Integrating Multimedia in Geographical Information Systems

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Developments in multimedia and scientific visualization have greatly expanded the technical capabilities of geographic information systems. Users can visually explore, analyze, and present data and gain insight on spatial relations and patterns. But how do users manage all the information that reaches them? Highly-structured interfaces such as hypermaps, discussed here, are a necessary and useful way to structure multimedia components and let users easily navigate data sets.

The past decade has seen considerable developments in geographic data handling. Geographic information systems (GIS) have introduced powerful ways to integrate spatial data from different kinds of sources, such as surveying, remote sensing, statistical databases, and recycled paper maps. Their functionality offers users the ability to manipulate, analyze, and visualize the combined data. GIS users can link their data to application-based models to try to find answers to questions like, "What is the most suitable location to start a new branch of a supermarket chain?" and "What effect will this plan or its possible alternatives have on the surrounding area?" GIS functions very well as a decision support system that is easily integrated into the specific environment of an organization.[1] Maps play a significant role here.

In a GIS environment, maps are used to visualize spatial data, to reveal and understand relations between them. Maps are no longer just the final products they used to be, when they functioned as a medium for both storing and presenting spatial data. The introduction of digital data has resulted in a split between these main functions of storage and presentation.

For cartographers, database technology and computer graphics techniques have provided new presentations such as three-dimensional and dynamic temporal maps, and ways of querying the database using an on-screen map. Maps are often the start of a spatial analysis. They are also useful for judging intermediate analysis results, as well as presenting final results. In other words, maps are now part of the process of spatial analysis, not just its end result.

The need for advanced analytical techniques is increasing in pace with technological developments. Tomorrow's GIS users will require a direct and interactive interface to their geographic and other (multimedia) data. This will, for instance, let them search for spatial patterns, guided primarily by their own knowledge. A more interactive interface is needed primarily because of the evolution in GIS from a data-poor to a data-rich environment, but also because of the intensified link between GIS and application-based models. These developments necessitate more advanced and sophisticated visualization techniques.[2,3]

Visualization and GIS

In a GIS environment, visualization is applied to three different, though associated, ends. First, it can be used for exploration, to play with unknown and often raw data. In several applications, such as those dealing with remote sensing data, there is abundant (temporal) data available. Questions such as, "What is the nature of the data set?" or "Which of these data sets reveals patterns related to the current problem?" must be answered before the data can actually be used in spatial analysis.

Second, visualization is applied for analysis, to play with or manipulate known data and begin to reveal patterns. In a planning environment, the nature of two separate data sets can be fully understood—for instance, the ground water level and the possible location of a new road—but not their relation. A spatial analysis operation, such as overlay, can combine both data sets to determine their possible spatial relation.

Finally, visualization is used for presentation, to communicate known data. The results of spatial analysis operations can be displayed in well-designed maps easily understood by a wide audience. The cartographic discipline offers design rules for map presentation and specifies different rules for different map functions and uses. From a map use perspective, cartographic products can be split into those that are instantly understandable (newspaper and television news maps, for instance) and those that might take some time to

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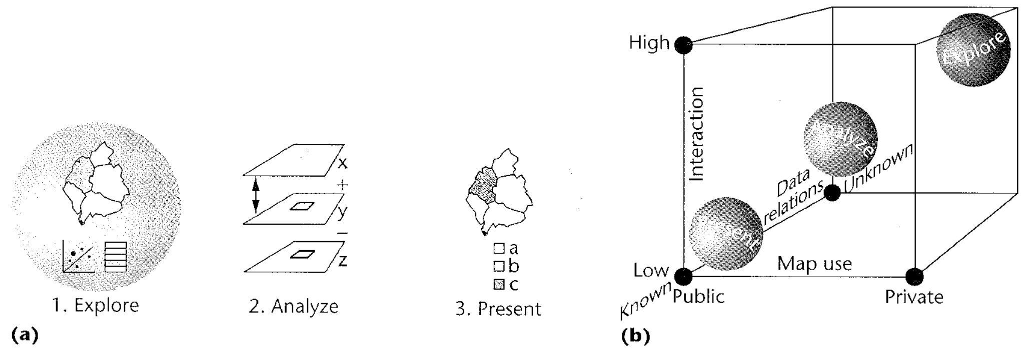

Figure 1. Visualization and GIS. (a) The three primary applications of visualization in GIS. (b) Visualization applications and user interaction requirements shown schematically.

study (such as road maps and political maps). This second category also includes maps that require additional education or expertise to decipher, such as topographic, geologic, and hydrologic maps.

