Organizational and Technological Interoperability for Geographic Information Infrastructures

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Outline

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1. INTRODUCTION

What will it take to share geographic information between real-world organizations? Despite progress in networking technology, database design, standards, and organizational wisdom over the last three decades, it's still rare for planners or public managers to share information across organizational boundaries. It's rare even when (as in environmental management for instance) key decision variables are linked by physical pathways (waterways, landforms, habitat) that cross jurisdictions, hierarchies, and other territorial lines. It's rare even for geographic information, despite its cost and its potential for widespread re-use, and has remained rare even as the Internet has come of age in recent years, and as public agencies have been called to increase their efficiency and public accountability. The problem seems to be part technical, part organizational, and often peculiar to the nature of geographic information: complex in structure and interpretation, rich in meaningful inter-relationships, and difficult to understand or use without special-purpose tools.

Part of the answer may be found in geographic information infrastructures-permanent, multi-purpose mechanisms built to help people make use of each other's geographic information. Learning to design such infrastructures, and to deploy and maintain them appropriately within a rapidly evolving technological and organizational context, seems key to effective inter-agency collaboration and sharing of geographic information. This chapter, then, looks at how to build organizational and technological infrastructures for sharing geographic information, based on recent empirical observations and ongoing prototyping efforts (Evans, 1997).

The research described here followed a hybrid approach, drawing on social and behavioral perspectives as well as on GIS technology, standards, and networking-as I have summarized in Section 2 below. Section 3's case studies of inter-organizational information infrastructures highlight essential change processes suggested by recent US experience. Section 4 examines the technological "style" needed for such infrastructures, exemplified by a networked service for digital orthophotos built onto the National Spatial Data Infrastructure. Section 5 sketches broader implications.

2. BACKGROUND AND PERSPECTIVES

"Sharing" can mean a great many things to people, from a simple moral principle (Fulghum, 1987) to quite abstract matters of semantics and perception (Frank, 1992). Here I have roughly followed Carter's (1992) definition, "the use of multipurpose information by members of a partnership." My focus is on groups that have different goals and tasks, but whose concern for a jointly owned natural resource leads them to work together, to coordinate their information activities, and to build some permanent underlying mechanism-an infrastructure-to share information, rather than rely on *ad hoc*, single-use methods. The next few paragraphs provide a foundation for discussing the technical design of such infrastructures and their deployment and growth within organizations.

2.1. Technologies for geographic information sharing

Over the last three decades, a diverse array of research in distributed data networks, standards, and multi-database theory has focused on information sharing.

First, as the Internet has come of age, so have tools for locating, retrieving, filtering, and using networked information, from the file transfer protocol (ftp) to Wide Area Information Servers (Kahle, 1991), Gopher (Schwartz *et al.*, 1992), and especially the World Wide Web (Berners-Lee et al., 1992). Frank (1994) sketches the role of data catalogs and navigational tools in several possible scenarios of a future spatial data infrastructure. The Internet and especially the World Wide Web have provided unprecedented levels of connectivity: much of that connectivity is still fairly simple at present (electronic mail and static Web pages), but information standards and distributed data designs promise a rich set of useful interactions among different information systems.

Information standards-shared vocabularies to facilitate communication-have been shifting in emphasis from comprehensive data format and quality specifications (U.S. National Mapping Standards, Spatial Data Transfer Standard) to interface standards that define the interactions with information without changing the information itself. "Minimal" standards of this second sort are useful in linking autonomous organizations that have different, yet established formats, procedures, or quality requirements. Noteworthy efforts include the US Federal Content Standard for Geospatial Metadata (FGDC, 1994), the Common Object Resource Broker

Architecture (CORBA) (Siegel, 1996), and the Open Geodata Interoperability Specification (OpenGIS) (Buehler and McKee, 1996).

Multi-database research pursues these software interactions in further depth, seeking to reconcile different data structures and models (Batini *et al.*, 1986; Peckham and Maryanski, 1988; Litwin *et al.*, 1990), and to interpret data semantics (definitions and relationships) (Siegel and Madnick, 1991; Sheth and Larson, 1990). Geographic information, with its multidimensional and topological nature, presents unique interoperability issues, both theoretical (Nyerges, 1991; Morehouse, 1990) and practical (Baker and Broadhead, 1992). Yet these multi-database concepts and methods are clearly useful for understanding and comparing geographic information sharing systems (Nyerges, 1989; Mackay and Robinson, 1992).

2.2. Organizational aspects of geographic information sharing

To many practitioners, the greatest obstacles to information sharing seem to be behavioral, rather than technical (Croswell, 1989); topics such as collaboration, consensus building, and coordination provide useful insights for geographic information sharing. Much of this literature follows a *variance* model, in which levels of certain inputs (factors) are seen to lead to performance outcomes by some functional relationship. This literature, reviewed by Grandori and Soda (1995), Pinto *et al.* (1993), and others, presents a complex set of factors for successful collaboration. For instance, Alexander (1995) finds collaboration to be facilitated by a clear interdependence between organizations, in the form of pooled resources, sequential tasks, or resource transfers -- all geared towards improved efficiency and survival in a complex organizational ecology. In the area of geographic information, important factors include appropriate pricing (Rhind, 1992) or, conversely, open access (Epstein, 1995); negotiation (Obermeyer, 1995); a common, "super-ordinate" goal (Pinto and Onsrud, 1995), a "killer application" (Brodie, 1993), data ownership (Carter, 1992), and technical expertise (Craig, 1995; August, 1991).

