Proactive Graphics for Exploratory Visualization of Biogeographical Data

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Developments in software functionality afford new opportunities for cartographic visualization that improve capabilities for data exploration. By using proactive tools such as animation and hypermedia, users may browse database contents to view the organization of the data as well as the organization of the database. When visual tools are proactive, users initiate queries and steer data presentation in a manner consistent with the associative power of the human intellect. This paper argues for increased emphasis on proactivity in designing cartographic displays. A hypermedia implementation is presented for a biogeographical database. Software functions include animation and hypermedia for browsing data at multiple scales and times. Issues of graphical design and hypermedia navigation are emphasized.

EXPLORATORY VISUALIZATION

Traditionally, cartographic displays have been designed for illustration. Reference and navigational maps illustrate the geography of a place; thematic maps depict statistical measures or the results of modeling and analysis. Cartographic illustration fills an important niche in geography, which like many scientific disciplines, relies heavily upon observation and good description. It is equally important to consider analytical roles for graphics in geographical research, and several authors have argued convincingly that cartographic displays may be designed for analysis as well as for illustration (MacEachren 1994; Buttenfield 1993; MacEachren et al 1992; Buttenfield and Mackaness 1991; Buttenfield and Ganter 1990; MacEachren and Ganter 1990).

DiBiase (1990) identifies four areas in which maps contribute to a research process: presentation, exploration, confirmation, and synthesis. Notably, the final three areas are based in analytical roles. Exploration graphics provide visual means to search for patterns and trends that may or may not be anticipated. In confirmation, graphics may be applied to pose hypotheses and make deductions. Graphical tools for synthesis are used in support of inference and induction. MacEachren's (1994) monograph in environmental science exemplifies maps in each area.

GIS applications offer a broad context for analytical graphics. In GIS environments, where so much of the information stream is iconic, users can look at map displays but cannot use them to direct analytical tasks. They can change a map's appearance (its symbology or data classification, for example), but this is only a part of analysis. What is needed are GIS software functions that manipulate maps to manipulate the underlying data. These functions will empower users to steer spatial modeling, to perform cartometric analysis, to access on-line documentation, and to perform spatial query (Buttenfield 1993).

This paper focuses upon spatial query, which is a form of data exploration. Graphical displays can facilitate database exploration, relying upon the natural acuity of viewers to search for possibly contradictory patterns. In addition, graphical displays may guide database query design, providing visual means to identify either logical inconsistencies or barriers to information access. The biogeographical example presented below implements graphical tools to direct database query and proposes graphical tools to mediate database navigation.

PROACTIVE GRAPHICS AND GIS

As a form of visual thinking (DiBiase 1990; Arnheim 1971), the key to success in data exploration lies in the ability to manipulate information freely. For example, exploration of enumerated data can be accomplished by generating a series of choropleth maps, each with a slightly different classification scheme. Egbert and Slocum (1992) have implemented software tools for this type of data exploration. However, designing exploratory graphics requires a certain responsibility, of course, since it is well known that biases may be introduced in the packaging of any factual information. Visual presentation of spatial data is no exception. Viewers have perceptual and cognitive limitations that can be partially compensated for by utilizing good principles of cartographic design. The ideal spatial data exploration software should allow users to initiate data queries iconically and to steer data exploration in a manner consistent with the associative power of the human intellect.

This is not a new idea. In 1945, President Roosevelt's Science Advisor, Vannevar Bush, developed the concept of a *Memex*, a tool for linking any two items in a large collection of information. Bush (1945) stated that the human mind operates most efficiently by association and "logical leaps" (as opposed to exhaustive tracking along a single logical sequence). From a contemporary human factors perspective, software systems offering query by association are easier to learn and use than systems offering relational (Boolean) query (Lachman et al 1979; Smith and Weiss 1988).

Two aspects of user requirements must be recognized when developing software tools that rely upon association. First, there is the issue of information distribution. Sir Francis Bacon's maxim that "Knowledge is power" applies to GIS, as it does to any automated information management system. In an associative environment, the receiving of information (through a successful data query, e.g.) is likely to generate a demand for further information. Distribution is facilitated by many software tools (most notably data and image compression and graphical user interfaces [GUI]). However, advancements in software functionality increase the complexity of the software overall.