These three different applications can overlap, or even occur together, depending on the user's involvement in the visualization process. The same user might well explore, analyze, and present data during the different stages of a visualization project.

Developments in scientific visualization, multimedia, virtual reality, and exploratory data analysis further stimulate the demand for sophisticated presentation techniques. Such developments also make other information available to supplement geographic data. While this expands the capabilities of a GIS environment, it also creates new data management problems. The geographic data adhere to a known reference system and can be relatively easily manipulated within a GIS environment. Other data, such as photographs or scanned documents, are not so easily integrated into such a reference system. One solution is to link these data to a geographic position so that they can be used with the geographic data. For example, a photograph of a building taken from a known location can be linked to the geographic data referencing that location.

In each of these external developments influencing GIS, it appears that from a technical point of view almost no barriers remain. In the case of multimedia, the user is confronted with a screen that has multiple windows displaying text, maps, even video images supported by sound. An important question is, "Can we handle it—can we manage all this information that reaches us?" Perhaps some answers will emerge from an overview of multimedia applications in geographical information systems.

Using maps for GIS visualization

Maps have been used for centuries to present spatial data. In the 1950s, only analogue maps were employed to analyze and explore spatial data in a scientific context. The first experiments with digital maps were initiated in the 1960s, and in the 1970s some basic analytical functionality was introduced. In the 1980s, these integrated mapping systems became generally known as GIS. As GIS functionality matured, it spread to all disciplines working with spatial data, and maps and diagrams are now used to visualize a wide range of data types. Figure 1 illustrates the basic structure of a GIS in relation to visualization applications.

In the last decade, the availability of advanced hardware and software spurred widespread interest in visualization in scientific computing (also known as scientific visualization), a science and engineering subdiscipline. McCormick describes visualization in scientific computing as the study of "those mechanisms in humans and computers which allow them in concert to perceive, use and communicate visual information."[3] In GIS, especially when exploring data, users can work with the highly interactive tools and techniques from scientific visualization. This activity is described as geographic or map-based scientific visualization. In this interactive brainstorming environment, the raw data can be geo-referenced, resulting in maps and diagrams, while other data can result in images and texts.

Why would users like to visualize spatial data? Displaying the data in maps will help them to understand the data, but above all it can provide answers to such questions as "what is?" or "where is?" The answers provided by the graphics will identify and locate geographic objects. Questions like "What makes it different?" and "What belongs together?" can result in complex visual answers that distinguish or associate geographic objects in new ways.

Design issues in mapping geographic data

According to Keller and Keller,[4] the visualization process includes three distinct steps: first, identify the visualization goal; second, remove mental roadblocks; and third, decide between data and phenomena. In cartography, the first step is summarized by the phrase "How do I say what to whom?" "What" refers to the spatial data and its characteristics. For instance, are the data qualitative or quantitative? "Whom" refers to the map audience and the purpose of the map. A map for scientists requires different design rules than a map on the same topic aimed at children. "How" refers to the design rules themselves, that is, the approach taken to the data and their visualization.

For the second step, Keller and Keller suggest gaining some distance from cartographic conventions, to move beyond traditional constraints. Why not choose an alternative mapping method? For instance, use an animation instead of a set of single maps to display change over time; show a video of the landscape next to a topographic map; or change the dimension of the map from 2D to 3D. New, fresh, creative graphics could be the result, and they would probably have a greater and longer lasting impact on the audience than traditional mapping methods.

This is where multimedia comes in. In the third step described above, you have to decide between map data or phenomena. To clarify this, consider an example of mapping rainfall amounts. Experts exploring rainfall patterns would like to distinguish among different precipitation classes, for example by using different colors, such as blue, red, yellow, and green, for each class. If presented to a wide audience, such as those watching television, the map would be most appealing to viewers if it showed areas with high and low precipitation. This can be realized using one color, for instance blue, in different tints: making dark tints correspond with high rainfall and light tints with low rainfall would result in an instantly understandable map. When exploring, then, a user might favor data visualization, but find phenomena visualization more useful for presenting the data.