The variance approach contrasts with a *process* model, in which individual decisions over time explain how the observed outcomes actually come about. Van de Ven and Walker (1984) and others emphasize the power of this model in explaining complex inter-organizational patterns. For instance, Boland and Tenkasi (1995) link shared information to consensus-building through the use of "boundary objects" (maps, structured narratives, and the like) to help structure one's world-view and relate it to that of another. Granovetter (1972) uses social network theory (strong *vs.* weak social relationships) to link individual "micro" decisions to overall "macro" outcomes.

The two kinds of research are not necessarily incompatible; either perspective on organizational research can be harnessed for useful research. Nonetheless, I found the process model more appropriate here, given the complexity of the information-sharing question and of the multi-organizational setting. Some attention to process was also helpful as I sought to understand organizational and technical aspects in concert, rather than in isolation from each other.

2.3. Interdependence of organizational and technological factors

Sharing geographic information is often characterized as either a technological problem or an organizational one. However, in an unsettled, rapidly changing technological and organizational context, it rarely fits cleanly into one or the other category (Evans and Ferreira, 1995), but is closely tied instead to the relationship between technological and organizational structures. Markus and Robey (1988) emphasize this two-way relationship, favoring it over "technological determinism" (in which technologies are presumed to have known, inexorable effects on organizations) and "social strategic choice" (in which technologies are seen as inexorably shaped by organizational intentions and actions). Barley (1986) invokes structuration theory (Giddens, 1984) to trace the ongoing, recursive influences, triggered by new technologies, between an organization's rules and resources and the behavior of its members. DeSanctis and Poole (1994) emphasize the "intertwined" nature of technological and behavioral patterns, and Orlikowski (1992) proposes a useful view of technology as a malleable structural property of organizations. In such a model, organizational intentions alone cannot give rise to a given technology, nor can a technology have a fully predictable effect on organizations. Rather, in every phase of a technology's existence-conception, design, deployment, use, evaluation, and modification-the human actors involved mediate both causal effects in essentially unpredictable ways.

Accordingly, this research examines both technological and organizational design choices and contexts; their mutual interaction; and their joint relationship to planning and policy. A focus on interactions implies a dynamic view of information sharing infrastructures, not as a set of fixed, interlocking components but as a chosen direction, or even a "style" of evolution through an uncertain future.

3. LESSONS FROM THREE INTER-ORGANIZATIONAL INFORMATION INFRASTRUCTURES

The background and perspectives just outlined were helpful in interpreting the experience of several groups of organizations in the US that have undertaken infrastructures for sharing environmental, geographic, and other information. I compared the design and history of these infrastructures, seeking to understand their patterns of growth and change over time, and to document the tangible impacts of inter-agency information sharing. The study's nature, and the complexity of its context, favored a case-study methodology (Yin, 1984). I chose three cases in which loosely coupled partnerships among autonomous organizations were motivated by the joint stewardship of a valued natural resource. These cases were the Great Lakes Information Network (GLIN); the Gulf of Maine Environmental Data and Information Management System (EDIMS); and the Pacific Northwest StreamNet and its precursors. For each case, I conducted on-site interviews, reviewed paper and electronic documents, conversed with my study subjects by telephone and electronic mail, and submitted draft summaries to them for review. Qualitative analysis drew on grounded theory (Glaser and Strauss, 1967) for inductive hypothesis generation. The next four paragraphs sketch the findings from each case, then draw some overall findings across the cases.

3.1. The Great Lakes Information Network

The Great Lakes Commission, an inter-state compact formed in 1955, began experimenting with the Internet in 1993 to enhance communication among the many groups concerned with the water and air quality and the regional economy of the Great Lakes. The resulting Great Lakes Information Network (Ratza, 1996) links the Great Lakes states (Minnesota, Wisconsin, Illinois, Indiana, Michigan, Ohio, Pennsylvania, and New York), the Canadian Province of Ontario, and several Federal agencies and other public and private groups in both the US and Canada.

Figure 1. The Great Lakes region and watershed. *(Source: Great Lakes Commission, Environment Canada, U.S. Geological Survey)*

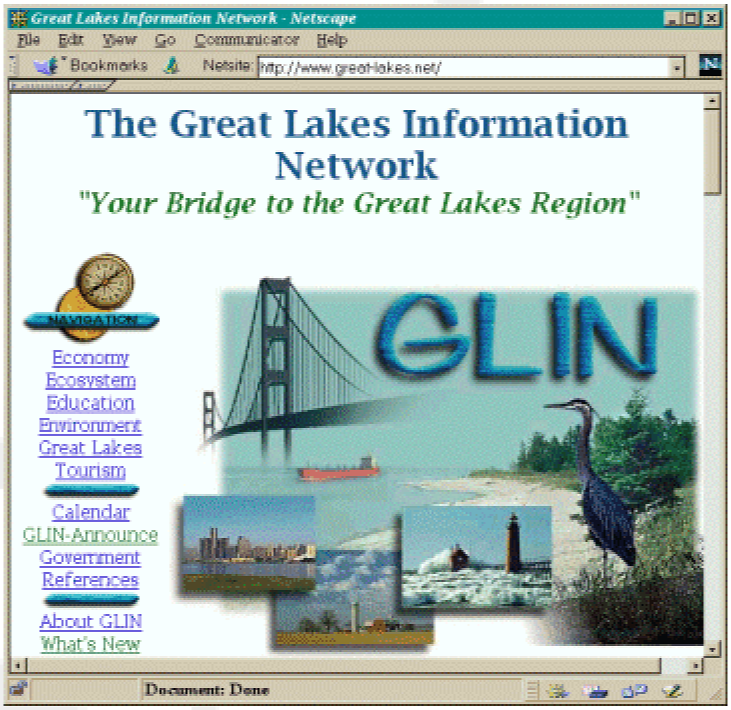


Figure 2. The Great Lakes Information Network homepage on the World Wide Web. *(Courtesy Great Lakes Commission. Used by permission.)*

