Cartography, GIS, and the World Wide Web

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For this, my initial cartography and GIS report, I have selected a theme external to, but with implications for, both – the World Wide Web (WWW, or simply "the web"). According to its primary architect, the WWW "was developed to be a pool of human knowledge, which would allow collaborators in remote sites to share their ideas and all aspects of a common project" (Berners-Lee, et al., 1994, p. 76). Conceived in 1989, as an extension of the Internet, five years later the web was responsible for only 3% of Internet traffic. Between spring 1994 and spring 1995, however, the web jumped to first place in web traffic and continues to retain that position. As both a technology and a cultural phenomenon, this new vehicle for information exchange has implications for all facets of science and society, and has attracted attention in many disciplines (see, for example, Berners-Lee, et al., 1994; Batty and Barr, 1994; Pitkow, et al., 1995; Nielsen, 1995; Doheny-Farina, 1996; Gunkel and Gunkel, 1997; Computing Research Association, 1997).

Web-based cartography and GIS is at an early stage of development. Even so, the nature of maps and of spatial information access is undergoing profound change. Taylor (1997, p. 2) contends that "the half life of knowledge in the field is probably down to a matter of months." Web sites featuring mapping and GIS are added daily – and the sites are being used (some generating hundreds of maps per day). I could fill the space intended for this essay with a list of web addresses (URLs) to sites "serving" maps and spatial data [for two such lists, see Chang, 1997; MacLennan, 1997].

The web allows information "objects" of many forms (maps, images, sounds, text, etc.) to be linked to any number of other information objects. A global database of information is evolving in which every information object is related to all other objects. As a consequence, the web has the potential to facilitate change in cartography and GIS through at least three fundamental mechanisms: (1) by dramatically increasing the applications of mapping and GIS – through greater access to tools and data, (2) through integration of mapping, GIS, and non-spatial information technologies (and associated spatial and non-spatial data) to create new forms of representation and new ways to address problems important to society, and (3) by creating new virtual “worlds” to be mapped, analyzed, and manipulated (and, like the physical world, exploited).

Research dealing with cartography, GIS, and the WWW can be divided into five main categories: (1) developing and extending theoretical perspectives on geographic representation within the complex interlinked environment provided by the web, (2) developing a theoretical approach to spatial information access within that same environment, (3) implementing representation and information access concepts and associated tools, (4) assessing web products and understanding users of those products, and (5) understanding ways in which the web facilitates use of maps and spatial information and the implications of that use. The first four themes are highlighted below. Theme five is part of a broad research agenda focusing on the role of cartography and GIS in science and society and will be addressed as part of my report next year.

I. Geographic representation in a web environment

The web is an object-oriented environment that supports access to a wide range of (potentially) dynamic, linked object forms that depict georeferenced information (including raster images, vector maps, tabular data, text, and even sound). Research addressing geographic representation within a web environment has considered visual, digital, and cognitive aspects of that representation (see Wilbanks, et al., 1997 for a more complete discussion of spatial representation as a fundamental dimension of geographic research). Representation research dealing with the web environment has directed particular attention to dynamic symbolization, 3D representation with VRML (Virtual Reality Modeling Language), spatial referencing of information, and database representation in a distributed environment. Each is considered below.

Dynamic symbolization

The potential for dynamic representations offered by the web has prompted and facilitated research on map animation (see, for example: Fauerbach, et al., 1996; Peterson, 1997; and a special issue of *Computers & Geosciences* containing several papers using or directed to animation, MacEachren and Kraak, 1997). While map animation is nothing new (see Thrower, 1959 for an early example and Campbell and Egbert, 1989 for a review), the web overcomes distribution challenges that have always impeded map animation efforts. The web also facilitates design of manipulable animations in which users can control, not only direction and pace of the animation, but also parameters of the referent to sign-vehicle mapping.

User manipulation of map parameters can be combined with animation in productive ways. Dykes (1997) builds upon previous research in dynamic cartography (Monmonier, 1989; Egbert and Slocum, 1992, Shepherd, 1995), exploratory spatial data analysis (Haslett, Wills, and Unwin, 1990; MacDougall, 1992), visualization in scientific computing (McCormick, et al., 1987) and geographic visualization (DiBiase, et al., 1994 and MacEachren, 1994) to conceptualize and implement an environment in which "smart" symbols permit user-driven examination of information from multiple perspectives. He implements his ideas using manipulable maps generated in web-compatible form using Tcl/Tk (a non-commercial graphical scripting language). The interactive tools developed are then applied to visualization of various spatial analysis methods (e.g., spatial autocorrelation).

