Extending Distributed GIS to Support Geo-Collaborative Crisis Management

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Abstract

Crises are often complex, geographical scale problems that require professionals to work in teams while dealing with a large amount of geographical information for making decisions. However, current geospatial technologies do not directly support group work with geographical information - they impede rather than facilitate human-human collaboration 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 geocollaborative crisis management by teams. Members of such a team are often geographically distributed; playing different roles while communication and collaboration of distributed crisis management team. In addition to the architectural choice, special attention is given to the computational approach for enabling collaborative geographical 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 geographical information environment, called GCCM_Connect, is presented as a proof-of-concept for the proposed architecture.

Keywords: Geocollaboration, distributed GIS, groupware, crisis management

1. 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, 2003 (Muntz et al. 2003)

Geographical information is increasingly used to address complex social and environmental problems such as managing crisis, creating new environmental policies, or planning of 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. In the meantime, dealing with complex geographical-scale problems also require compilation of a large number of spatial data sources for integrated analysis and visualization. Recent developments in distributed computing, geographical information science, and computer-supported-cooperative-work (CSCW) suggest that maps and geographical information systems (GIS) are likely to take on a new role of facilitating human-human collaboration and communication (MacEachren 2000). Despite such potential use of geographical information, current geographical information technologies are mostly design for use by individuals. When it comes to working in groups with geographical information, people 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 they were each the only user (Churcher and Churcher 1999). For collaborative work, it is important for participants to be able to browse, annotate, and query, visualize geographical data with full awareness of each other and collaboratively act on their common goals.

The central theme of this paper is on computer support for group work with geographical information, commonly known as *geocollaboration*. Geocollaboration 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 available. Barriers on supporting geocollaboration are two-folds. First, we know very little about how teams work with geographical information through GIS and other related technologies. Second, there has been lack of technological advances in achieving feasible solutions to computer mediated geocollaboration. To deal with the former, research efforts must be directed towards understanding the role of maps in different application domains where geocollaboration is the norm. In addressing the later (technology) barrier, future development of geographical information technologies must explicitly model collaborative activities, distributed users, and semantics of geographical data sources.

Towards the goal of supporting geocollaboration, this paper advances the research agenda of distributed GIS in two aspects: (1) *identify necessary extensions of distributed GIS that match the need of IT support to geocollaboration*; and (2) *propose an architecture and a framework to develop distributed GIS for distributed collaborative application*s. Although distributed GIS has the great potential as a technology core of map-mediated group work with geographical information, it has traditionally been viewed as a technology about sharing geographical data and GIS processing power across organizations and users. This paper is the first to propose geocollaboration 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 geocolaborative applications that is feasible and flexible in a web-service-based open network environment. We initially place our discussion in the context of geocollaborative crisis management, and focus on map-mediated real-time collaboration among geographically distributed team.