This raises the second aspect of user requirements: information access. Awareness that information is available is likely to increase the demand for that information. Database users expect that mechanics of information delivery remain transparent. Their interest is in studying the problem at hand not in having to grapple with the technology of access. There is an increasing number of GIS users, such as geologists, foresters, and urban planners, whose knowledge of spatial data is deep and whose interest in developing system expertise is shallow. Adoption of database query tools that rely on associative thinking and avoid steep learning curves will make spatial data accessible to these users and deliver a huge benefit to the scientific and lay public alike.

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Developments in hardware and software engineering bring opportunities for the creation of tools supporting these requirements. Animation provides visual exploration of seriated data (Monmonier 1993) and applications for exploring temporal change abound in the literature (see for example the bibliography by Buttenfield et al 1991). Multimedia tools integrate multiple modes of presentation, including text, still graphics, animation, sonification, and video capture. Monmonier (1992) and MacDougall (1992) present excellent examples of how multimedia can be applied to spatial data exploration.

In a cognitive sense, multimedia expands the channels available to viewers for information processing. This can benefit data exploration in several ways. Offering multiple modes of presentation tends to increase user engagement with the working environment and often enhances user expectations (Scaletti and Craig 1991). Because human sensory systems excel at specific types of tasks, dividing information among several sensory modalities may reduce the complexity of the overall message (Brown et al 1989). For example, the visual system has acuity for contrast, motion, and fine detail. The auditory system excels at detecting serial patterns and attending to tasks requiring only peripheral attention. This is why it is possible for a person to drive a car through rush hour traffic while attuned to a news story on the radio.

The drawback of simple multimedia is that viewers do not have choices about what they see next. Even with "hot buttons" and interactive menu selection, viewers are limited to an information stream that has been anticipated by system designers. For database query, this means that one can only find items that have been explicitly stored in the database. When contradictory patterns are uncovered, spatial and temporal inference may be impeded.

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Hypermedia extends multimedia by linking the multiple modes transparently, permitting associative browsing and effectively transforming the user's role from interactive graphics into what can be called "proactive graphics." The term "proactive" is used here in its conventional sense of taking action before it is requested or mandated. Its connotation is assertive. The prefix "pro" is taken from the Greek *pro* meaning "prior" or "before." Interactive computing provides capabilities to respond to system dialog boxes and menus, although it is limited capabilities to take actions anticipated by system designers (e.g., opening and saving files in pre-determined formats, generating displays according to system graphic defaults). Proactive computing, also referred to "hyper-active" computing (Laurini and Thompson 1992), simulates a system responsive to commands and queries that may not have been anticipated by system designers (Buttenfield 1993).

Users of proactive systems move with apparent freedom between modes of presentation, choosing the mode best suited to the focus of their interests. For example, someone working with a biogeographical database may prefer to see a three dimensional terrain surface with cartographic symbols depicting annual and cumulative tree growth. Another user might prefer either a statistical view provided by frequency histogram or a tabulation of actual data values. Proactive database queries should allow toggling between these modes of presentation at any point in exploration. To date, GIS system designers have not incorporated proactive tools for database query, although iconic tools to change map appearance have become common.

Many current activities implementing proactive browsing tools are not reported in conventional publishing outlets but can be viewed simply by "surfing" the internet. Fully operational proactive systems incorporate a scripting language for users to define their own commands or navigational links. Examples of scripting languages include "html" (hypertext macro language) on WAIS and MOSAIC, which has limited graphical functions. The scripting language used for the hypermedia application described in this paper is called "Lingo," and forms part of the Macintosh-based package Macromedia DIRECTOR.

