of collaborative activities. This view is inline with the *task-technology fit* theory (Zigurs and Buckland,1998) which was developed in the domain of computer-supported co-operative work (CSCW). This theory states that the *support for cooperation provided by technology has to match the cooperative tasks people perform*. Unfortunately, there seems to be a real and inherent gap between what we know we must support socially and what we can support technically–a fact known as the *social-technical gap* (Ackerman, 2000). An important cause of this gap is the inherent dynamics in the way people interact: co-operating groups are dynamic, the tasks they co-operatively perform change over time, and so does the context in which they perform these tasks (Greenberg, 2001). As a result, the requirements for the technology to support co-operating among people change over time. For this reason, we favor methods that allow the end users themselves to select and combine the groupware behavior and GIS functions that fit their needs, perhaps through a degree of run-time adaptation or *tailoring*. With GIS web services and groupware services become increasingly available (Slagter, 2004), collaborative GIS applications can be readily built using distributed computing frameworks based on web services and component technologies.

A. Architectural choice

The architecture of a system refers to the description of components, connectors, and their configurations (Bass et al., 1999). From the perspective of geo-collaboration support, an architecture has to cope with a GIS service specification model, a groupware specification model, and their dynamic integration based on task knowledge. Figure 5 is a high-level architectural specification of map-mediated geo-collaboration.

Because most of these service models are still at the proposal or development stage, our description of a geo-collaborative application model is necessarily a futuristic one. For this reason, we make the following assumptions:
(1)All participating GIS nodes (machines with GIS installed) have published their data and services according to the Open Geospatial Consortium's Web Service Reference Models.
(2)All participating groupware kits have been designed as web services that are published to the Internet. All providers should follow a common groupware reference model, such as CooPS (Slagter, 2004).

Furthermore, we consider geocollaboration as project-oriented, and, sometimes, mission-critical, team work. This is close to the concept of *virtual project communities* (VPC) using the terminology by Dustdar and Gall (2003). Dustdar and Gall argued that the requirements for supporting VPC go beyond what are commonly provided by groupware technology. Groupware do not support workflow management, and do not have knowledge of goals or underlying business processes of the group. Crisis management teams (unlike other virtual project communities), on the other hand, are strongly mission-oriented. The overall goal and sub-goals of the collaboration are to share knowledge among all participants, and to use the knowledge to guide planning and coordination of group activities. Participants are also organized by their roles that bear certain responsibilities in the collaborative processes.

We shall now look into the details of this architecture as described in Figure 5. It consists of three layers:

- The *Service layer*(at the bottom)provides the functionalities required for real-time geo-collaborative applications: groupware services, GIS Web services, and process planning services. The last one represents a model of business or domain specific processes as a set of web services to be consumed by task-oriented applications.
- The *geo-collaborative server* layer is the core of this architecture. It has three large functional modules. The *Service Integration and Mediation* module creates a custom configuration of functionalities according to the immediate goal(s) of the current session. A session is a segment of individual or collaborative activity that accomplishes some sub-goals of the overall mission. Following Edwards (1994), a session is described as a triple (U_n, T_n, O_n), which represents the participants, task, and object (artifacts) that are involved in the n^{th} activity. The *Session Management* module manages the creation, maintenance, and closing of sessions, as well as interactions among sessions. Each session maintains its own state of information such as the change of