For its first two years, GLIN saw rapid, mostly unplanned growth in size and usage, thanks to the "evangelistic" efforts of its founder and director, the tireless support of its technical architect, and the nature of the emerging World Wide Web. It encountered several challenges related to its growth. The first of these challenges was the difficulty of moving from a small, mostly centralized proof of concept to a truly distributed data resource, owned and run by its participating agencies. "The little pilot has become a messy beast!" said GLIN's technical director a year into the project. By that time, he was struggling to support some 400 accounts on a central server (where only 30 had been anticipated), and dozens of other relevant sites were going online all around the region, with no indexing or cataloging scheme in place.

A second challenge for GLIN was its interaction with other information-sharing initiatives in the region. Indeed, several other information-sharing infrastructures were being built for the Great Lakes region at the same time. GLIN's relationship to them was not always clear, which led to some degree of duplication and competition instead of cooperation and coordination. In all, however, GLIN has made impressive strides in equipping public and non-profit organizations throughout the Great Lakes to use the Internet meaningfully in their work.

3.2. The Gulf of Maine Environmental Data and Information Management System

In early 1990, three New England states (Massachusetts, New Hampshire, and Maine) and two Canadian Maritime provinces (New Brunswick and Nova Scotia) formed the Gulf of Maine Council on the Marine Environment to facilitate joint use and protection of their shared coastal and marine habitats.

In its initial Action Plan, the Council called for "a common regional protocol allowing for the transfer and periodic updating of data and information" among its participants. The means chosen for this was an Environmental Data and Information Management System, or EDIMS (Brown *et al.*, 1994). Built in the pre-Web years, EDIMS began as an *ftp*/*telnet*-accessible directory of the region's available data on coastal and marine resources. This metadata directory, already advanced for its time, was intended as a first step towards a region-wide, distributed set of data resources. However, after an enthusiastic start under a dynamic team leader, funding for EDIMS ran out in late 1993 and the project went "dormant" for a couple of years-just as the World Wide Web was becoming a household word.

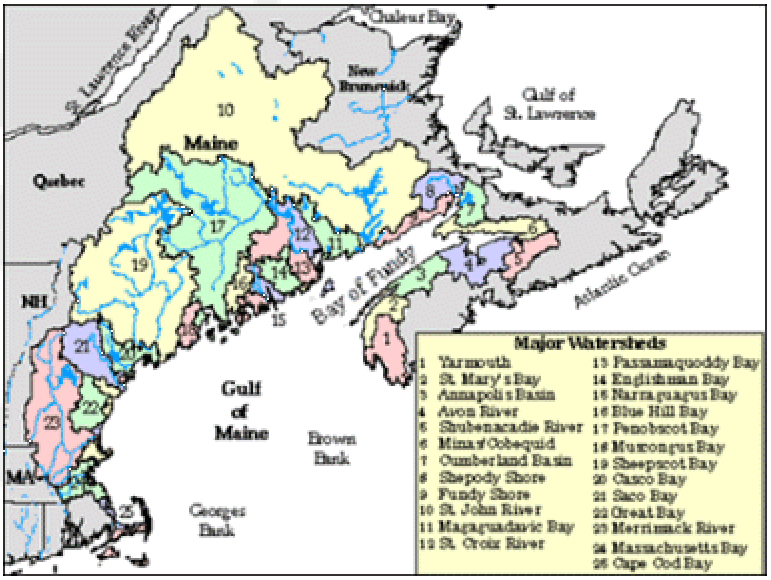


Figure 3. The Gulf of Maine region and watershed. *(Source: National Oceanographic and Atmospheric Administration)*

When its funding resumed in 1995, EDIMS struggled to reinvent itself within a vastly different networked world, and to redefine its role among a divergent set of organizations and needs. For instance, the Gulf of Maine Council now had many alternatives for electronic communications, and it was now more interested in its online "presence" than in the technical or scientific issues addressed by the EDIMS databases.

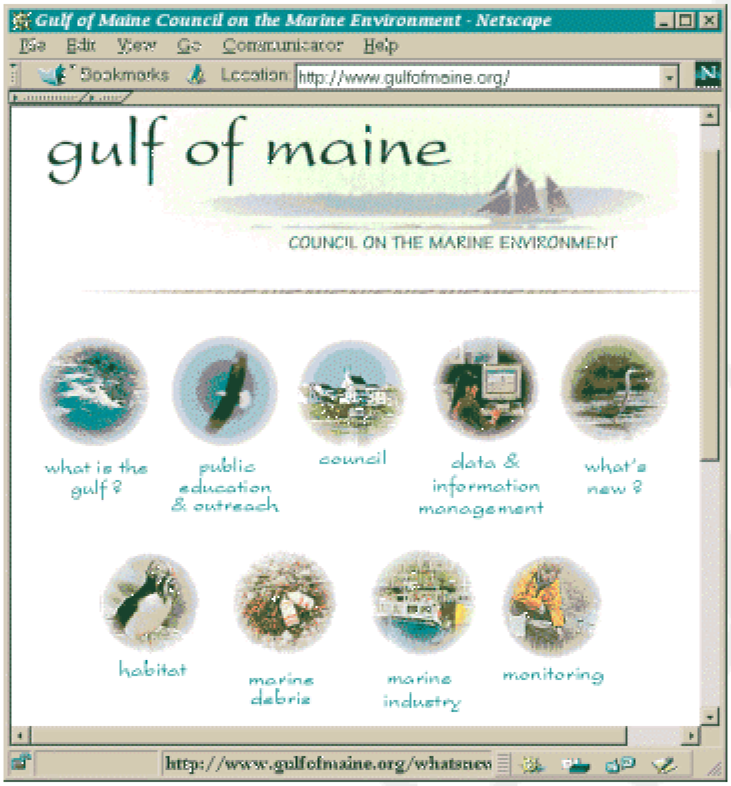


Figure 4. The Gulf of Maine Council homepage. *(Courtesy Gulf of Maine Council on the Marine Environment. Used by permission.)*