A HYPERMEDIA EXAMPLE: RADIAL GROWTH IN TREMBLING ASPENS

The example prototype[1] is based on Jelinski's (1987) dissertation research associating environmental constraints in the Waterton Lakes National Park with radial growth of trembling aspens. Trembling aspens reproduce asexually, and therefore, the clones are genetically identical, which

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[1] The prototype for *Aspens* is available on floppy disk and through anonymous ftp (file name: aspens.sea.hqx. For information on obtaining a copy see the *Message from the Editor* (page 1).

makes them ideal candidates for biogeographical study. Jelinski was interested in the apparent contradiction that radial growth rates were higher where local environmental conditions (elevation, precipitation, and soils) were more harsh. His analysis was based on numerical modeling.

After Jelinski completed his work, the authors of the prototype created a hypermedia version of his database with the intent of revisiting the research problem from a perspective of exploring apparently contradictory patterns using software tools that were both iconic and proactive. Iconic tools were chosen to embed database navigation into a metaphor of map use. Users can pose queries of the form "Zoom into the map and show me the data for this particular study site" by clicking on a map symbol representing the study site. The query "Present a statistical summary of this site's data" is enabled by clicking on the study site label. Proactive tools were chosen on the premise that exploration would be most productive when the information stream could be manipulated freely. The authors felt that proactive graphical tools should improve distillation of contradictory patterns simply by improving access to all possible views on the database.

USER NEEDS FOR EXPLORING CONTRADICTORY PATTERNS

The data includes radial growth aggregated at two levels of resolution and collected for a forty year time period (1947-1986). Six study sites within the Park are identified at the coarse level of resolution, based upon differing environmental factors. At a finer level of resolution, each study site contains either five or six aspen clones. Two study sites lie on the prairie that is at the mouth of a sinuous valley, have a low annual precipitation (75 - 100 mm.), and soils composed of glacial outwash and debris. Two other sites are located four kilometers up the valley: one in alpine grassland and the other at a higher elevation near the treeline. A fifth site lies in the same valley three kilometers beyond, where precipitation is less arid (100 - 124 mm.). A sixth study site lies to the south in a different valley, where precipitation is high (124 - 155 mm.), soil is fertile, and local conditions would appear optimal for aspen growth. The contradiction is that, for the forty year period in question, radial growth is not maximized at this site but in the prairie sites, where conditions are more hostile.

The set of user requirements accounted for in designing the hypermedia document were straightforward enough to predict but somewhat complicated to implement. Users browsing the database want continual access to both graphical information and the geographic descriptions summarized above. Provision of the graphical information has to be flexible because it is difficult to predict a user's desire to view data as a table of numerical values, as a statistical chart, or in map form. Regardless of the presentation format, the level of resolution and the specific year must be clearly indicated. Temporal and spatial presentations have to remain stable, meaning that if a user changes the spatial resolution, the timeframe should not change.

Lastly, the hypermedia document needs to be designed in a dynamic rather than a static format. Two purposes are served by this. First, animation or a changing display lets users recognize a graphic that is at least active if not proactive. The sooner graphical activity is recognized, the more quickly data will be explored. Second, the purpose of the visual presentation format is to make the geographical contradiction apparent so that users do not have to dig it out haphazardly from the volume of data. The visual display is intended to put the question "Why do aspens grow more rigorously in hostile conditions?" on the table. It is not the purpose of the graphic to answer the question so much as to let the question drive the user's curiosity about information contained in the database. The graphical impression guides database browsing. Since the contradiction becomes evident over time, a dynamic display format is the obvious choice for visual emphasis.

DESIGN AND IMPLEMENTATION

The document's graphical design is centered around an animation draped over fishnet terrain. In the animation, changing symbol size represents annual incremental growth, and symbol color (hue and saturation) represents cumulative growth for the forty year (1947-1986) period. Size progressions are scaled according to Flannery (1971); the eight-shade color progression ranges from saturated yellow (low cumulative growth) to low value green (high growth). The animation operates at two levels of resolution. At the coarse level, leaf symbols depict growth for the six study sites, and the terrain model covers the entire Waterton Lakes National Park (Figure 1 [top], page 17). Six different animations are available at the fine level (Figure 1 [bottom], page 17), showing growth for the five clones selected at each study site. The map symbol chosen for this level depicts a clump of trees to represent the forty aspens sampled in each clone. Marginalia include a bar graph showing all years of aspen growth, a map legend identifying color classes, a timeline cumulating growth patterns year by year, and an "Information/Help" button.