Virtual worlds

VRML is a device independent scene description language that supports representation of 3D environments (VRML, 1996). As with web-based animation, VRML facilitates developments in 3D geographic representation that extend previous cartographic and GIS research. VRML is conceptually different from previous 3D software environments in two key ways. First, any object in a VRML world can be hyperlinked to any other object(s) – not simply to objects within the VRML world, but to objects anywhere in the WWW (***cite siggraph tutorial***). A VRML world can, thus, serve as a 3D interface to the web (opening new spatialization of information possibilities -- see below). Second, each VRML object can determine the "level of detail" with which to display itself, on the basis of the observers relative virtual position. To be useful for geographic applications, this feature will require advances in cartographic generalization methods before the selection of display detail for geographic objects can be automated (Fairbairn and Parsley, 1997).

Important research issues related to VRML, that are just beginning to be considered, relate to the limitations of the current VRML specification for supporting geographic registration of data layers and geographic operations on those data (Moore and Dykes, 1997). A collaboration between the International Cartographic Association, Commission on Visualization and the Association of Computing Machinery, Special Interest Group on Graphics (ACM-SIGGRAPH) has begun to target these issues and is expected to propose extensions to the VRML specification and/or other approaches to linking VRML and GIS (MacEachren and Kraak, 1997; Rhyne, 1997 – for more details, see http://siggraph.org/~rhyne/carto/ and http://www.geog.psu.edu/ica/icavis/vis-acm.html).

Spatial referencing of information and information networks

Several authors have considered the potential of spatial metaphors as a way to represent relationships and links among objects in hyperdocuments generally and in the web specifically. This research ranges from a focus on hypermaps (in which geographic maps act as an organizing structure among objects in the system) to a focus on “spatialization” of non-spatial data. In the latter, a map-like display is used as a metaphor to represent proximity in some abstract attribute space.

Hypermaps introduce spatial referencing to all components in an object-based hyperdocument (Laurini and Milleret-Raffort, 1990). The concept of a hypermap precedes the advent of the web, with the Domesday Project, perhaps, the first implementation (Rhind, et al., 1988). The potential of hypermaps is dramatically increased when implemented in a web environment, as is the complexity of links and the user’s task of navigating among them. Kraak and van Driel (1997) provide an overview of hypermap concepts and discuss a web-based hypermap implementation in which users are provided with spatial, thematic, and temporal hypermap navigation possibilities.

In the context of digital libraries (discussed further below), the concept of “spatialization” has been applied to the representation of similarity among objects in the library’s information space (Skupin and Buttenfield, 1996, 1997; Fabrikant and Buttenfield, 1997). Skupin and Buttenfield (1997) define spatialization as “a projection of elements of a high-dimensional information space into a low-dimensional, potentially experiential, representational space.” Proximity of objects in the representation space signifies similarity of objects represented. Their approach derives from Lakoff’s (1987) “spatialization of form hypothesis.” This hypothesis suggests that image schemata are used metaphorically to structure most abstract concepts (see MacEachren, 1995 for discussion related to geographical representation).

Database representation

The representation issues presented above emphasize user interaction with web-based representations. Attention is also being directed to geographic database representation in distributed environments generally (see Buehler and McKee, 1996 and Zhang and Lin, 1996) and the web specifically. Li (1996) presents an overview of the database models available within which web-based distributed GIS can be developed.

II. Geographic information access in a web environment

As the interconnectedness of geoinformation increases and geoinformation technologies are progressively distributed, new methods are required to facilitate user access to both the technology and the information. Much of the theoretical research related to geographic information access in a web environment focuses on digital libraries. The Berkeley Digital Library Project, for example, emphasizes integration of GIS and digital library methods for document description and access. The approach taken, labeled Multi-Valent Document architecture, treats documents as multilayer entities (as in a GIS) to which access methods can be applied and through which links to contextual geographic information can be provided (Foster, 1996). In a complementary effort, developers of the Information System for Los Angeles focus on the use of spatial and temporal referencing as a means of organizing and integrating heterogeneous documents (Hunt and Ethington, 1996). The system goes beyond simple spatial and temporal indices by building spatio-temporal elements into the search and retrieval infrastructure of the system. Users can define the parameters of a search using historically appropriate spatial layers or even multiple spatial layers from different times.

