Cartography and GIS: Extending collaborative tools to support virtual teams

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Geographic research, decision-making, and education are, more than ever before, group activities. The methods and tools of cartography and Geographic Information Systems (GISystems), however, have been developed for use by individuals. As noted in my report last year, this individual focus is starting to change – but slowly. That report introduced a space-time typology borrowed from the literature of computer supported cooperative work (CSCW). The typology relies on spatial and temporal distinctions to characterize the context of collaboration as being same or different place and same or different time. Last year I focused on same place geospatial collaboration (geocollaboration) at both same and different times. Here, I pick up where that report left off, considering research to delineate the potential and challenges of different place geocollaboration. The challenges include technical hurdles associated with implementing visual geospatial data analysis methods in a distributed setting, development of representation and interaction concepts and their implementation that can facilitate distributed group work, and understanding the cognitive and social issues involved in mediating that work through visual interfaces.

Research on different place collaboration, in geography as elsewhere, builds on a relatively large body of literature that has addressed same place (face-to-face) group work and computer tools to facilitate it. For a review of the same place group work literature in geography and pointers to a wider literature, see (MacEachren in press-a). Different place group work adds, to the other requirements of group work, the need for a mechanism to share data and ideas at a distance. Asynchronous different place work has occurred for centuries (e.g., through use of postal and messenger services to exchange information and perspectives). Synchronous different place work has been possible since the advent of the telegraph and telephone. The primary difference today, and the reason that different place geographic work is likely to be a major R&D focus over the next decade, is that much more than verbal information can now be exchanged at a distance, instantly. The ability to exchange geospatial data, maps, and imagery (as well as voice, text, and video) is essential to making same time/different place geocollaboration possible.

It should not be surprising that much of the attention directed to different place geocollaboration thus far has been given to the technological issues of simply making it possible for groups to work with geospatial information at a distance. These technological issues are covered in section one below. As systems are starting to be implemented, however, there is an increasing need to consider the human aspects of different place geocollaboration. Although there have been relatively few attempts by geographers to address these later issues, there is relevant research in other disciplines that considers the human aspects of interacting at a distance about real (geographic scale) places or within virtual places. These perspectives are considered in section two. This essay concludes with a discussion of preliminary efforts to develop an integrated human-centered system framework for subsequent research, and a few ideas about directions that research might take.

1. Building environments to support geocollaboration at a distance

A starting point for supporting different place geocollaboration is provided by development of web-based mapping and GIS tools together with technologies for geospatial information retrieval from distributed databases. These developments were reviewed in my 1998 report (MacEachren 1998). The progress on asynchronous geocollaboration detailed below follows directly from that work and emphasizes sharing of geospatial information and perspectives on that information. Synchronous geocollaboration (addressed in section 1.2), while relying on some of the same technologies to disseminate and access information, adds attention to ways in which behaviors can be combined into coherent actions and activities.

1.1. Asynchronous collaborative activities

Most of the work on environments to support asynchronous geocollaboration has occurred within the context of public participation GIS (PPGIS). Here, attention has been directed, particularly, toward developing web-based tools that facilitate public participation in geographic decision making. This work has considered a range of issues that include what data to serve to the public (Braun and Guertin 1997), metadata and interface issues for serving these data and maps through the web (Gibb and Medyckyj-Scott 1996), how to visually represent the data and planning scenarios to users (Sarjakoski 1997), and how to support distributed information access and public involvement in decision making (Carver, Kingston, and Turton 1998).

In relation to data requirements, Braun and Guertin (1997) present results of a study that examined spatial information needs of neighborhood groups, from which they developed a list of the data themes that are most important to include in a PPGIS. Their focus was on the needs of neighborhood home owners associations. In this context, they identify four items of location information to include in a base-level system (fire district boundaries, flood plain boundaries, location of auto accidents, and location of crimes) and five attributes of land parcels (land use, zoning designation, whether owner occupied, whether owned by a neighborhood resident, and assessed value). Making data accessible to a community of users with diverse backgrounds requires attention to the way in which elements in the database are described (to the system and to users). Gibb and Medyckyj-Scott (1996) suggest that (in addition to the standard data dictionary containing formal database object definition), two further levels of metadata are needed. First is metadata that helps determine fitness for use (e.g., quality, ownership, geographic extent). Second is “actionable metadata” – information that can be acted upon by software (e.g., that supports creation of predefined map types).