The implementation is a working prototype with full hypermedia functionality. As described above, the default view is cartographic. Alternatives for statistical graphics or numeric tabulation are available at any time. Instructions for changing the display are provided by clicking on the "Information/Help" button, as are text screens containing geographical descriptions of the Park and the study sites. Informational displays on trembling aspens include text, range maps for North America, and photographic images. Information about the authors is also available. The animation runs by default–the screen display remains dynamic even if the user takes no action. The animation can be paused, enabling users to freeze the animation to examine aspen growth for specific years. Iconic toggles are also available, allowing the user to change the zoom in to a finer level of resolution or to pan across to view a different study site.

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Implementing scale changes on demand has proven to be the most intricate programming task to be solved. Users viewing data who toggle to the finer level of resolution will want the map scale to change but the time period to remain the same. One option is to store all possible timeframes (40) for all possible map views (six study site maps and one Park map) as 280 individual castmembers and write a Lingo script to direct which one should appear for the current year in display. This solution would entail very large storage requirements. The option that is implemented reads in growth values at the start and computes seven simultaneous views as the animation years go by. Regardless of what study site a user zooms to (or when) symbol size and color are available for the correct site in the correct year. All that really needs to be decided at the system level is which of seven sites (rather than which of 280 views) to display.

This design responds to user requirements stated above. Browsing and data queries are both iconic. The user can follow associative thinking and logical leaps to view maps, statistics, text or metadata, and in these respects, the prototype is proactive. It is not however, fully proactive, since it lacks a scripting language for viewers to develop their own links and command structures. In order to implement these types of proactive functions, users will need to have access to existing navigational paths. Here too, graphical tools can contribute to proactivity.

NAVIGATIONAL LINKS

Graphical tools can be used to examine or explore the structure of the hypermedia document itself, as well as reinforcing the spatial metaphor (Tilton and Andrews 1994). A map displaying existing hypermedia links provides users an exposition of the authored relationships and database paths they may travel. It provides system designers with a visual display of the document's navigational structure during development and contributes to system debugging or expansion. The objective to achieve in a proactive environment is to meet the objective that all displays appear to lead to other displays. System designers rely on users' natural curiosity to see what lies behind the panel.

At the extreme, hypermedia systems can be designed such that every item on the screen is "hot": no matter where a user clicks, a navigational link is enabled. Some commercial hypermedia products (for example, Microsoft Corporation's encyclopedic atlas *Encarta*) are designed this way. Other products, such as Borland's *Just Grandma and Me* offer screens where discrete items are "hot." The Aspens prototype is implemented with discrete navigational links. Users quickly figure out that where navigational links exist; they are most often attached to green objects or green text items.

Figure 2 (page 18) shows a navigational map of the current version of the Aspens prototype. In the Figure, the bar graph icons represent timelines that appear in all map views. The conic section icons represent map legends appearing in all map views. Icons depicting pages of text, photographic images, and maps identify screens of analogous content. Lines between icons identify working navigational links.

At present, this navigational map is not available in the prototype, although versions of it have been used during design and implementation, if only to keep track of what has been implemented to date. Users at present have neither a comprehensive idea of the extent of the database they may query nor an idea of where icon links might take them. Many users do not realize at first that items in the display are "hot" because their appearance differs from the radio buttons and checkboxes customary in other multimedia and hypermedia displays. However, it takes only a brief demonstration to alert users to the rich fabric of navigational links underlying any hypermedia document. Very quickly, users are clicking on anything and everything to identify "hot" items embedded in the graphical display. Making the navigational map available at any point in the prototype could serve users who become disoriented.

Presentation of the navigational map could serve a more proactive role. While providing information about the organization of the prototype (and by implication, of the database), the graphic itself could provide an active mechanism for improving database query and access. Benoit Mandelbrot (1994) was recently quoted as saying, "Pictures are very helpful in understanding complicated phenomena by finding out how simple components get organized. You look at something and understand where to look next." If the purpose of a graphic is to identify where to explore next, why not embed that graphic with software tools to go there and explore it? It's more than a rhetorical question, and programming tools currently exist to address the issue. Moreover, cartographers are ideally suited to generate such tools, given the strong disciplinary tradition attending to graphical design and communication.