The most comprehensive digital library research effort is that associated with the Alexandria Digital Library Project, funded by the U.S. National Science Foundation, National Aeronautics and Space Administration, and the Advanced Research Projects Agency (Buttenfield and Goodchild, 1996). In addition to research on spatialization as a way to represent relationships among objects in a digital database (see above), the Alexandria Project has addressed methods for delivering distributed geographically referenced information, including maps (Buttenfield, 1997) and images (Smith and Buttenfield, 1997), through a common geographical interface. Among the key issues considered in this effort are development of a metadata schema that will support general spatial queries and development of an approach to georeferencing photographs (so that they can be accessed by spatial as well as attribute queries) (Smith and Buttenfield, 1997). Buttenfield (1997 and in press) has identified a number of other research issues for distributed digital libraries that include: development of standards for universal object identifiers needed to support interoperability of distributed archives, understanding issues of size and scalability in digital libraries, development of standard web protocols for map browsing, methods for distributing what will be increasingly large information catalogs, and modeling of digital library users (see below).

As Schenkelaars and Egenhofer (1997) point out, the kind of interaction needed with a digital library will influence the kinds of access tools required and the metaphors that are appropriate to support those tools. They distinguish among spatial querying, spatial browsing, and exploratory spatial access and suggest a magnifier tool that users can move to locations for which they want more detailed information. In related research, Cartwright (1997) has proposed the concept of a

“GeoExploratorium” as a virtual space that allows users to explore geographic information using different metaphors. The metaphor set he introduces builds on the basic map metaphor (inherent in most GIS and digital atlases) and includes the Storyteller, the Navigator, the Guide, the Sage, the Data Store, the Fact Book, the GamePlayer, the Theatre, and the Toolbox. Each metaphor fills a particular role in facilitating access to and understanding of geographic information (e.g., the Guide leads users to relevant information and the Sage provides access to experts).

A particularly important component of digital spatial library efforts involves modeling the manner in which information seekers can interact with a collection. Fabrikant and Buttenfield (1997) propose a visual browsing query process schema for interaction that includes three stages: overview, zoom and filter, and details-on-demand. Their current implementation is restricted to “known-item-searches”, and thus does not adequately support exploratory querying. Johnson and Gluck (1997) address the issue of exploratory querying directly by first making a distinction between data retrieval (DR) and information retrieval (IR). The former uses a deterministic model to retrieve documents that meet specific query criteria. The latter, in contrast, is generally based on a probabilistic or approximate model that retrieves information relevant to the query. One method of implementing IR is through application of Wang’s (1994) “fuzzy query language” in which imprecise modifiers (e.g., almost near) can be used in queries.

Digital libraries on the web are not limited to document access. They can also integrate functionality that allows the user to work with the information immediately, rather than having to pass the information to some other software environment. Interactive Portugal is an ambitious digital library effort of this kind. The project is designed to allow users to retrieve orthophotos from a set covering the entire country at 1:40,000 and add information to develop local databases that can be connected to the main system (Fernandes, et al., 1997). A central component of this effort is the development and realization of the concepts of “sketching” and “dynamic sketching” (Nobre and

Câmara, 1995). Sketching is a web implementation of simple drawing and measurement tools that allow a user to perform operations such as outlining the bounds of a region and determining its area. Dynamic sketching goes beyond this to integrate simulation modeling with digital library methods. A typical application would allow a user to access an orthophoto of a coastal area and sketch in a location at which an oil spill happened along with some arrows indicating possible wind direction and ocean currents. This sketching becomes input to a simulation that models movement of the oil spill over time.

III. Implementing geoinformation technologies on the WWW

As with various technological changes in the past (e.g., advent of scribing, photography, mainframe computers, etc.), applied research is needed to explore the potential and limitations of specific software environments as well as to develop tools that take advantage of the distributed architecture of the web. Within the former, individual software environments are typically assessed through case studies involving the design and testing of prototype systems. Examples include Tcl/Tk (Dykes, 1997), VRML (Fairbairn and Parsley, 1997; Rhyne, 1996), and Java (Racin and Colbert, 1997; Lehto, 1997). Research has also addressed software integration to achieve geographic application goals. Examples here include the integration of Java with Active X (Engen, 1997) and VRML with Java (Moore and Dykes, 1997). In the latter research, Moore and Dykes develop a virtual 2D Java interface to a 3D VRML world that is based on a concept of a virtual compass and GPS. The implementation allows for a variety of spatial functions (e.g., viewshed analysis in which a combination of 2D Java images and 3D VRML worlds allow interactive query of points in the viewshed).