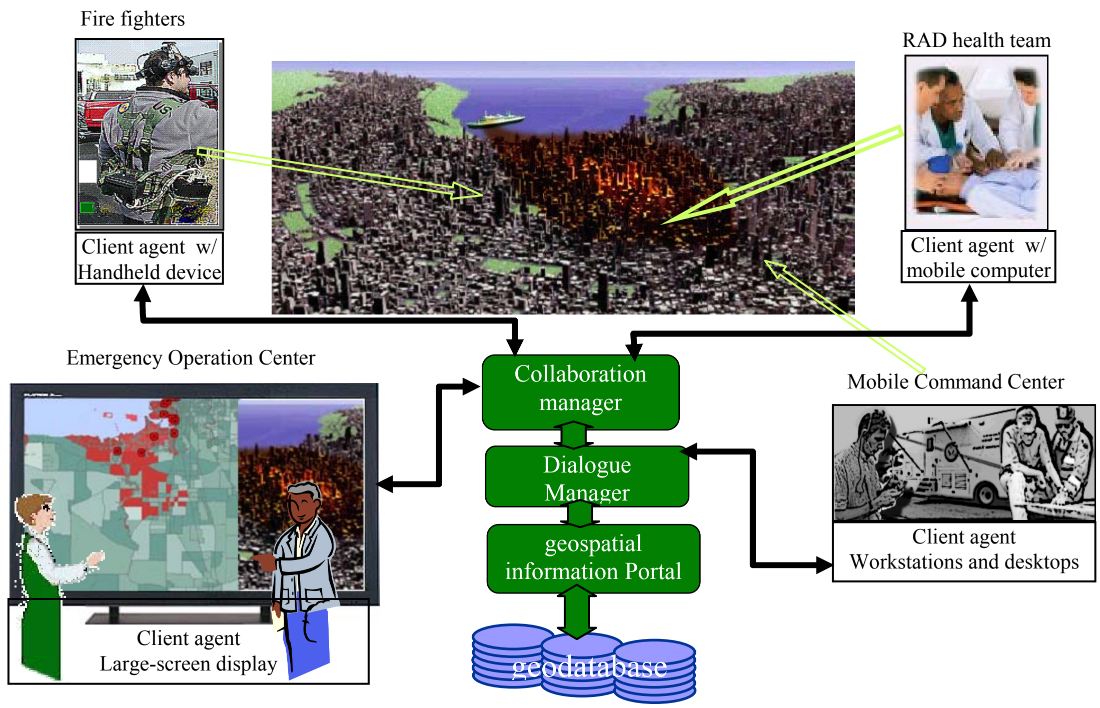
2. Motivating Example: GeoCollaborative Crisis Management

This work is motivated by the need to support geocollaborative activities in 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 impact to human society, economy and natural environment. Crisis management (involving immediate response, recovery, mitigation, and preparedness) relies upon geospatial information to depict geographical distribution of events, its 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 events and subsequent recovery efforts. The potential roles of Geographical Information Systems (GIS) in providing information to crisis managers have been detailed repeatedly (Mondschein 1994, Kumar et al. 1999), but recent field studies (Zerger 2002, Zerger and Smith 2003) showed that GIS is rarely utilized in real-time crisis response. The reasons for 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 the collaborative nature of crisis management activities that is not supported by traditional GIS.

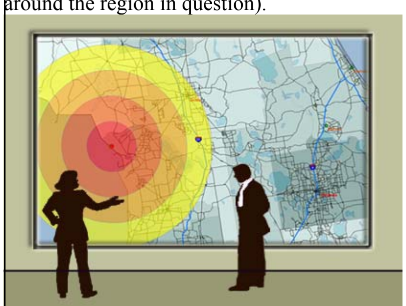
Crisis management requires multiple individuals and organizations sharing information, expertise, and resources in support of rapid situation assessment and decision-making. For example, the response effort for the 9.11 attacks involved hundreds of federal, state, local, and private groups with separate knowledge, jurisdiction, and 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 through communication of the situation and coordination of actions. Making spatial decisions on resource allocation, dispatching, and medical treatments requires collecting and sharing geographical intelligence through collaborative efforts among multiple, distributed agencies and task groups. As a common representation of geographical knowledge, maps encourage efficient communication of knowledge, perceptions, judgment, and actions. In this sense, crisis management can be conceptualized as a type of geocollaborative activities.

We envision a multimodal, dialogue-enabled *GeoCollaborative Crisis Management* environment. It integrates two sets of linked technologies to meet these needs: large screen displays for face-to-face group work in Emergency Operation Centers (EOCs) and portable devices for use by mobile field personnel. In an EOC, large screen displays, coupled with natural, multimodal interfaces that support dialogue, allow the users to: (a) display and interact intuitively with geospatial and non-geospatial information – without in-depth GIS training; (b) see and discuss the situation, make decisions, make those decisions visible, and quickly revise decisions (no paper maps need to be printed out), (c) serve as a portal to remote sites and collaborators, and (d) store decision processes for later retrieval (training and performance review). Out in the field, teams of first responders (police, fire, medical) make on-site assessment of the situation, evacuate people, and respond to various events while they keep in touch through mobile phones or wearable computers. Besides dealing with the distribution and diversity of devices, another major research thrust of the work is to extend distributed geographical information systems so that they facilitate dialogues among humans in collaborative crisis management operations (where humans are both face-to-face and remote from each other) as well as dialogue 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 crisis.