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One can envision many applications for generating a proactive version of a navigational map. For example, many screens in the current prototype are "dead ends" in the sense that the only available navigational path retraces the previous link. Again, this is identifiable to users, since the cursor changes shape on these screens and starts to blink. For example, the numeric tabulation screens are currently dead ends. If accessed from the Park map, one can only return to the Park map. One can imagine a user who wants to set up a link to jump from the numeric table listing data for each study site to a map of one of the sites. A proactive navigational display might include graphical functions on a proactive navigational map such that the link is established simply by dragging a line from the table icon over to the study site map icon.

Another proactive application for a navigational map would reflect the frequency with which particular navigational links are traveled by perhaps scaling the width of links according to the number of times each has been accessed. For efficiency, links that are not used could be eliminated to tailor the document to a particular class of users. Alternatively, specific paths could be rendered inactive by recoloring or "graying out" links. This might be beneficial for securing access when portions of the database undergo revision or update, without shutting down access to the entire database. The recoloring would also alert users who view the navigational map that a database upgrade is in progress.

SUMMARY

This paper argues for integrating proactivity into graphical displays to assist with database query and the exploration of contradictory patterns. Proactive graphics permit spatial tasks to be accomplished iconically and provide a means for users to focus upon the substance of their research instead of having to attend to system commands. The natural curiosity of users to find out what lies over the next hill can be exploited successfully in designing proactive database query tools that rely on associative intellectual skills. Embedding such tools seamlessly into graphical displays allows direct manipulation of information, which is a comfortable type of interface metaphor for most users.

A working prototype of radial growth in aspens demonstrates that proactive tools are amenable to data exploration. However, many obvious hypermedia links are missing. Users have suggested incorporating photographs of the study sites, capabilities for rotating the terrain surfaces, reversing the animation, and (most commonly) the ability to jump to a specific year in the animation. The prototype also lacks functions to extract data, maps or text information and save it to a file, even though these items are stored and accessible. For these reasons, it is referred to as a working prototype, as opposed to a full-blown proactive database query system.

The aspens prototype is presented to strengthen the argument that graphics can be utilized for analysis as well as for illustration. Here, the analysis is exploratory, and the graphic display provides a clear indication of the contradiction between environmental conditions and radial aspen growth. Iconic tools facilitate exploration because users can manipulate the form in which data is accessed from the database. These tools are proactive in the sense that users make their own choices about what parts of the database they will browse next. Further, database browsing is accomplished by map browsing–direct manipulation of the icon representing the item of interest. While it is true that the item on the map is not the same as the feature it represents, querying the map item becomes a direct metaphor for querying the database.

One can extend the metaphor to other types of analytical tasks, where proactive tools could be designed to steer computations or perform cartometric analysis or locational modeling. Incorporating proactivity would in every case provide a metaphor where changing the information display would change the state of the system, of the model, of the database, or of its access paths. This approach moves software tools for geographical analysis beyond designing a transparent interface. It proposes throwing the interface away. The idea may seem radical and, indeed, is fraught with questions about who takes responsibility for preserving data versions and who protects users from themselves. These are important issues that must be addressed.

Integration of proactive tools is likely to improve the insights that can be gained from the incredible volumes of digital geographical data that continue to become available. And, it is likely that direct manipulation tools and metaphors will become conventional in information systems software simply because the direct manipulation metaphor is so seamless to users. It is completely natural to adapt to direct manipulation interfaces once they are recognized. Weiser (1991) comments that what is at first novel becomes commonplace when it becomes invisible. For example, no one consciously reads a street sign or the floor indicator on an elevator. "The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it" (Weiser 1991, 94). Cartographic emphasis on designing visual displays that maximize effective communication can lend major insights into the design, implementation, and evaluation of proactive software tools. Here is a scientific niche just waiting to be filled.