The Centre for Computational Geography at the University of Leeds has been particularly active in developing web-based GIS to support public participation in decision-making. Their emphasis has been on decision-support systems that increase both public access to data and involvement in the decision-making process (Kingston et al. 1999). They contend that such systems require three essential elements: virtual spaces for interaction (with both group discussion spaces and private places for individual work), user-adaptive interfaces (that match knowledge and ability of a range of users), and mechanisms to access relevant information (as discussed above). In addition to articulating requirements for PPGIS designed to support decision making, an important contribution of the work by the Leeds group is a delineation of research issues. These include understanding: the role of social context, spatial scale, and locality in decision making; how spatial decisions are conceptualized and made; how individuals react and interact with on-line GIS; and how both institutions and the public envision public participation evolving (Carver, Kingston, and Turton 1998). To address these questions, this group has undertaken a program of prototype development and empirical assessment of those prototypes in real applications. One component of this work involved comparing public use of a virtual decision making environment (VDME - developed by the research team) to use of a physical model of the environment for which decisions were being made (Kingston et al. 1999). Overall, users liked the flexibility of the online system over the physical model-based environment, with younger participants more positive about the on-line system than older participants (Evans et al. 1999) (Kingston et al. 2000).

Research directed to same place PPGIS has included attention to the ways in which GIS can empower local communities by supporting the collection of locally generated data (e.g., about pollution sources or crime) not contained in government generated databases (see: (Elwood and Leitner 1998, Obermeyer 1998)). Al-Kodmany (2000) has implemented, and experimented with, an approach to web-based distributed collection of community input, using gridded web maps that allow users to attach annotations (to each grid cell) that supply information or record an opinion about a decision concerning that location. Systems such as this, that support distributed public input to a community GIS, have been slow to develop. Among the problems that must be overcome are issues of data validity and attribution (Evans et al. 1999).

Rinner (1997), in a series of papers that complement work on PPGIS, focuses less on public participation support and more on tools that facilitate the process of collaboration within computer-supported decision-making (CSDM), whether among specialists or the wider community. His approach integrates geospatial representations within a discussion forum environment (ZENO) that is used to structure argumentation processes. The approach emphasizes "geographical mediation," defined as moderated discussion in a spatial planning procedure. Rinner (1998) considers the "atoms" of a geo-referenced discussion to be: (1) arguments (contained in messages) and (2) geographical objects (e.g. houses, parcels, roads). His prototype system supports access to map locations to which arguments refer, attachment of a geographical reference to each new argument, access to discussion messages through map symbols that signify geographical objects, and insertion of new messages for a map object or region. Maps are seen as a central tool in this environment, serving as both information repositories and vehicles for communication. Three map types specific to geospatial CSDM are identified: annotation maps (enabling comments by users, as in Al-Kodmany's system), argumentation maps (that support negotiation and discussion by integrating information and arguments in a map-based display), and alternative maps (that depict possible outcomes, an idea also addressed by Armstrong and Densham (1995) in the context of same place geocollaboration). The concept of argumentation maps is the novel contribution of this work. Argumentation maps link geographic objects with argument objects, representing relations between geo-objects through arguments and between arguments through geo-objects (e.g., arguments might be judged to be related because they reference adjacent geo-objects). For more detail on argumentation maps, see: (Rinner 1999a, Rinner 1999b).

1.2. Synchronous collaborative activities

Development of environments for synchronous different place geocollaboration can be subdivided into two categories (having potential for overlap): geospatial group decision support and support for science. While the research on PPGIS and other asynchronous geocollaboration (discussed above) is dominated by geographers, that on synchronous geocollaboration is cross-disciplinary (with geographers in the minority).