Considering the three different applications of GIS visualization (to explore, to analyze, and to present), it is noteworthy that the tools for the last function are the most developed. This gives rise to a new problem, however. When making a traditional map to communicate spatial information, a cartographic grammar is available to make the most effective map possible.[2,5] GIS, however, lets users make their own maps without being aware of basic cartographic grammar. Without application of appropriate design rules, there is no guarantee that the maps will be effective.

In the second GIS application, making maps to analyze data, cartographic rules could also be applied, but this is unlikely given the typically individual nature of initial data analysis. In a data exploration environment, it is likely that even the user does not yet know the nature of the data. But once analysis begins, because users know their own data at this point, they would not need a formal set of rules to decipher maps based on them. Only when showing their maps to others does trouble arise. Visualization methods more appropriate to shared use and interpretation need to be developed. To this end, some ideas for animations and the display of temporal data have recently been suggested.[6]

New rules, new tools

The concepts of private visual thinking and public visual communication[7] should be introduced at this point. Private visual thinking refers to users working with their own data. It describes the exploration applications of GIS. Public visual communication refers to how cartographers create well-designed maps. It characterizes presentation applications. Analyses can be found somewhere in the middle between the two. This becomes more evident when you realize that private versus public map use (tailored to an individual versus designed for a wide audience) is just one axis of the map use cube depicted in Figure 1. Along the two other axes are unknown versus known data being presented, and high versus low user interaction.

Traditional cartography has focused mostly in the corner where a wide audience, presenting known data, and low user interaction meet. Recent developments in cartography oppose this view, because new products like electronic atlases not only require a new line of thought, they also create one. To illustrate this, plot the evolutionary stages in the development of these atlases along the diagonal from the corner "wide audience, presenting known data, low user interaction" toward the corner "private use, presenting unknown data, high user interaction." Early electronic atlases were just sequential slide shows, but more advanced electronic atlases have highly

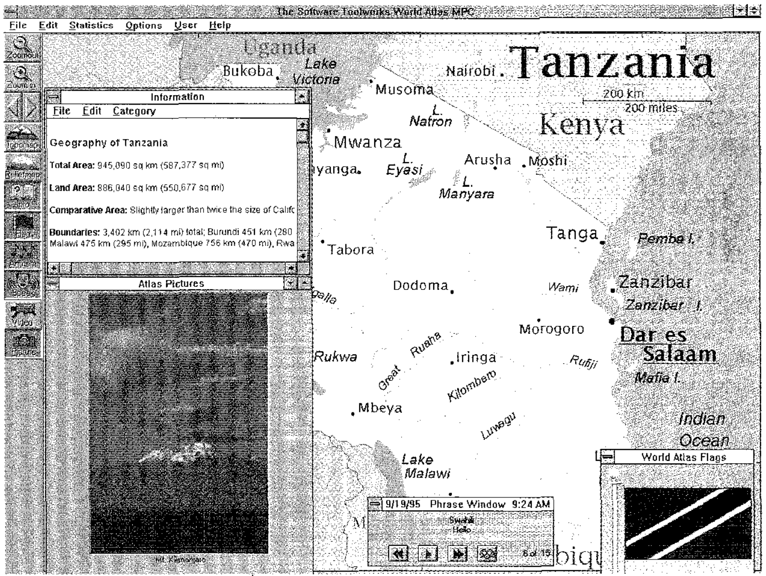

Figure 2. A page from an interactive electronic multimedia atlas, showing a map of Tanzania. A file with textual information on the country is activated, and an image of Kilimanjaro is displayed. When Tanzania was selected from the Africa map, the national flag appeared and the national anthem played simultaneously. The phrase window includes other sound facilities the user can listen to, such as 16 Swahili phrases. For some countries, small video clips are available, as seen in the menu on the left side of the figure. (Source: the Software Toolworks World Atlas, version 5.)

interactive "multimedia mapping" capacities and let users enter their own data.

Each category of map use requires its own visualization approach. We still need to develop techniques and design options to reach optimal graphics in any location in the cube. In the corner "wide audience, presenting known data, low user interaction," cartographic theory already offers good solutions. But what about the remainder of the cube? Exploratory users prefer to play with original raw data and look at them from different viewpoints. Here or in any location of the cube, the maps used can provide insight into spatial relations, if they are designed with specific uses and needs in mind and incorporate tools that enhance user interaction.