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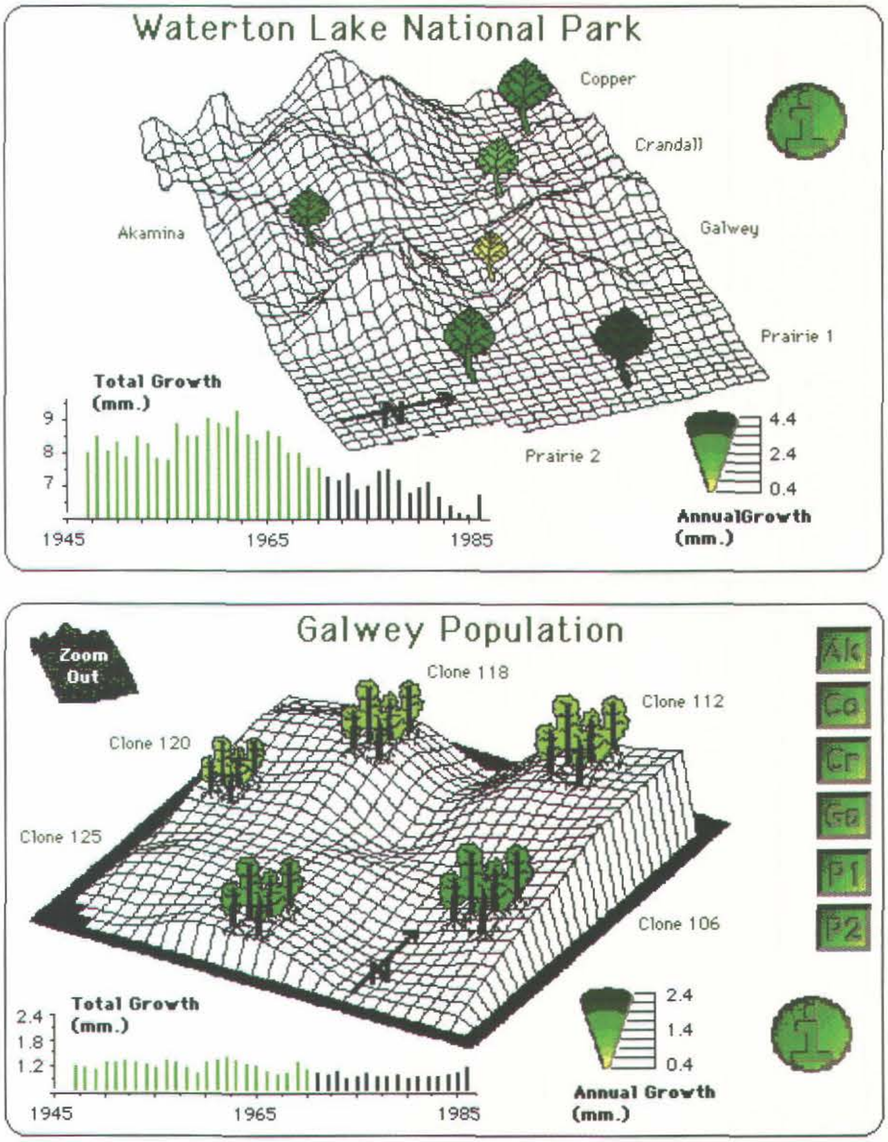

Figure 1. Two sample screens from the aspens prototype. Upper image shows coarse resolution view, lower image shows one of six finer resolution views, for Galwey study site. Items appear in their approximate locations. Green items provide navigational links to other parts of the database.