Unlucky timing was only one part of the EDIMS story; another was the limited resources given to building an information infrastructure. With annual budgets on the order of US$50,000 (about one-tenth those of GLIN and StreamNet), dubious support and direction from the Gulf of Maine Council, limited information-systems expertise, and little influence on its partner agencies, the EDIMS project had difficult odds. A third piece of the story was the lack of a clear shared goal among participants. Indeed, few in the region saw themselves as "Gulf of Maine citizens," and the region's most obvious trans-boundary resource, the dwindling offshore fishery, was a federal issue, outside the purview of the Gulf of Maine Council. So overall, the EDIMS project was an interesting, early vision of regionally distributed information, but unexpected events and organizational weaknesses prevented it from achieving its goals.

3.3. The Pacific Northwest StreamNet and its precursors

Beginning in 1984, the states and Indian tribes of the Pacific Northwest region of the United States (Montana, Idaho, Washington, and Oregon) worked with the US Bonneville Power Administration to build two region-wide rivers information systems to support the management of riparian fisheries and other natural resources.

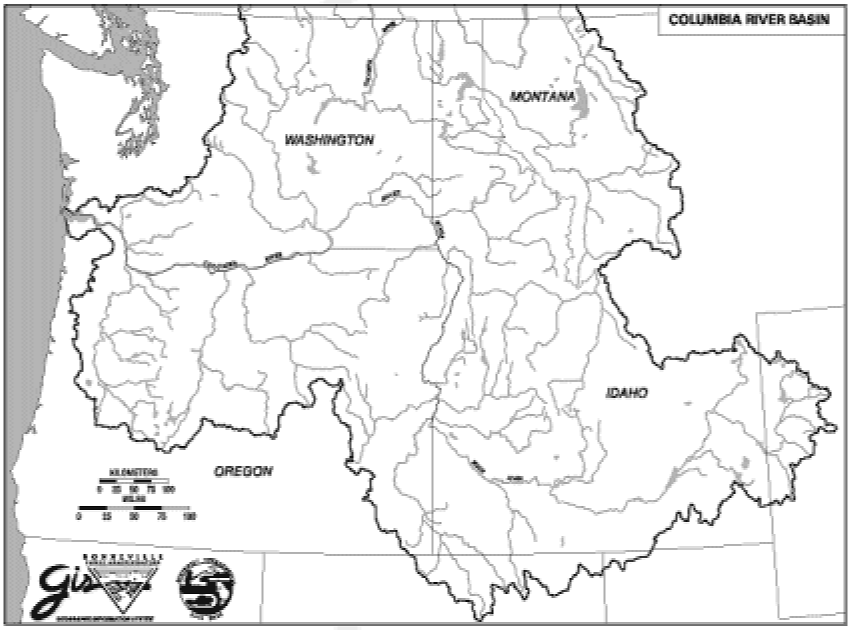


Figure 5. The Pacific Northwest region and Columbia River watershed.
(Source: Bonneville Power Administration)

The first of these, the Northwest Environmental Database (NED), was a geographic database on fisheries, wildlife, and hydroelectric facilities throughout the four-state region. It was built from a detailed Rivers Study in 1985-7, using the US Environmental Protection Agency's River Reach Files to codify the hydrologic network. Its comprehensive, regionally consistent information was key to a landmark policy decision in 1988, which designated 44,000 miles (71,000 km) of the river network as "Protected Areas," off-limits to federal hydroelectric development.

NED's regional consistency and maintenance declined after about 1990, but it spurred a second region-wide rivers database, the Columbia River Coordinated Information System (CIS). This database tracked anadromous (*i.e.*, ocean-migrating) species such as salmon and steelhead within the Columbia River Basin, using the same Reach File identifiers. Both systems were built before the Internet was widely available, and they shared digital data by traditional non-networked methods, via coordinators in each state using the common stream identifiers.

Both systems encountered challenges in maintaining region-wide standards and joint usage among agencies with a wide spectrum of technological maturity. In particular, as participating state agencies developed their own GIS capabilities in the early 1990s, they tended to abandon the regionally consistent Reach Files, at a 1:250,000 scale, in favor of more detailed local identifiers at 1:100,000 or larger scales. Anticipating this shift in 1985, NED's designers had planned to update the Reach Files to larger scales within about three years; but usable 1:100,000-scale products didn't become available until nearly ten years later.

Thank you for visiting the StreamNet home page. StreamNet is a cooperative venture of the Pacific Northwest's fish and wildlife agencies and tribes. We provide data and data services in support of the region's Fish and Wildlife Program and other efforts to preserve and restore the region's aquatic resources.

Figure 6. StreamNet homepage. *(Courtesy Pacific States Marine Fisheries Commission. Used by permission.)*

Another challenge was maintaining a productive rivalry among regional database and standards efforts. NED and CIS each had proponents and detractors, and some duplication of effort and staffing remained unresolved for several years. In addition, the US Forest Service was heading up regional inter-agency responses to the spotted-owl controversy and related environmental concerns.