New cartographic tools might usefully focus on combining multimedia components such as sound, text, animation, and still and video images to elucidate data patterns and relationships. Developing such tools presents a challenge for the cartographer. They will probably not be as restrictive as traditional cartographic grammar, but they should also not be quite as free as the technology allows.

GIS, maps, and multimedia

Multimedia allows for interactive integration of sound, animations, text, and video images. In a GIS environment, which traditionally can work only with coordinates, pixels, their attributes, and spatial relations, multimedia technology offers a link, often via the map, to all kinds of other information of a geographic nature. These could include text documents describing a parcel of land, photographs of objects that exist in the GIS database, or a video showing the landscape of the current study area. Old maps, whose conversion into a properly geo-referenced system is too costly, could also be directly incorporated into the system via hyperlinks.

The GIS literature offers several definitions of multimedia. One proposed by Bill describes it as "a computer-based system for integrated processing, storage, presentation, communication, creation, and manipulation of independent information from multiple time-dependent and time-independent media."[8] The idea of using the map to combine sound, animations, text, and images with spatial data in a GIS environment is not that strange, since GIS is about data integration, and the newly-added multimedia components can be seen as additional "variables" that provide a fuller understanding of the mapped spatial data.

It is also possible to use the map as a kind of index to phenomena or objects represented by one of the multimedia components. Since multimedia equipment can produce music of CD quality, it is easy to imagine what a multimedia map of Europe on composers would look like. Pointing to Beethoven's birthplace might activate his Ninth Symphony, for example, showing his picture and music scores as well as a video of a landscape that visualizes the atmosphere of the music. This level of integration is almost realized in some of today's interactive multimedia encyclopedias (see, for instance Compton's Interactive Encyclopedia.

Figure 2, which shows a page of an electronic atlas, illustrates potential uses of multimedia in GIS. The user has access to a variety of maps, images, text, sound, and video, all relating to and providing additional information about the chosen geographical area.

What is the current status of multimedia integration into GIS? The answer is somewhat more limited than the above examples suggest. Texts can be generated from the database, and scanned photographs of geographic objects, paper maps, and text documents can often be displayed. But today's GIS packages have only limited capacity to handle video, animations, and sound (except for a beep to signal an error).

Increasingly, however, GIS packages are being better integrated in the desktop environment. This makes available certain "window"-type facilities that can link other software with GIS, and GIS vendors have introduced data viewers to bring these new opportunities to the general GIS user.

Examples include ESRI's ArcView (shown in Figure 3), Intergraph's Vistamap, and Tydac's SpansMap.

Data viewers are map-based data browsers. The first generation of these products allowed the user to look at data prepared and structured in the vendor's own major GIS package, but the new generation is more open and can work with data in different formats. The user is guided by a generic graphical user interface (GUI) that supports the display of maps and provides access to the data behind these maps. Pointing at an object on the map immediately highlights the corresponding record in the database or diagram. These systems also accommodate multimedia and operate on a general desktop environment. For instance, the map allows direct links with spreadsheets and video and animation programs.

These data browsers also serve as simple data explorers. The desktop environment lets the user open multiple windows, each displaying the data from a different (multimedia) perspective. The most interesting part of this approach is the real-time interaction between user and data. In a controlled version of this process, "geographic brushing," the user selects data or objects in one window; this highlights the particular selection in all other windows (textual, dynamic graphics, tabular, or statistical). Moving a pointing device in, for instance, the map or a diagram automatically changes the selection and shows alternative graphics and statistics.

To encourage integration of multimedia functions into GIS, the European Science Foundation organized a meeting in 1994, in the framework of the GISDATA program (the scientific program on geographical information systems data integration and data base design[9]). The primary goal was to set the research agenda in this field. Several key issues emerged from the meeting, ranging from structuring multimedia information (navigation strategies) to the use of multimedia to enhance spatial analysis (should we encourage multimedia in GIS, or GIS in multimedia), to interface design.

Maps with multimedia components

A map perspective is a useful way to explore uses of multimedia in GIS. Using a map as a starting point for organizing information lets us consider how best to bring in and structure individual multimedia components with respect to the data set presented in the map. Individual multimedia elements can be linked to maps to present and enhance geographical information for visual exploration, analysis, and presentation.