1.1.1. Geospatial group decision support

Research dealing with different place GIS-based decision support tools complements that on asynchronous PPGIS environments. The conceptual issues of facilitating information access, negotiation, and decision-making are similar. What differs is the technological infrastructure needed to support these activities in real time for distributed participants and the nature of human-human interaction when mediated by technology (discussed in section 2).

Churcher and Churcher (1999, 1996) were among the first to implement a collaborative web-based GIS, linking groupware tools with components that serve (to the web) layers of spatial information generated by a commercial GIS (ArcInfo). The result resembles an electronic whiteboard (with map information painted onto the "board) on which multiple users can sketch as they discuss a planning decision. Research by Jones, et al., (1997) takes this idea several steps farther, extending a single-user GIS for distributed group use by integrating a user interface management system, knowledge-based techniques and agents to support group work. In addition to support for viewing and annotating of shared maps, their component-based system enables multiuser operations on the database and private use of the system to work out ideas before "going public" with those ideas. Also using a component-based approach, Kumar, et al (1999) have developed a collaborative environment that integrates digital library methods of information retrieval, simulation and feature extraction tools, and visualization capabilities in a GIS-based collaborative environment for supporting disaster relief operations in urban environments. Their environment is intended for both synchronous and asynchronous use. While all of these environments, purportedly, are designed for decision support, none includes tools to facilitate voting (on either the weights assigned to different criteria in the decision making process or on decision alternatives). A clear description of the issues that such voting entails and of a working distributed voting system (designed for non-geographic applications) is provided by Ferscha and colleagues (1999).

1.1.2. Supporting collaborative science work

Limited attention has been directed by geographers to different place synchronous group work to facilitate science. Different place science work with geospatial data has, however, been considered by others in the form of both collaborative visualization and distributed "collaboratories. "

One of the first collaborative visualization environments designed to support analysis of geospatial data was the Real-Time Environmental Information Network and Analysis System (REINAS) (Long et al. 1995, Pang and Fernandez 1995). This prototype system collected data from distributed in-situ instruments, stored information in a federated database, and supported collaborative visualization of oceanographic and meteorological information. Visualization capabilities were organized into three modes: monitor, forecast, and analyze. Collaboration facilities included a session manager, mechanism to share data and data display tools, "floor" control (to manage control among multiple participants), local and public windows, audio/video support, and different collaboration/compression levels. Related research by Wood and colleagues (Wood, Brodlie, and Wright 1996, Wood, Wright, and Brodlie 1997) provides a conceptual framework for developing a system architecture to extend the single-user dataflow model of visualization toolkits to support multiple users. Similarly, the single-user dataflow-based environment Vis5D (Hibbard et al. 1996) has been extended for use in immersive virtual environments (Wheless et al. 1996) and, coupled with networking software, has been applied to same time different place collaborative geovisualization (MacEachren in press-b, MacEachren, Kraak, and Verbree 1999). In complementary work, emphasizing a component-based architecture, Bajaj and Cutchin (1999) propose a data, simulation, analysis, and display loop that displays communication flow among modules of a visualization environment designed for study of a groundwater simulation model.

Collaborative scientific visualization can be thought of as one component of the broader concept of distributed scientific collaboratories. The term *collaboratory* is attributed to William Wulf (Kouzes, Myers, and Wulf 1996). It was defined in an U.S. National Science Foundation report he was involved with as "a center without walls, in which the nation's researchers can perform their research without regard to geographic location – interacting with colleagues, accessing instrumentation, sharing data and computational resources, and accessing information in digital libraries" (Cerf 1993). In discussing collaboratories that support experiment-oriented scientific work, Schur, et al., (Schur et al. 1998) identify four collaboration “types” that seem to be generically relevant: peer-to-peer (within discipline), mentor-to-student, interdisciplinary, and producer-consumer.