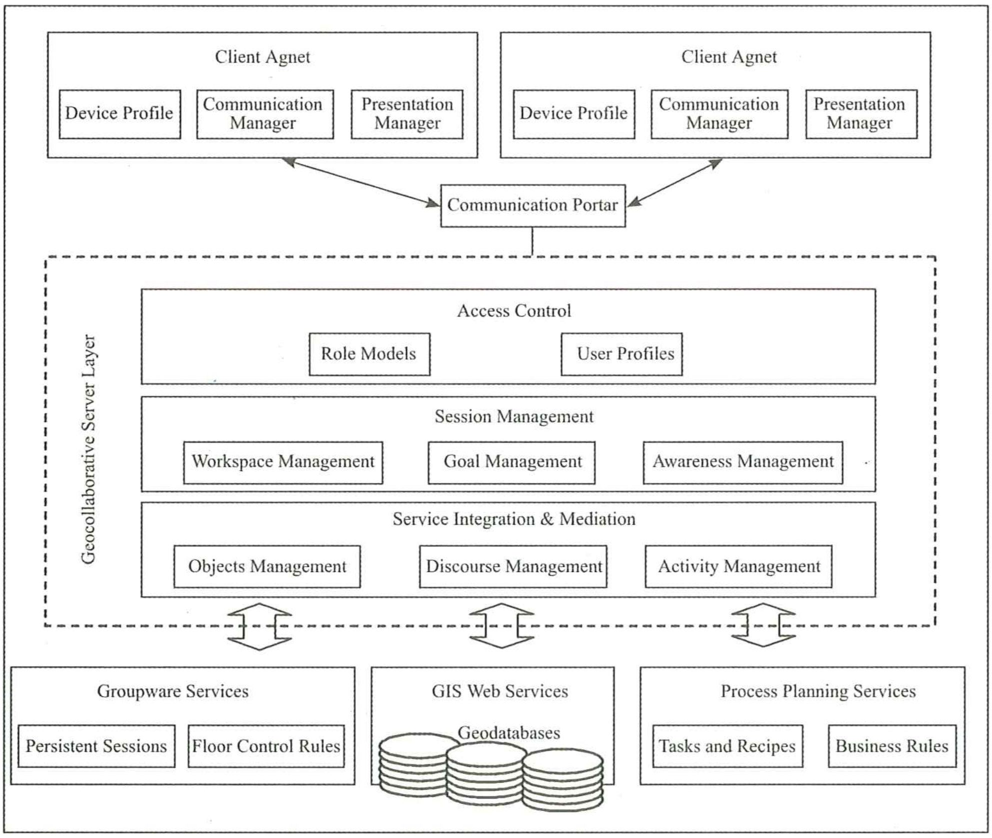


Figure 5. A distributed architecture of geo-collaborative applications

participants, map contents, and goal status. A user may join or leave a session through an explicit request and confirmation, or through implicit rules of collaboration. Sessions are interrelated through their task hierarchy or through their conditional dependencies. A session may need to wait for another session to complete before continuing, due to fact that the result of the second session is a knowledge-precondition of the first session. In such cases, session management is responsible for intercepting relevant events and propagating them to the awareness of interested sessions. Details on collaborative session management will be reported in a separate paper. The *Access Control* module authenticates users and admits a user's request to a particular activity based on a pre-specified role model. User profile information is useful for minimizing the overhead of access control.

- The Client Layer is relatively thin, which is necessary to run on mobile devices. A client agent is responsible for recognizing user's inputs and communicating requests to the geo-collaborative server. Selected device profile information (such as screen size, spatial and color resolutions) should accompany each request in order for the geo-collaborative server to generate customized replies that fit the device's capability.The *Communication Manager* module handles the network and protocol specific details of making requests and receiving responses. The *Presentation* module deals with device dependent layout of graphics, texts, and GUI controls. Communications among users are not through direct peer-to-peer message channels, but through a relay and mediation process by the geo-collaborative server which serves as the centralized message processing and relay center. This is different from that of a groupware environment in Figure 3 and Figure 4. The reason for adopting a centralized control of communication is because of the need to capture group message flows in order for the system to construct a representation of a team mental model (Mohammed and Dumville, 2001).

The architecture of Figure 5 is a natural extension of the foundational work on distributed GIS architectures and standards (as review in section II.A). There are several benefits as the direct result of this architecture design. *First*, this architecture support dynamic run-time configuration of collaborative functions, which is inline with several distributed GIS architectures (Tsou and Buttenfield, 2002; Preston et al., 2003). *Second*, it is designed with mobile geo-collaborative teams in mind. The client program is lightweight and can fit to most mobile devices. *Third*, it supports collaborations with complex business processes and task models, such as crisis management and workflow management. The architecture can support such activities is due to the explicit representation and reasoning of domain activity and the role of such knowledge in guiding human-machine-human collaborative behavior.

B. Implementing a geo-collaboration server as a Web service

Full implementation of geo-collaborative environment based on the architecture as depicted in Figure 5 is currently a future goal rather than reality due to many social and technological gaps. Groupware technology is still far from being standardized for use in the web service-based open network environment. We still have very little knowledge about how people, particularly crisis management teams, collaborate with and through maps. Although we know that human activities are the primary determining factors for how GIS should be used in collaborative applications, exactly how such knowledge can be captured and used in map-mediation of geo-collaboration is still an open question. Next, we present *GCCM_connect*, which is a proof-of-concept implementation of a map-mediated geo-collaborative environment and a partial implementation of the architecture in Figure 5.