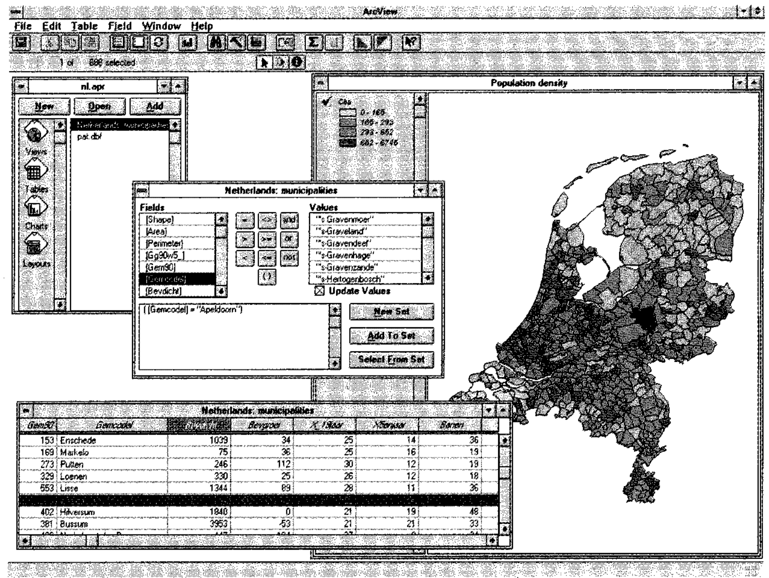

Figure 3. An example of a geographic data viewer. ESRI's ArcView 2.0 is used to browse a database on Dutch municipalities. Those areas selected in the map are highlighted in the table as well, or vice versa. Such packages also let users link pictures or sound to certain geographic units via hot links.

Sound

Maps incorporating sound used to present spatial information are often less interactive than those used to analyze or explore. As an example, consider the use of maps as indexes to sound libraries. In some electronic atlases, such as the Electromap World Atlas (see Figure 2), pointing to a country on a world map starts the national anthem of that country. Sound might also be applied as background music to embellish a mapped phenomenon, such as industry, infrastructure, or history. In these examples, sound is used simply to enhance the graphics.

The nature of sound (frequency or pitch) can also be used to offer the user additional information about the phenomena being visualized. The location of a pointing device in the map, for instance, might define the volume of the noise. Moving the pointer to a less accurate region would increase the noise level. Both examples relate to data analysis. The same approach could be used in data exploration: For exploring a country's languages, for example, moving the mouse across a map might start a short sentence in each region's dialect.

Text

GIS is probably the best representation of the link between a map and text (the GIS database). Imagine a map with a country's population density, in which all provinces are colored according to one of four different classes applied. To enhance the presentation, the user can point to a

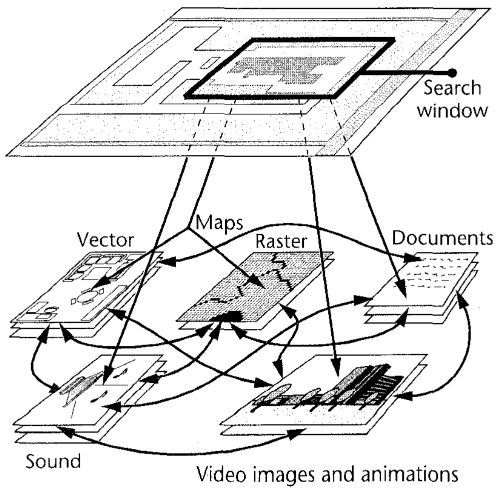

Figure 4. The hypermap concept of geo-referenced multimedia, showing the links between individual multimedia components and the map.

province, which will result in the display of its name and the actual population density. Electronic atlases often have all kinds of encyclopedic information linked to the map as a whole or to individual map elements.

It is also possible to analyze or explore this textual information. For example, a user might want to compare one country's statistics on a particular phenomenon to those of another. Multimedia, however, has more to offer. Scanned text documents, such as those describing the ownership of land parcels, can be included, as can old maps, perhaps even those whose reference system is unknown and cannot be matched with the current system. Such documents would add an important historical dimension to the geographical data being explored.

Video and still images

Maps are models of reality. Linking video or photographs to the map will offer the user a different view on reality. Topographic maps present the landscape, but it is also possible to present, next to such maps, non-interpreted satellite images or aerial photographs to give the user a fuller understanding of the landscape.