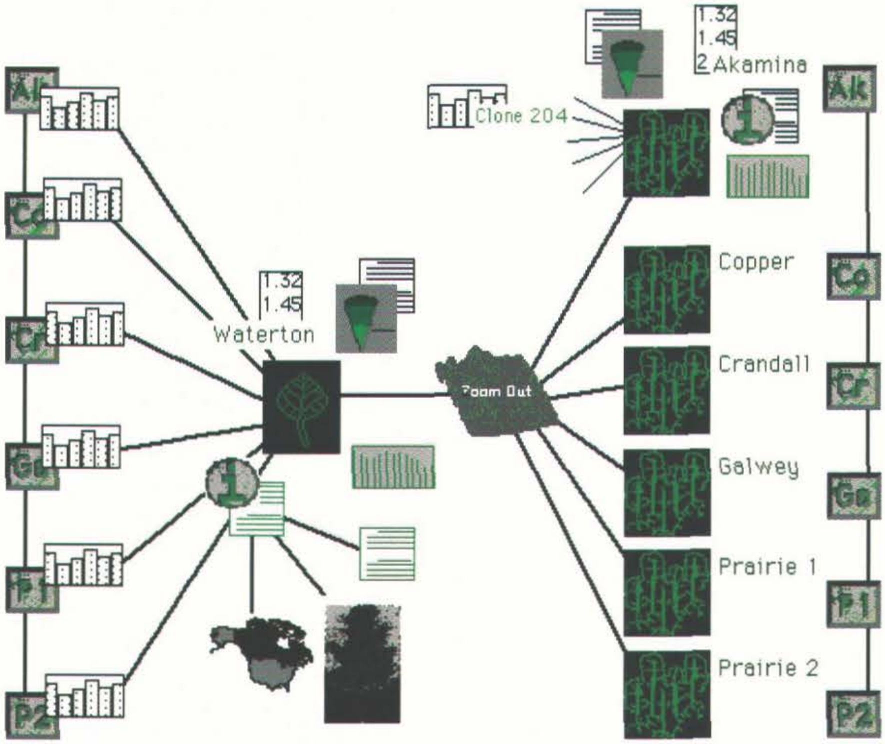

Figure 2. Navigational map for the aspens prototype. Green items contain navigational links to other parts of the data base. Link paths are shown by black lines. All six study site screens contain the same items as the Akamina site.

RESUMEN

Los avances en la funcionalidad del software ofrecen nuevas oportunidades para la visualización de la cartografía, lo que permite mejorar la exploración de datos. Por medio de herramientas proactivas, tales como: animación e hipermedia, los usuarios pueden ver la información sobre los datos, como también la organización de los mismos. Cuando las herramientas visuales son proactivas, los usuarios pueden preguntar y manejar la presentación de datos de manera consistente con el poder asociativo del intelecto humano. Este compendio enfatiza la necesidad de incrementar proactividad en los diseños cartográficos. También se presenta la implementación hipermedia para información de datos biogeográficos. Las funciones del software incluyen animación e hipermedia para la búsqueda de datos en tiempos y escalas diferentes.

SOMMAIRE

De nouveaux développements des fonctionnalités logicielles offrent à la visualisation cartographique de nouvelles opportunités qui améliorent les possibilités d'exploration des données. Grâce à des outils interactifs tels que l'animation et les hypermédias, les utilisateurs peuvent naviguer à travers une base de données pour observer l'organisation des données et celle de leur base. Lorsque les outils visuels sont interactifs, les utilisateurs entament l'interrogation et dirigent la présentation des données d'une manière qui convient au pouvoir associatif de l'intellect humain. Ce document plaide pour une emphase accrue sur l'interactivité dans la conception des expositions cartographiques. Une exécution hypermédiatique est présentée pour une base de données biogéographiques. Les fonctions logicielles incluent l'animation et les hypermédias pour passer en revue les données à des échelles et des heures multiples. Les questions traitant de la conception graphique et de la navigation hypermédiatique sont soulignées. ❑

Color figures for "Designing Animated Maps for a Multimedia Encyclopedia," pp. 3-7.