A complement to research on specific software environments is that directed to interaction between client and server machines in the distributed web environment. Wood, et al., (1996), extending from a basic visualization reference model that underlies much of modern scientific visualization, suggest four client-server models for using the web to facilitate visualization of environmental data. All four are represented in systems for geographic information access through the web:

(1) as a *data server* – where all display and analysis takes place on the client machine (geographic examples include: Trainer, 1997; Cobb and Olivero, 1997);

(2) as an *image server* – where the display is created on the server and is viewed on the client machine (geographic examples include: Beardsley and Quinn, 1996; Ostling, 1997; Garvey, 1997; Sarkola, 1997; van Liedekerke and Jones, 1997; Ashdowne and Cartwright, 1997);

(3) as a *3D model interaction environment* – where a VRML model is created on the server and can be explored on the client machine (geographic examples include: Rhyne, 1996; Fairbairn and Parsley, 1997; Henderson and McKague, 1997);

(4) as a *shared environment* for dynamic control of visualization – where the data manipulation is done on the server, but control of that manipulation is exercised by the user on the client machine,

where rendering and display is also done (geographic examples include: Cowen, 1996; Zhang and Lin, 1996; Fernandes, et. al., 1997; Racin and Colbert, 1997; Engen, 1997; Choo and Lee, 1997).

To account for the range of shared environments built thus far for geographic applications, the shared environment category must be expanded beyond that initially proposed for scientific visualization. Object-oriented approaches to system design have resulted in modularization of systems with distinct components for data storage, data access, analysis, visualization-display, interface controls of other operations, etc. For any implementation on the web, a decision about whether each component will reside on the server or client must be made (Zhuang, 1997).

IV. Assessing WWW Products and Understanding Users

The web is quickly becoming the spatial data delivery mechanism of choice (see Trainor, 1997; Garvey, 1997; and Masser, 1997). Provision of geographic data, maps, images, and analytical tools on the web has prompted applied research designed to understand users and their needs as well as to assess the potential of web products to meet these needs. Examples of the first include U.S. Census Bureau use of formal focus group methods to formulate a “customer typology” that specifies the kinds and levels of access required (Trainor, 1997) and survey-interview methods to assess the Pennsylvania Spatial Data Access System (Fauerbach, 1996). In an effort to evaluate published web maps more generally, Harrower, et al., (1997) employed semantic differential rating tasks to measure communication effectiveness of web maps and the potential connotations that various web map design choices might prompt.

In spite of a long tradition in cartography of perceptual-cognitive research directed to understanding how individuals read and use maps (see, for example, MacEachren, 1995 and Lloyd, 1997), only limited steps have been made toward extending this research to deal with interactive geoinformation environments (see MacEachren, 1995 and Egenhofer and Richards for theoretical perspectives and Rheingans, 1992; McGuinness, 1994; Monmonier and Gluck, 1994; Evans, 1997; Edsall, et al., 1997 for empirical studies of interactive mapping/GIS environments). This literature provides a base from which to develop theories and methods for understanding how human-representation interaction changes in a user-controlled geoinformation environment. Web environments, however, are different from those focused on in most of the research to date. Differences include a greater mix of information forms (i.e., images, maps, tables, etc.), access to more information of all forms, and the non-hierarchical nature of the hyperlinked environment.

If we are to take full advantage of the web as an information dissemination medium, a concerted effort is needed to develop and test theories that can explain human-representation interaction in user controllable hyperlinked geoinformation access and display environments. In the context of the Alexandria digital library project, Fabrikant-Buttenfield (1997) have taken steps in this direction. Building on the concepts of spatialization of text, discussed in Skupin and Buttenfield (1996), they develop an interface that integrates three spatial metaphors (dealing with concepts of distance, scale, and arrangement). For each, they propose testable research questions and a methodology for addressing each question.

V. Conclusions

Web-based cartography and GIS is evolving rapidly. In addition to theoretical and application issues discussed above, research dealing with cartography and GIS on the web presents complex publication challenges. As a result, we are beginning to see use of the web as a medium for formal publication. Examples include web supplements to articles in *Cartographic Perspectives* (http://maps.unomaha.ed/NACIS/cp26/article1.html), on-line publication of the ESRI User Conference *Proceedings* (http://www.esri.com/base/common/userconf/archive.html), and a special issue of *Computers and Geosciences* (on exploratory cartographic visualization), published simultaneously as a print, CD-ROM, and WWW document (www.elsevier.nl/locate/cgvis).

It is clear from the research highlighted above, that the web is prompting both applied research and new theoretical perspectives on geographic representation and geographic information access. Most of the research thus far has focused on extending cartographic and GIS theory to cope with a fundamentally different information processing and delivery environment and on the implementation and assessment of web-based tools and products. As methods for representing and assessing geographic information in the web environment mature, a plethora of research questions arise about how information is used, for what purposes, by whom, and to what effect -- questions about the changing role of cartography and GIS for science and society. These issues are beginning to be addressed (Lamm, et al., 1996; Krygier, 1997; Gunkel and Gunkel, 1997; Adams, in press) and will form a central theme of my report next year.

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