The analysis of a geological map can be enhanced by showing landscape views (video or photographs) from characteristic spots in the area. A real estate agent, for example, could use the map as an index to explore all houses currently up for sale. Pointing to a specific house would show a photograph of the house, the construction drawings, images of the surrounding neighborhood, and a walkthrough video of the house's interior.

Animations

Maps often represent complex processes. Animations are a particularly expressive way to explain these processes. It is possible to present, for instance, the structure of a city, showing subsequent map layers that explain the logic or history of a certain structure or land parcel (first the basic geographic relief, followed by hydrography, infrastructure, land use, and so forth).

Animations are also an excellent way to introduce temporal components of spatial data. These might include the evolution of a river delta, the history of a region's coast line, or the weather conditions of the past week. An interesting example is ClockWork's Centennia (previously Millennium), an electronic historical atlas that shows an interactive animation of Europe's boundary changes from the year 1000 up to 1993. This type of product can be used to explore or analyze the history of Europe or other regions.

Putting it all together

The usefulness of individual multimedia elements and the ways they are linked to the map must be judged according to the purpose (exploration, analysis, or presentation). Also, because such components will probably be used together, interface and structuring will require special attention. This is especially so if you intend to answer the question raised at the beginning: "Can we still handle it?" Most examples described above are realized as stand-alone projects. To adequately and effectively incorporate them into a full GIS environment requires further study.

Introducing the hypermap

In the examples in the previous section, the map was viewed as a way to link and order individual multimedia components. For users of spatial data, a map is a natural data access medium or interface. The introduction of multimedia, however, also introduces structuring and interface problems, because multimedia permits the combination of geo-referenced and non-geo-referenced data. To address these problems, I discuss the hypermap concept. From a visualization perspective, a hypermap can play a key role in structuring the individual multimedia components with respect to each other and the map. Hypermaps will let users navigate data sets not only by theme but also spatially.

A hypermap can be described as geo-referenced multimedia. This concept, introduced by Laurini,[10] is based on hypertext and hyperdocument principles. Hypertext refers to a set of nodes (abstractions of text or graphics) connected by links that offer the user a nonsequential tour around the data. Apple's HyperCard made this technique widely available. Hyperdocuments introduce multimedia components into the HyperCard concept. Hypermaps introduce spatial referencing to all components in the system and allow for a spatial and thematic navigation around the data. All possible links are predetermined, but individual users do not necessarily follow the same paths.

An example, illustrated in Figure 4, shows how hypermaps might be used. First, defining a search window makes available all information in the system in relation to the area chosen. In the figure, an area around a building on the university campus is indicated in the main map. Identifying a specific building or complex on the map could then give access to more detailed maps and plans of the area's sewerage system, individual floorplans, their photographs, or a video of daily life in the building. It would also be possible to get an overview of the nature of the lectures given at that location. In the foreign language department, for example, the notes for a particular course can be read or heard. Pointing in the lecture room where the course is given returns the user to the map. Spatial and thematic links are plentiful, with the map as a starting point.

We are developing the hypermap in an authorware environment using IconAuthor software. The prototype uses the Delft University of Technology campus as a sample area and will incorporate the multimedia components described above. Individual items will have coordinates attached and, when relevant, will be connected by traditional hyperlinks as well. These will let the user select an area on the campus map and get a list of available elements with their links. Our research is currently focusing on the spatial search engine.

The prototype will also be available on the World Wide Web as part of the activities of the Commision on Visualization of the International Cartographic Association. See their Web site at http://www.gis.psu.edu/ICAvis.html.

Conclusion

Incorporating multimedia components such as sound, text, video and still images, and animations in a GIS environment presents new opportunities and challenges for data analysis and integration. The technology for incorporating multimedia into GIS creates an infrastructure that offers users powerful new interactive visualization environments. In addition to the traditional presentation of spatial data, interactive maps can be used to analyze and explore these data.

Experiments with individual multimedia components in relation to spatial data have proved promising. The hypermap concept should be further researched as a tool to structure these non-geo-referenced data in relation to the map. This requires a parallel development of cartographic design approaches to meet GIS visualization requirements for most productively exploring, analyzing, and presenting spatial data. **MM**

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