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, work together to determine the impact area, order and carry out evacuations, and deploy RAD health teams to identify 'hot zones' in residential and agricultural areas. Based on available information, immediate decisions must be made about where and how to evacuate or quarantine residents, establishing decontamination checkpoints, deploying rescue and health teams, ordering in-place sheltering, 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 communicate with a range of devices and is capable of supporting knowledge work with geospatial information.

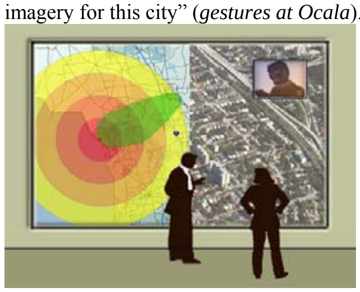


Jill: "We have a situation at Crystal River Nuclear plant. They're warning of a radioactive particulate release requiring evacuation."
Jim: "Show me the 10, 20, 30, and 40 mile EPZ zones around the plant (*gestures to location*)."
GC: (The system displays 4 buffered rings around the region in question).



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 ag 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

Crisis management imposed demanding requirements on information technology support in terms of data storage and 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 their effects are mostly geographically distributed and location dependent. Crises require 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 a fast developing situation.
- From the *information retrieval perspective*, there are three principle constraints on human use of geographical information in crisis response: *immediacy*, *relevancy* and *sharing* (Cai et al. 2005). The simultaneous presence of all the three demanding requirements (immediacy, relevancy, and sharing) in crisis response applications creates a unique system design problem.
- From a mission and activity perspective, the underlying technology must support team work with geographical 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 geographical 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 in the same time, impose challenges and new research questions that help moving distributed GIS beyond its current state.

3. 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 field of computer-supported cooperative work (CSCW). This section will review relevant literature and major advances in each and their integration.

3.1 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 for 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), and data clearinghouses (e.g., FGDC's data clearinghouse (clearinghouse3.fgdc.gov) and USGS National Map Seamless Data Distribution System (seamless.usgs.gov).

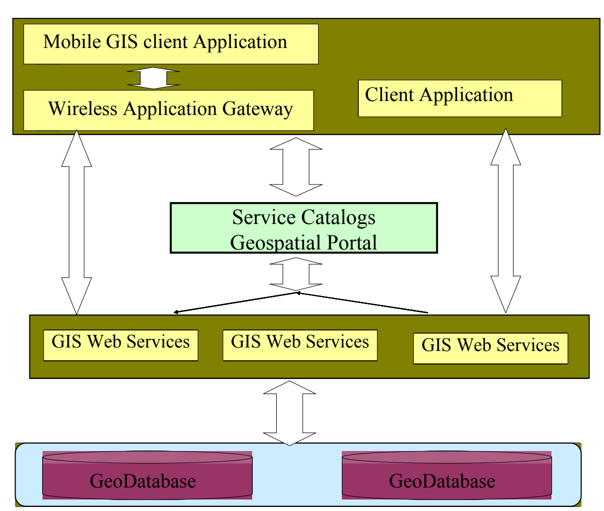


Figure 2 Service-oriented distributed GIS architecture

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 geographical 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. 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 distributed GIS depends on the purposes. For Web-based interactive mapping applications, a 3-tier client-server architecture is common. The first tier is called "the client tier" which is used by 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 for different hardware. 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 traditionally non-GIS users can select the set of functionality required without the need to implement 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. Geographical 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 application. The aggregation of GIS Web services can even be done in real-time if the 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 content and functionality. The geographic industry has published geographic web services standards, which layer on top of some of those generic standards. The Open GeoSpatial Consortium (OGC) envisions that geospatial data and geoprocessing resources will be fully integrated into mainstream computing and information infrastructure.