In 1996, NED and CIS were merged into an Internet-based repository and data-interchange system known as StreamNet (BPA, 1996), with state-of-the-art data querying and interactive map-building functions, and a steering committee (almost a separate "shadow" organization) that maintains shared ownership of technical and business aspects of the infrastructure. By some accounts at least, StreamNet became regarded as the region's principal source of regional rivers and fisheries data; whether and how this will grow into a fully distributed data resource remains to be seen.

3.4. Synthesis of the three cases

From an organizational viewpoint, the three cases illustrate well the importance of a clearly articulated common goal in building and maintaining infrastructures for sharing information. The Great Lakes case succeeded thanks in part to several widely held regional environmental concerns; the Pacific Northwest banded together to harmonize fisheries and hydroelectric development; and in the Gulf of Maine case, the lack of a clear shared goal kept commitment levels low.

Second, all three infrastructures had to define themselves in relation to other, related information activities. Although all three infrastructures were initially conceived as the single or primary gateway to data for their respective regions, none held that simple luxury for long. Furthermore, all three cases found it easy to build a "scaffolding," a temporary technical and institutional structure to get started; but moving to a distributed architecture, or to dynamic data rather than fixed "brochures," or maintaining an infrastructure over time, were much more difficult. In no case did a comprehensive blueprint exist for assembling the mix of networked technologies, data structures, institutional relationships, and resources needed for an effective infrastructure. Improvised learning and growth were at least as important than any *a priori* set of factors.

A structuration model, as described earlier, offers one way to interpret this complex set of influences, and to reconcile individual choices and events with broader trends over time. Such a model highlights the mutual influences between people's actions and the structures (that is, the rules and resources) within which they operate. In these cases, the structures of concern are *(i)* technologies (e.g. data standards and software tools), *(ii)* organizations (e.g. teams and committees, expertise, budgets), and *(iii)* policies and plans (congressional decrees, jurisdictions, laws, etc.)

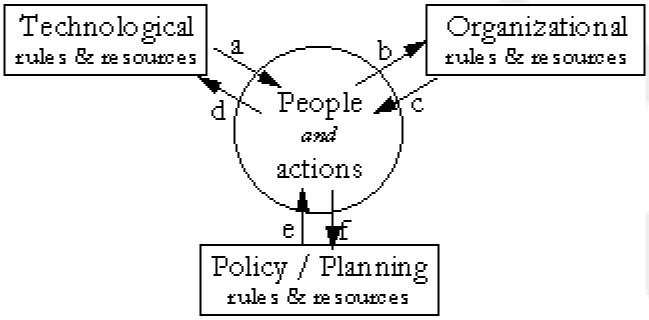


Figure 7. Mutual influences of technology, organization, and policy/planning on people and actions

In this model, each of these structures exerts some influence (arrows **a**, **c**, **e**) on the individuals involved, who may respond by trying to alter the various structures that govern their actions (arrows **b**, **d**, and **f**). For instance, in the Pacific Northwest case, a simple data standard led many to collaborate on a shared regional database (arrow **a**); their actions helped to bring about the Protected Areas consensus (arrow **f**). In the Great Lakes, one person's initiative and energy did much to build a norm of shared information among the region's various groups (arrow **b**). In the Gulf of Maine, regional environmental stewardship was a fairly new idea, so collaborative work was difficult (arrow **c**); and so on.

These reciprocal influence patterns provide a persuasive model of growth and change, and suggest a number of "levers" for perturbing exiting behavior and guiding it towards a particular target-though not with fully certain outcomes, as all of these influences are mediated by human actions. Thus, constructs as complex as information-sharing infrastructures need to be designed and built as living, growing "organisms" rather than fixed artifacts. This requirement may be especially important when dealing with geographic information systems, for which the technical tools are still evolving rapidly, and which tend to encourage relationships that cut across traditional hierarchies and boundaries (as implied by Chorley (1988) and Goodchild (1992)). For organizations, this loosely planned, "nimble" approach to building and deploying real-world information infrastructures implies a shift from autonomy to interdependence, with policies and plans defined not by authority within a hierarchy, but by persuasion within an organizational ecology (akin to Moore's (1996) "business ecosystem"). This loosely coupled interdependence is an organizational counterpart to the "interoperability" concept that has become popular in information systems.

Interdependent organizations with loose boundaries and relationships will tend to favor and thrive on certain styles of technology: for instance, modular, layered components, rather than predefined "stovepipe" suites of hardware and software, allow for more improvised learning and change. Such organizations will also tend to blur the traditionally separate technologies of internal data management and external data dissemination. The following section clarifies what such a technology style might look like, using a specific example, a prototype spatial data service on the National Spatial Data Infrastructure.

4. LESSONS FROM AN INTERACTIVE ONLINE ORTHOPHOTO DATA SERVICE

The organizational case study just described provides insights into the state of the art of information sharing infrastructures as they emerged among government agencies in North America in the mid-to late 1990s. To further clarify these findings, and to ensure their continued relevance in a rapidly changing technological context, a second phase of this study took a different approach, and built a prototype online service for digital orthophotos. (Orthophotos are aerial photographs that have been aligned digitally with a standard geographic coordinate system. In the US and elsewhere, many public agencies have built digital orthophoto series, but have found them difficult to distribute to users due to their large size and the difficulty of integrating them other maps and GIS datasets.) The orthophoto service was developed as part of the US National Spatial Data Infrastructure (NSDI) (National Research Council, 1994; Tosta and Domaratz, 1997), with support from the Federal Geographic Data Committee (FGDC) and the Massachusetts Executive Office of Environmental Affairs.