Several of the efforts to develop scientific collaboratories have dealt with geospatial data (Forseman et al. 1996, Olson et al. 1998, Plale et al. 1998). In the Upper Atmospheric Research Collaboratory (UARC) project, a multi-year interdisciplinary effort, tools have been developed that integrate the “chat room” concept borrowed from the MUD/MOO world (Multi User Domain/MultiUserDomain Object Oriented) environments with shared windows providing graphic/map-based depictions of observational data and model results. The environment, in month-long tests, has been used to support synchronous and asynchronous collaboration among up to 50 scientists (with individuals periodically checking in and an out of the environment). A related environment, developed for collaborative work with historical seismological data, while not called a collaboratory by its designers, is another good example of the kind of distributed laboratory envisioned by Wulf. The goal of this environment (that supports collaborative space-time queries, queries of seismic zones, and generation of seismic intensity maps) is to construct and transfer knowledge in real time during a seismic crisis (Padula and Rinaldi 1999).

2. Human aspects of collaboration at a distance

In addition to research focused on building environments to support collaborative work with geospatial information, attention is beginning to be directed to human aspects of collaboration at a distance. These include: support for multiple perspectives and negotiation among alternatives, representing participants (both human and agents) and facilitating their joint behavior in distributed work (and play), and usability of tools and environments.

2.1. Perspectives and negotiation

Individuals and groups adopt perspectives on a problem domain and those perspectives evolve with new information and further experience within the domain. When individuals or groups of individuals work together, it becomes necessary to share these perspectives, perhaps adopting (if only temporarily) the perspective of others, or negotiating a new joint conceptualization of a problem domain (Boland and Tenkasi 1995). For computer environments to facilitate group work, they must support creation and alteration of individual perspectives as well as negotiation procedures that enable subsequent creation of shared perspectives. For a review of research on both perspective and negotiation within the context of CSCW, and a discussion of how these research themes might be integrated, see: (Stahl and Herrmann 1999).

One promising conceptual approach to the issue of multiple perspectives and negotiation among them is provided by the theory of “boundary objects” (see: (Demeritt 1996, Fujimura 1992, Star 1989, Star and Griesemer 1989)). Boundary objects are any “object” (including concepts) that is included in the different perspectives of two individuals or groups. This concept provides a theoretical structure for understanding how representations (e.g., maps, equations, words, graphs, images) can serve as mediators between one perspective and another. Harvey and Chrisman (1998) contend that “social-constructive theories and the concept of boundary objects open new ways to understand the relationships between technology and people.” They describe how the term “wetlands” acts as a boundary object for discussions among citizens, politicians, and government agencies in discussions about environmental issues. The term connects these diverse groups through shared use (and partially shared meaning) but also separates them because each defines the term somewhat differently (something that they might not realize immediately). Harvey (1997) uses the concept of boundary objects as part of a framework for participatory GIS design applied effectively to a problem in which two state agencies in a Swiss Canton, cooperating on management of water resources, worked to merge separate GIS datasets for rivers and streams.

2.2. Representing participants and facilitating joint behavior

To facilitate (rather than impede) collaboration, CSCW tools need to represent, not only the information being used, but also the participants in the collaboration and their behaviors (MacEachren in press-b, MacEachren et al. 2000). This is particularly true for same time collaboration; whether same or different place tools for facilitating joint behaviors are used.

Representation of participants and their actions in collaborative environments has, not surprisingly, been a focus of attention in research to develop collaborative virtual environment (CVE) technology. While geographers have not yet been very active in this research, the work does incorporate geographic issues in several ways. Greenhalgh and Benford (1999, 1995), for example, have proposed and implemented a spatial model of interaction to manage awareness and communication in CVEs. Their approach applies spatial partitioning to CVEs. Individuals are able to interact with each other when in the same virtual space locale (room, zone, region) but not when in different locales. Within these locales, devices enable the manipulation of awareness (e.g., attenuating or amplifying awareness of individuals to each other). In addition to using spatial metaphors to construct collaborative spaces, CVEs often focus on collaboration about places. One interesting example designed to support learning by groups of children is the Narrative-based, Immersive, Constructionist/Collaborative Environment (NICE) (Roussos et al. 1999). NICE allows children to plant and tend a virtual garden and simultaneously generate a narrative (a picture book story) about this process. See below for discussion of its usability.