In order to facilitate this vision for 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 fully based on XML schema and provide a language for the modeling, transport and storage of geographic information including both the spatial and non-spatial properties of geographic features. It also allows description 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 achieve the ability to access, process, and display geospatial information in the field (Nusser et al. 2003, Casademont et al. 2004). Due to the limited computational power of mobile computers, it is impractical to run a full GIS system on the device. Instead, mobile GIS commonly take advantage of geographical 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).

3.2 Group Work with Geographical 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 ability to formally encode spatial phenomena and their interdependencies, are inherently well suited to facilitating collaboration among human participants in thinking and decision-making about the geographic-scale environment (MacEachren 2000). In spatial decision-making context, cartographic and GIS have been used by groups in two types of applications: (1) spatial decision making by experts (Group-SDSS) (Armstrong and 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 of 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 in supporting real-time geocollaboration for distributed crisis management team, we limit our interest to the role of GIS in same-time different place collaboration. Two most interesting systems in this category are *GroupArc* and *TouchanNavigate*.

GroupARC (Churcher and Churcher 1996, Churcher and Churcher 1999) is a lightweight geographical 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 (ArcINFO). GroupARC provide chat room functions and electronic whiteboard for viewing and discussions on geographical data. Participants' viewing areas are color-coded for awareness. Users can point at specific feature, annotate with free-hand sketch, manipulating scrolling bar, or perform simply queries, and the result 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.

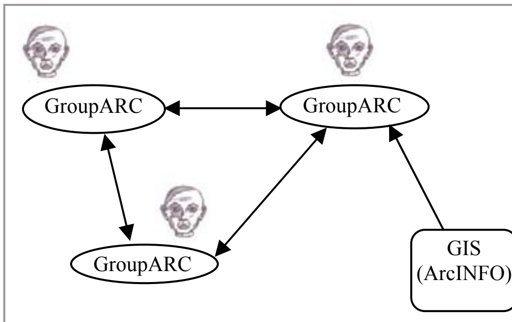


Figure 3. GroupARC architecture

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 an 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).

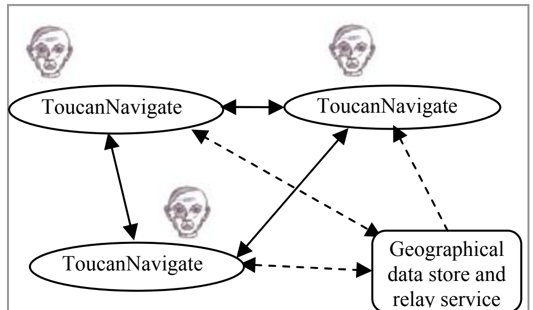


Figure 4. Toucan Navigate architecture

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 decisions were mainly due to the lack of technology solution to the necessary GIS functions to members of a collaborative session without having to run a version of GIS on each client. This architecture issue will be revisited under the current state of distributed GIS. In the next section, we will propose an alternative approach where distributed GIS is extended with collaborative functions.

4. Extending Distributed GIS for Collaborative Applications: an Architecture

In order to design a system that supports collaborative work with geographical information, it is necessary to integrate functions that were currently scattered in 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 groupware with necessary GIS functions.

They argued that the second approach is better, since it does not require a GIS for every participant in order for them to join collaborative sessions (but the first approach does). We argue here that the above two approaches are equally bad strategies for geocollaborative applications. The dependencies of geocollaborative software on either a groupware system or a GIS system would likely to create nightmare in terms of deployment, maintenance, and adaptation in the future. We believe that a geocollaborative application is likely to need a small subset of functions from GIS and groupware, but what this subset is depends on the kinds of collaborative activities. This view is inline with the *task-technology fit* theory (Zigurs and Buckland 1998) that 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, as does the context in which they perform these tasks (Greenberg 2001). As a result, the requirements for the technology to support co-operating 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 fully built using distributed computing framework based on web services and component technologies.