The prototype (online at *http://ortho.mit.edu*) provides orthophoto data and standardized metadata through intuitive Web interfaces. It has also proven to be a useful testbed for learning how to give a broad class of users networked access to the orthophotos and metadata; how to distribute the orthophotos efficiently over a slow network; and how to link the online orthophoto service to client-side GIS software.

4.1. Design goals

The orthophoto service followed several design goals, within an overall rubric of making digital orthophotos more accessible to a wide audience. The first of these, as mentioned above, was to build onto the National Spatial Data Infrastructure (NSDI): this allowed the project to fit into a broader community and related activities, and to suggest likely futures for the NSDI's Clearinghouse and Framework initiatives. Second, an important part of making the orthophotos more accessible was to provide multi-resolution views. The assumption was that few users wanted entire images (over 60 MB apiece)-that most wanted either low-resolution overviews, or high-resolution snippets of small areas. Third, given that many potential users had thin, dial-up access to the Web, it was important to use network bandwidth sparingly. A fourth design goal was to piece together simple, easily available software components, to facilitate experimenting with the service and adapting it to other data series or operating environments. A final goal was to ease the task of integrating online image data with local maps and common desktop GIS software, so as to begin bridging the gap between local and remote data.

4.2. Development process

To accomplish these goals, a process of learning-by-doing was important: that is, a development path that provided early and frequent products, from which more complex systems could be built. The first outcome was a set of metadata files describing the images, which complied with the US federal metadata content standard (FGDC, 1994) and were searchable via the Internet's Z39.50 protocol (Kahle, 1991). Next was a simple, preliminary user interface to pre-tiled image excerpts, produced by cutting each large orthophoto into 16 equal-size pieces; then cutting each of these pieces in the same way, into snippets of about 80kB each (after compression); and resampling the larger images down to the same size.

This scheme provided an early online presence for the orthophoto service, but its limitations were clear. On the client side, the rigid tiling kept users from precisely specifying their desired viewport; on the server, each orthophoto required an impractical number of files.

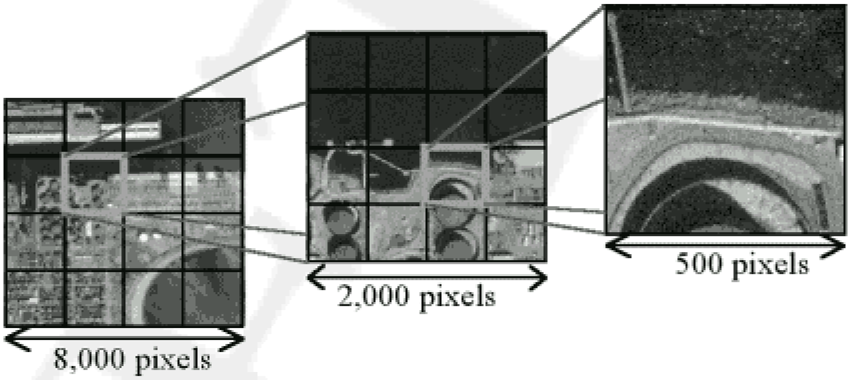


Figure 8. Preliminary fixed tiling scheme

Extracting sub-image snippets in real-time, using the Web server's Common Gateway Interface (CGI) to run scripts on the server, promised to address both of these limitations. After some experimentation, a modified version of the *pnmcut* freeware utility from the *pbmplus* suite (© Jef Poskanzer; available at *http://www.acme.com*) proved adequate to the task. This led to a new data-serving architecture based on extracting and compressing image snippets in real time, rather than choosing among static image files.

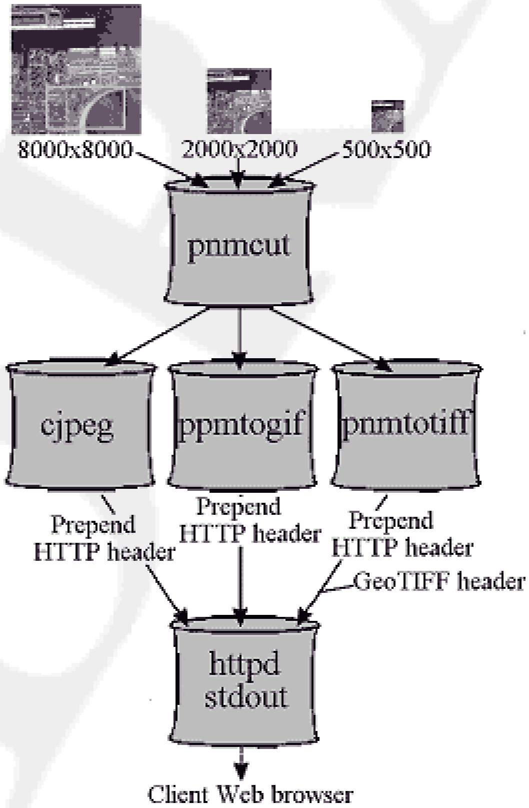
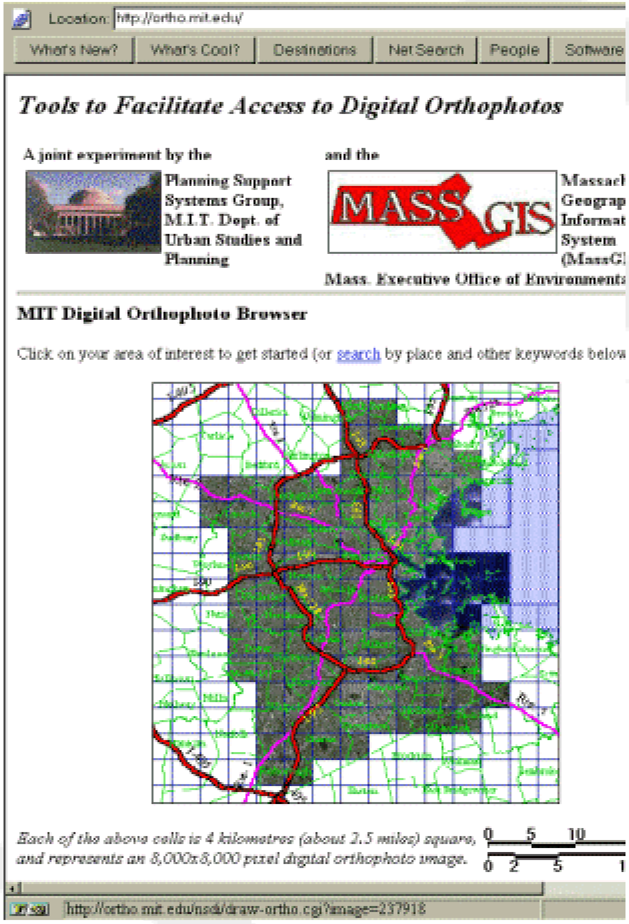