The approaches developed and experiences reported with implementation and use of these and other CVEs provide a base for research to address the unique issues of representing participants and their behaviors (and facilitating joint behavior) in geocollaborative virtual environments (GCVEs). One promising approach to facilitating joint behavior (and group work) in GCVEs is to link human actors with computational agents, taking advantage of what each does well. An agent is any entity “living” in the environment that is able to modify both the environment and itself. Agents can “perceive” and represent their environment, communicate with other agents (and perhaps with human actors) and exhibit autonomous behavior based on its knowledge, perceptions, and interactions. Ferrand (1996) proposes a multi-agent approach to dealing with the perspective-negotiation issues within a geospatial problem context. In the environment he proposes, each human actor will have a “cognitive agent” who acts as an assistant and mediator among other actors through their agents (see (Noll et al. 1999) for related non-geographic work on “guide” agents in CVEs). Ferrand’s cognitive agents have four components: (1) interface – enabling access to spatial information, presents maps that depict different proposals and the spatial reference of different arguments; (2) reasoning – supporting tasks such as checking validity of constraints or assessing topological relations of objects and arguments; (3) knowledge base – with three subparts (representation of the “world,” representation of the actors and their perspectives, and mediating rules and laws which dictate an appropriate process of negotiation and possible outcomes); and (4) communication – handling exchange of information.

Tools that apply computational methods for facilitating joint work, of course, do not require agent technologies. In the context of intelligence analysis for battlefield management by military units, Jones, et al., (1998) developed an “intelligent” collaborative multimedia system for intelligence collection and management (CoRAVEN). CoRAVEN is a proof-of-concept environment through which analysts are able to view spatial data (maps), temporal data (a synchronization matrix representing the schedule for intelligence collection) and graph-based models for fusing evidence (Bayesian networks). The environment uses Bayesian networks to structure the relationship of evidence to intelligence requirements and provides a collaborative audio-visual environment for the visualization and sonification of the networks, their evidential sources, and their relationship to the geographic and temporal structure of the situation.

2.3. Usability of tools and environments

A third human aspect of collaboration at a distance, taken up by a number of authors, is the usability of tools and environments being designed and implemented. In the context of geocollaboration, Jankowski and Stasik (1997) discuss the need for usability studies and the design of a prototype intended to support such studies in the context of space and time distributed collaborative spatial decision making. Five design criteria were proposed, against which usability would be judged. The first of these specified six particular functions that the system should support (explore information, generate solution alternatives, share and discuss solution ideas, evaluate alternatives, negotiate, and vote). The remaining four criteria address flexibility that the system should have (allow users to select tools in any order, allow equally easy access to analytical and visual tools, support facilitated and non-facilitated problem solving, and support private and public work). While these criteria can be a useful guide for other usability research, Jankowski and Stasik have not yet published results from the planned usability assessment of their prototype.

A usability assessment has been conducted of the collaborative experimental research environment (CORE, one of the collaboratories discussed above). For this assessment, Schur and colleagues (1998) applied a range of methods, including: follow-up interviews with individuals who used CORE over a period of time, demonstrations followed by discussion (focus groups), and direct observation of groups using CORE with scenario walk-throughs and unscripted work. Results are detailed for two groups (experimental researchers using an NMR spectrometer to study protein structure and intelligence analysts working in the area of nonproliferation of nuclear materials). Five findings are detailed, that: social dialogue is critical for collaboration, both scientific and intelligence analysis work is performed in a framework, system design must consider the context of social interaction, culture and trust play significant roles in acceptance and success of collaborative technologies, and timeliness of information is critical to productivity.

Much of the research published to date dealing with usability of tools and environments for different place collaboration has focused on virtual environments. While several studies have addressed group behavior in geographic scale environments or geographic problem solving, the individuals and teams doing the research are from a range of disciplines that include computer and information science, urban planning, and psychology. Tromp, et al., (1998) provide a useful methodological framework for usability studies in collaborative virtual environments and apply the framework to study of group behavior (considering issues such as the relationship between emergent leadership and computational resources and the sense of presence and copresence among participants). One example of usability assessment for a GCVE environment is provided by Brkljac and Councell (1999). They detail a web-based collaborative environment that integrates GIS with virtual reality modeling language derived urban models to support group work, both by professionals on common tasks such as historic preservation and by members of the public participating in decision making. Their approach to usability assessment is an informal one, consisting of reflections on the experience they have had in building, implementing, and observing use of their environment.