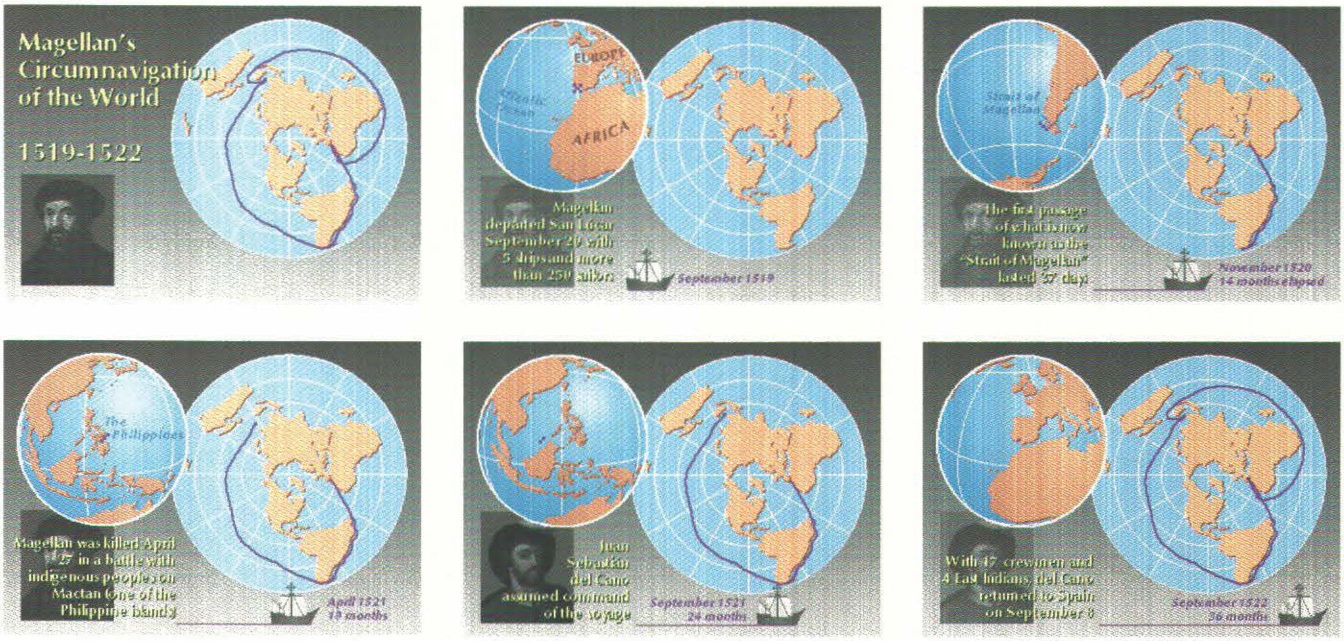

Figure 1: Six frames from a prototype animation of Magellan's circumnavigation (reduced to approximately 38 percent of original size).

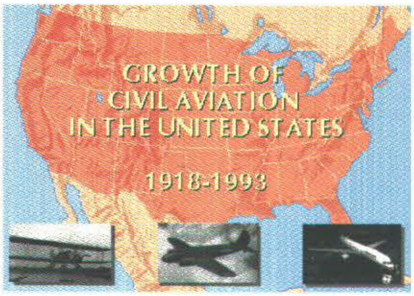

Figure 2: One frame from a prototype animation of the growth of civil aviation in the United States (reduced to approximately 38 percent of original size).

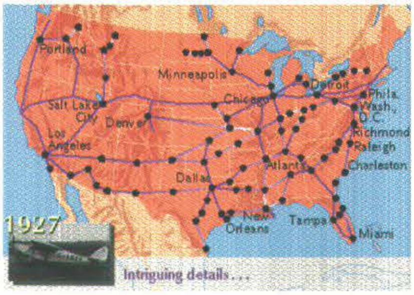

Figure 3: One frame from a prototype animation with color cycled flight paths (reduced to approximately 38 percent of original size).

Figure 5: One frame from a "multimedia map" of the American Revolutionary War from the 1994 edition of the "New Grolier Multimedia Encyclopedia" (reduced to approximately 38 percent of original size).

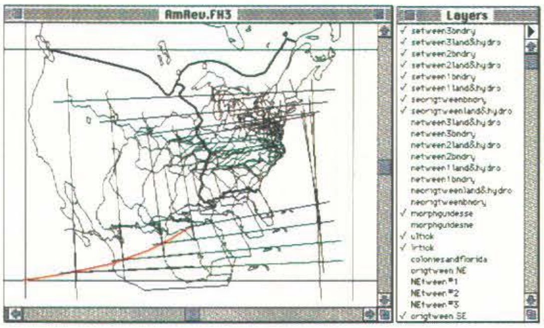

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Figure 6: Digital compilation of the zoom shown in Figure 5.