GCCM_Connect (see Figure 6) is a distributed multi-agent system that is designed to mediate collaborative activities among emergency managers in emergency operation centers (EOCs) and first responders in the field. Compared with other collaborative environment, GCCM_Connect has several unique characteristics: (1) users interact with the system using natural spoken language and hand gestures, instead of using keyboards and mice; (2) participants of a collaborative session can jointly manipulate their (shared) map workspaces as a

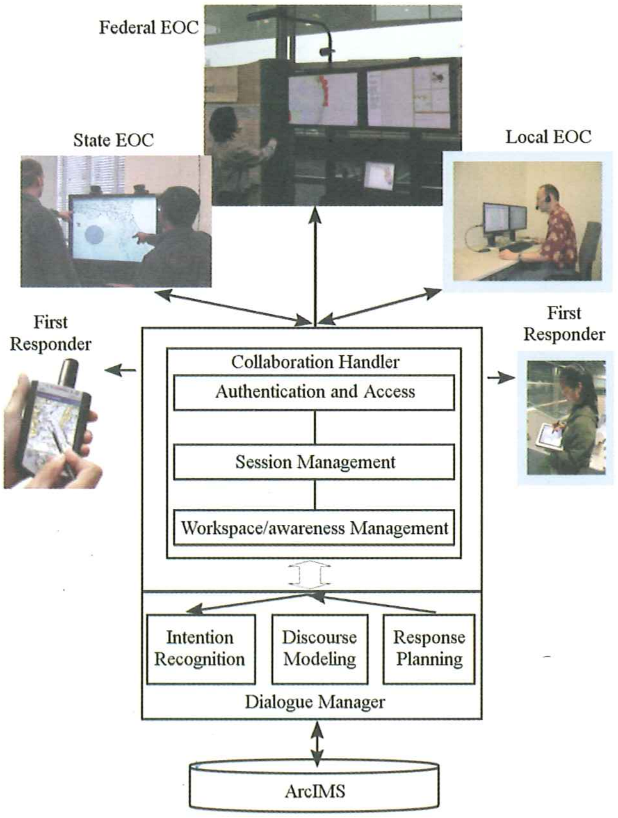


Figure 6. GCCM_connect environment

way to construct group mental models on the task; (3) large-screen displays are used in emergency operation centers to enhance the idea of shared visual graphics as a mechanism of collaboration; (4) interactions follow the principles of conversational dialogues (Cai et al., 2005).

GCCM_Connect is designed as a web service that can be discovered and accessed from any device with Internet connections. Both the clients and the server were developed using Microsoft .NET framework, and hence they only work on devices running a version of .NET. Functions on session management and awareness support were developed in-house instead of using groupware web service. ESRI's ArcIMS plays the role of a GIS web server. GIS data in and functions of ArcIMS are accessed using ArcXML messages, which is the commercial protocol closest to the OGC's Web Map Service (WMS) specification.

The intelligence of GCCM_Connect in understanding human language and facilitating collaboration came from a unified computational model of collaboration and discourse. The Dialogue Manager captures the intelligence of human conversational participants in the sense that it takes into account the large number of potential contextual factors, and that it anticipates the next step in a sequence of task-oriented steps based upon the interpretations of the multimodal inputs from the users. We use a shared plan (Grosz and Kraus, 1996) and tractable context dependent schemes for dynamic update of the knowledge about the users.

According to linguistic studies of human-to-human interaction, task-oriented dialogues often form natural groups of utterances, called *subdialogues* or *discourse segments*. The intention or purpose each dialogue segments provides information about what activity segments the users are focusing on. This activity level knowledge is the basis for the *response planning* module to decide GIS functions needed to process the current request. For more details on the principle of discourse modeling in GCCM_Connect, see (Cai et al., 2005).

V. DISCUSSION AND CONCLUSION

Most spatial decisions using geographic information were made by teams, but existing geospatial information technologies in general, and distributed GIS in particular, have been designed for use by individuals. This paper broadened the agenda of distributed GIS research by adding geo-collaboration as a new dimension of system design requirement. In this paper, we explained the nature of group work with geographic information using geo-collaborative crisis management as an application context. We have laid out an ambitious goal of supporting geo-collaboration by extending distributed GIS with collaborative functionalities. The focus is on the articulation of a system architecture that integrates ideas of web service-based distributed computing paradigm, common GIS web service standards, and activity-centered system design.

This new application and architecture of distributed GIS raise many important theoretical and technical issues that are not yet fully addressed here. Supporting human-human collaborations requires interoperability among potentially different and incompatible semantic processing systems. There are a large number of contextual factors (such as device characteristics, physical environments, team structure, and organizational norms) that are potentially relevant to the design of the system behavior. It is not clear how much of the spatial data semantics and operational contexts of geo-collaboration can be formalized. These problems are inherently more difficult since human collaboration is dynamic and situation-specific. Technical advances in distributed computing and GIS implementation methods must be coupled with theoretical breakthroughs in the science of geo-collaboration. Successful extensions of distributed GIS in supporting geo-collaboration will ultimately impact many frontiers of GIScience, such as Public Participation GIS and Group Spatial Decision-Making.

ACKNOWLEDGMENTS

This research is supported by a grant from NSF (NSF-EIA-0306845). The author acknowledges contributions from many other members of the team, mainly, Levent Bolelli, Hongmei Wang, Isaac Brewer, and Ingmar Rauschert.

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