Figure 9. Real-time image extraction and reformatting

This new scheme used Unix "pipes" to control streaming input and output in real time. First, the *pnmcut* utility extracts a user-specified portion of a master image at one of three resolutions. It then sends the sub-image through one of three image compressors/formatters (*cjpeg*, *ppmtogif*, or *pnmtotiff*, all part of the *pbmplus* suite). If requested, a GeoTIFF header is put on the image; and the result is sent back to the client, with a Web protocol (*http*) header.

With this architecture in place, a final step was to build similar real-time services to create customized geographic header files for each snippet, so that users could easily incorporate a downloaded image into a few common desktop GIS software packages.



Tools to Facilitate Access to Digital Orthophotos

A joint experiment by the Planning Support Systems Group, M.I.T. Dept. of Urban Studies and Planning

and the Massach Geograp Informat System (MassGI Mass. Executive Office of Environment

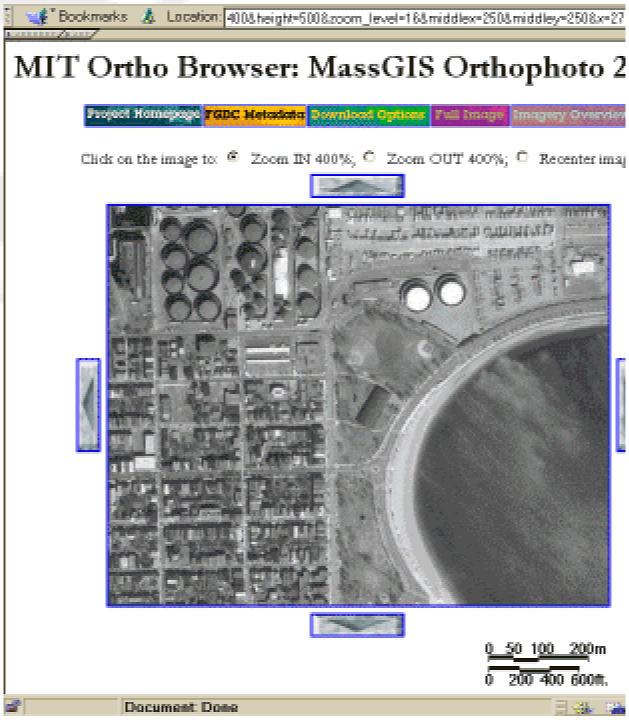
MIT Digital Orthophoto Browser

Click on your area of interest to get started (or search by place and other keywords below

Each of the above cells is 4 kilometres (about 2.5 miles) square, and represents an 8,000x8,000 pixel digital orthophoto image.