More formal usability assessment has been conducted in a pair of studies that address the potential of immersive CVEs to facilitate learning, by children, about the natural (real) environment. In a first experiment with NICE, pairs of children collaborated remotely to plan, plant, and tend a virtual garden (Roussos et al. 1999). Results of this experiment demonstrated that it was possible to generate a strong sense of presence and to create a highly successful distributed virtual social space within which children could comfortably interact. In addition, however, the research team found that features that made the environment compelling to children and spurred social interaction (e.g., plants wearing sunglasses and avatars representing remote users) interfered with science learning objectives. In a subsequent study, there was an effort to focus the research more explicitly on testing the impact of an immersive CVE for a specific learning objective. In this case, the objective was for children between the ages of 6 and 10 to learn that the earth is not flat (Johnson et al. 1999). To address this learning goal systematically, the research team created a collaborative immersive experience for children that focused narrowly on the learning objectives, addressed theoretical questions about learning specifically, and avoided extraneous components in the CVE that could be misleading or distracting to the children. Results were somewhat mixed, but did demonstrate a positive impact of the learning experience, particularly for students who performed at below average levels on a pretest. While the experiment does provide some insights on issues that research should focus on (related to collaborative different place immersive CVE that support learning), lack of comparison to a same place collaborative learning situation using non-immersive tools means that there is no way to determine whether the expense of technology used is justified.

3. Integration and Conclusions

Much of the research dealing with different place geocollaboration (and that in other disciplines that we might draw upon) has been *ad hoc*. The goal of the research has been, typically, to build a system that supports a particular application and (perhaps) to assess usability of the system to enable system refinement. Making real progress in geocollaboration will require a more systematic approach to the suite of technological and human issues involved. To develop such an approach, we can look to the extensive literature on group work for ideas toward a conceptual framework that supports designing, implementing, and understanding the use of geocollaborative environments. For proposed typologies and models of group work, see: (DeSanctis and Gaullupe 1987, McGrath 1984, Nunamaker et al. 1991) and for recent work to categorize acts of collaborative work in an electronic meeting context (building on McGrath and others), see: (Horrocks, Rahmati, and Robbins-Jones 1999).

In the context of geocollaboration, Isaac Brewer and I (MacEachren and Brewer submitted) have proposed a comprehensive conceptual framework for research on collaborative geographic visualization environments. This framework has six components, each summarized below, briefly:

1. problem context – a distinction among four contexts: decision support, design, knowledge construction and refinement, and training-education;
2. collaboration tasks – four pairs related to group decision making and scientific work, respectively: generate-explore, negotiate-analyze, choose-synthesize, execute-present;
3. commonality of perspective – two continua related to group decision making and science: conflict to cooperation and different paradigm to same paradigm;
4. spatial and temporal context – same time same place, same time different place, different time same place, different time different place;
5. interaction characteristics – three components of interaction: typology of connections among actors, size and aggregation of the group(s), and constraints on information transfer among actors;
6. environment as mediator – many issues with how to represent both: the information forming the basis of collaboration and the participants in collaboration and their behaviors.

We believe that this conceptual framework (with possible extensions and adaptations) will be useful in highlighting open research questions as well as comparing and integrating research results.

Geocollaboration is a relatively new but important area of research for geography and related disciplines. The dramatic changes in technology that are making wireless, mobile communication and data dissemination possible will have a dramatic impact on how and where work is done and how individuals and groups collaborate. In addition to the geospatial technology issues that must be addressed, and the range of human factors issues to be considered, geocollaborative technologies are likely to have profound impacts on society. Thus, social, political, economic and other geographers, who are well equipped to address these impacts, will play as big a role in development of geocollaboration as will those focusing on the underlying GIScience problems.

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