4.1 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 geocollabortion 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 6 is a high-level architectural specification of map-mediated geocollaboration.

Because most of these service models are still at proposal or development stage, our description of geocollaborative application model is necessarily a futuristic one. For this reason, we make the following assumptions:

(1) All the 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).

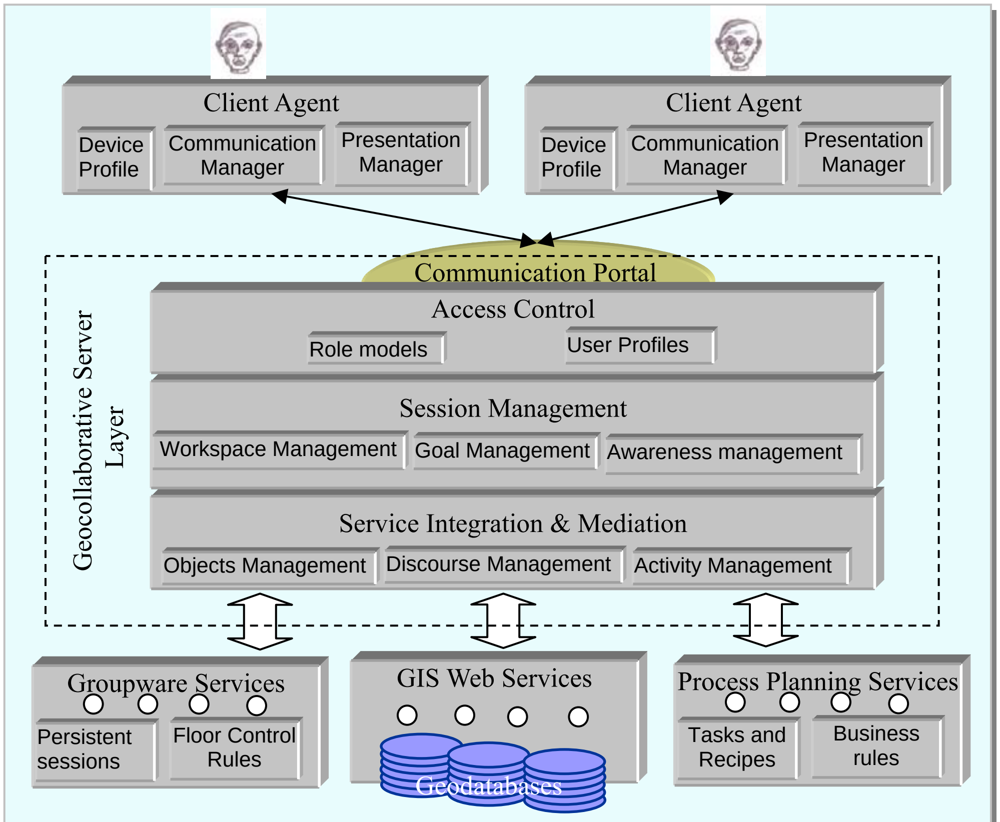


Figure 5 A distributed architecture of geocollaborative applications

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

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

- The *Service layer* (at the bottom) provides the functionalities required for same-time geocollaborative 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 *geocollaborative 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 of the current session. A session is a segment of individual or collaborative activity that accomplishes some subgoal 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 maintain its own state informa-

tion such as the change of participants, map contents, and goal status. A user may join or leave a session through explicit request and confirm, 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 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 input and communicating the request to the geocollaboration server. Selected device profile information (such as screen size, spatial and color resolutions) should accompany each request in order for the geocollaboration server to generate customized reply that fits 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 geocollaboration server which serves as the centralized message processing and relay center. This is different from that of 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 2.1). 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 geocollaborative 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. This is due to the explicit representation and reasoning on domain activity and the role of such knowledge in guiding human-machine-human collaborative behavior.