http://ortho.mit.edu/nsdi/draw-ortho.cgi?image=237918

Figure 10. Digital orthophoto service: front page

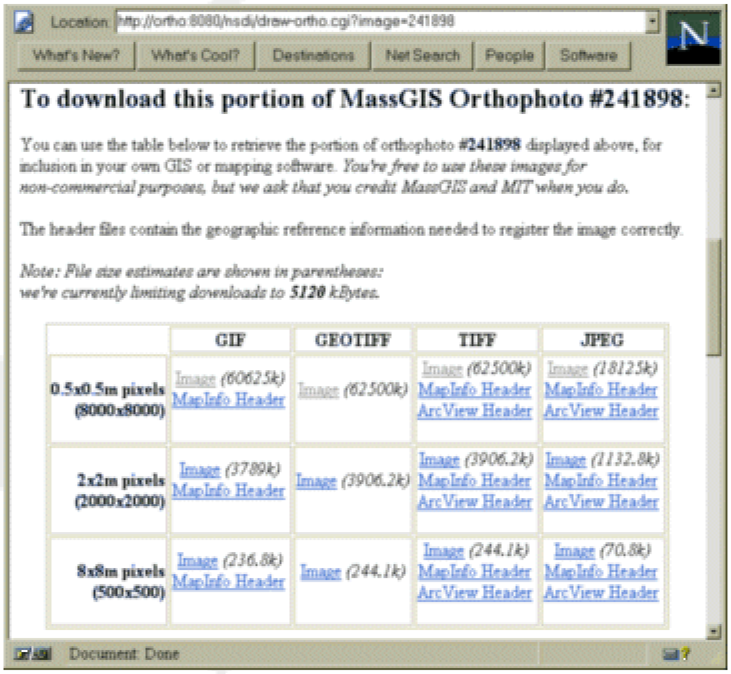


MIT Ortho Browser: MassGIS Orthophoto 2

Click on the image to: ● Zoom IN 400%; ○ Zoom OUT 400%; ○ Recenter ima

Figure 11. Interactive interface to the digital orthophoto service *(detail)*

The resulting service provides an intuitive interface to over 7 GB of digital orthophotos in several popular graphic formats, with encapsulated georeferencing information. Furthermore, it does use the network sparingly (most image views are under 80 kB in size), yet its resizable viewport serves high-bandwidth (or very patient) users as well, with a throughput of about 90kB/s through the real-time data-processing "pipes." The server-side scripts are easily modified to suit new orthophoto series, and the maintenance overhead on the server is minimal (two extra files per orthophoto, occupying about 7% additional disk space). Finally, thanks to its standard metadata content and Z39.50 query interface, people across the Internet can discover this service, peruse metadata entries to determine its fitness for their use, and use hypertext links in the metadata to get to the images themselves.



Location: http://ortho:8080/nsdi/draw-ortho.cgi?image=241898

To download this portion of MassGIS Orthophoto #241898:

You can use the table below to retrieve the portion of orthophoto **#241898** displayed above, for inclusion in your own GIS or mapping software. *You're free to use these images for non-commercial purposes, but we ask that you credit MassGIS and MIT when you do.*

The header files contain the geographic reference information needed to register the image correctly.

*Note: File size estimates are shown in parentheses: we're currently limiting downloads to **5120** kBytes.*

	GIF	GEOTIFF	TIFF	JPEG
0.5x0.5m pixels (8000x8000)	Image *(60625k)* MapInfo Header	Image *(62500k)*	Image *(62500k)* MapInfo Header ArcView Header	Image *(18125k)* MapInfo Header ArcView Header
2x2m pixels (2000x2000)	Image *(3789k)* MapInfo Header	Image *(3906.2k)*	Image *(3906.2k)* MapInfo Header ArcView Header	Image *(1132.8k)* MapInfo Header ArcView Header
8x8m pixels (500x500)	Image *(236.8k)* MapInfo Header	Image *(244.1k)*	Image *(244.1k)* MapInfo Header ArcView Header	Image *(70.8k)* MapInfo Header ArcView Header

Figure 12. Downloading images and header files

4.3. Interpretation

By several measures, the orthophoto service has attracted a large audience. According to the Web server's access log, it has continued to see several thousand hits per day since it was launched in the fall of 1996. The logs also illustrate the variety of sites accessing the server, including educational institutions, city, state, and federal government agencies, and firms involved in construction, engineering, logging, real estate, mapping, and photogrammetry. Anecdotal evidence sheds light on the service's many uses. Boston city government staff, for instance, or architects and engineers working on Boston's Central Artery, found that the orthophotos provided quick, detailed, easily understood views of urban patterns, useful for communicating with neighborhood associations and for correcting and updating street maps.

Although the Massachusetts GIS data center sells bundles of these images on CD-ROMs at low cost, using the orthophoto service's custom-prepared data snippets is often easier than making a telephone call to order the full images. Granted, this shift towards data interdependence wasn't immediate or universal: at least one visitor to the site systematically downloaded a large portion of the image data for future internal use. But as the orthophoto service has proven reliable and remained available, other users have opted to retrieve imagery data only as needed. Furthermore, beyond public data access, a service like this one also lessens the "data packaging" needed to support internal purposes.

Finally, although most users get to the imagery data through a browser using one particular Web form, requests to the orthophoto server may also be embedded in HTML pages, word-processing documents, or desktop mapping systems. On the server side, data requests could be sent to other servers on the network, in order to tap into adjacent or overlapping data libraries. Thus, this orthophoto service is built to fit into a "tapestry" of independent, heterogeneous software components that use a few key pieces of vocabulary to interact. This technological interoperability favors, and thrives on, the loosely-coupled, interdependent organizational structures described earlier, and allows for "learning as we go" into a complex, uncertain future.

5. CONCLUSIONS

For real-world organizations to share geographic information, building the right kinds of infrastructures will be crucial. A few recent real-world examples of such infrastructures highlight the intertwined and unpredictably changing nature of their technological, organizational, and policy environments. These examples also suggest that building effective inter-organizational mechanisms to share geographic and other information, and harnessing them for joint work, may require larger-than-expected organizational shifts, towards loosely-coupled interdependence. Interoperable organizations of this sort are likely to function in concert with modular technology components, of which the orthophoto service is a seminal example. This service, which prepares custom orthophoto snippets to suit a diverse audience, is tuned to current bandwidths, smoothly integrated with client-side software tools, easily managed and easily replicable. This service has proven popular at least partly because it is designed not merely as a standalone product, but as a component within a larger "tapestry" of interacting software systems, and thus functions well within interdependent, interoperable styles of work.

Together, these findings have important implications for infrastructure-building efforts at several scales. For instance, it suggests that standards efforts may be best spent defining how different software clients, servers, and peer services will interact, and what part of the communication "stack" to agree upon, rather than what data formats everyone should use. Furthermore, growing and adapting these specifications over time is crucial to stay abreast of a changing environment and user base. These concerns are of particular interest for the future of the National Spatial Data Infrastructure (which will be built from the diverse data services of individual regions and participants); and for its regional and smaller counterparts. Likely impacts go well beyond technology, possibly leading to ephemeral, task-oriented partnerships between large numbers of organizations, and to broader participation and more effective consensus in policy decisions based on the best available information.

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