4.2 Implementing Geocollaboration Server as Web Services

Full implementation of geocollaborative 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 geocollaboration is still an open question. Next, we present *GCCM_connect* which is a proof-of-concept implementation a map-mediated geocollaborative environment and a partial implementation of the architecture in Figure 5.

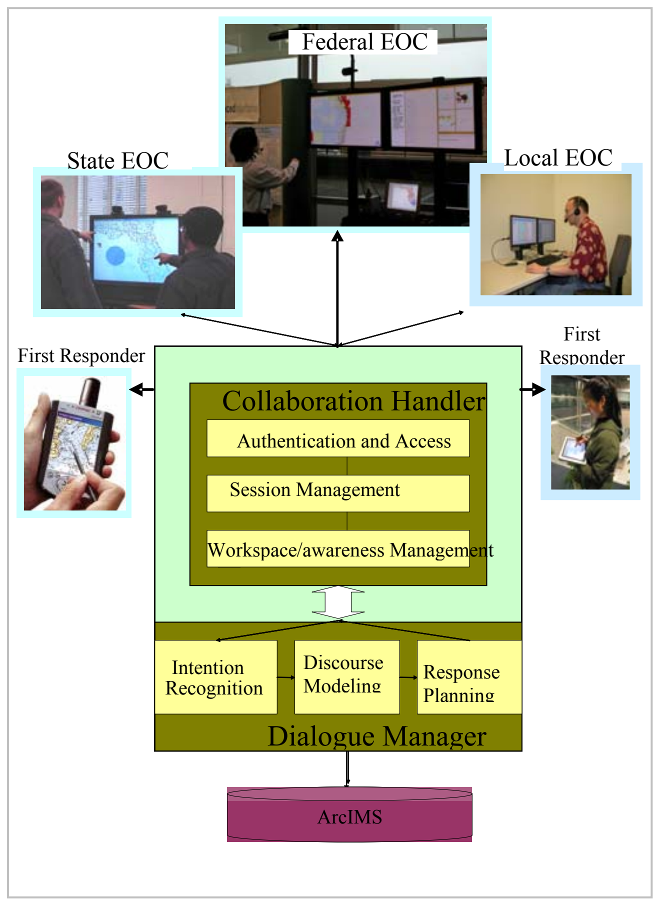


Figure 6 GCCM_connect Environment

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 aspects: (1) users interact with the system using natural spoken language and hand gestures, instead of using keyboard and mouse; (2) participants of a collaborative session can jointly manipulate their (shared) map workspace as a 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 DOT NET framework, and hence they only work on devices running a version of DOT NET. Functions on session management and awareness support were developed in-house instead of using groupware Web service. ESRI's ArcIMS serves the role of GIS Web services. GIS data 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 interpretation of the multimodal input from the user. We use a shared plan (Grosz and Kraus 1996) and tractable context dependent schemes for dynamic update of the knowledge about the user.
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 provide 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).

5. Discussion and Conclusion

Most spatial decisions using geographical information are done 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 geocollaboration as a new dimension of system design requirements. In this paper, we explained the nature of group work with geographic information using geocollaborative crisis management as an application context. We have laid out an ambitious goal of supporting geocollaboration by extending distributed GIS with collaborative functionalities. The focus is on the articulation of a system architecture that integrate ideas Web service-based distributed computing paradigm, common GIS Web service standards, and activity-centered system design.

This new application and architecture of distributed GIS raises many important theoretical and technical issues that are not 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 environment, team structure, and organizational norms) that are potential relevant to the design of the system behavior. It is not clear how much of spatial data semantics and operational contexts of geocollaboration can be formalized. These problems are inherently harder since human collaboration is dynamic, situation-specific. Technical advances in distributed computing and GIS implementation methods must be coupled with theoretical breakthrough in the science of geocollaboration. Successful extensions of distributed GIS in supporting geocollaboration will ultimately impact many frontiers of GIScience such as Public Participation GIS and Group Spatial Decision-Making.

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