PROACTIVE GRAPHICS AND GIS:
PROTOTYPE TOOLS FOR QUERY, MODELING AND DISPLAY

Barbara P. Buttenfield
NCGIA, Department of Geography, 105 Wilkeson,
SUNY-Buffalo, Buffalo NY 14261
internet geobabs@ubvms.cc.buffalo.edu

ABSTRACT

Recent developments in GIS hardware and software bring opportunities for creation of new tools for geographical research. Tools include multiple modes of presentation (multimedia) adding animation, sonification and video capture to static displays of text, tables, maps and images. These modes expand the available information channels, and empower viewer to incorporate conventional with experimental modes of data presentation. Hypermedia extends multimedia by linking the multiple channels of information transparently, enabling the viewer to choose the mode best suited to their preference and their application. Integrated with GIS techniques, hypermedia provides proactive control for steering computations, for spatial modeling, and for iconic query. Hypermedia tools effectively transform the user's role from what has been termed 'interactive graphics' into 'proactive graphics' (the term is proposed by this author).

This paper presents proactive tools for specific GIS operations, including database query (automated feature identification), modeling (calibration of a location-allocation model) and map display (automatic scale-changing and symbol modification). Implementations of proactive tools must consider both graphical principles (design and methods for evaluation) and computational issues (creation and maintenance of links between the prototype and the database or model). These issues will be discussed in the paper.

BACKGROUND

The growth of GIS as a scientific discipline has followed several prerequisite factors. The first relates to the commitment of U.S. national agencies in several countries to generate spatial data in digital form, and to place that information in the public domain. A second factor relates to software developments integrating spatial statistical models with GIS operations. A third factor relates to developments in data representation technology and techniques, including internal representations (improved data structures and algorithms for searching and sorting), and external representation techniques (advances in algorithms for data display). The research presented in this paper focuses upon visual tools that link internal and external data representations transparently.

The reliance in GIS upon visualization has for the most part been limited to external representation. This is ironic, given the reliance in GIS upon both display and upon analytical exploration. Both have strong traditions emphasizing the use of graphics to analyze data patterns, to generate and in some cases to test hypotheses (Cleveland, 1983). Given the current state of knowledge and current technology, visual tools in GIS can be implemented now to expand and refine analytical powers for exploration of geographical and statistical landscapes.

The Scientific Visualization initiative begun at the National Science Foundation (McCormick et al, 1987) marks a chronological point at which the scientific community formally recognized the potential for visual tools to be integrated into numeric modeling and analysis. The McCormick Report defines visualization as

"... a method of computing. It transforms the symbolic into the geometric, enabling researchers to observe their simulations and computations. ... Visualization embraces both image understanding and image synthesis. That is, visualization is a tool both for interpreting image data in a computer, and for generating images from complex multi-dimensional data sets." Implicit in these statements is a belief that visual displays can be used to analyze as well as to illustrate spatial information, to generate hypotheses as well as interpret scientific results. At the time the McCormick Report was published, the advent of low-cost graphics software was substantially changing methods of data representation. Exploratory Data Analysis (EDA) techniques developed by Tukey and colleagues at Bell Labs during the past decade have a strong graphical component, and their incorporation into statistical packages effectively tied graphics to statistical description and exploration. Demonstrations of individual techniques such as data brushing have begun to appear in the cartographic literature (MacDougall, 1992; Monmonier, 1992).

In GIS interactive computing environments, then as now, users are presented with map displays based upon graphical defaults that rarely ascribe to sound principles of cartographic design (Weibel and Buttenfield, 1992). In spite of the fact that GIS systems rely heavily on map displays of archived data, data manipulation and map manipulation remain isolated tasks. For the most part, the dialog between system and user remains constrained by a limited number of commands pre-defined by system developers. From a human factors point of view, it seems likely that requiring that users type keyboard commands to modify maps and screen displays reduces efficiency for the user, and may increase fatigue levels and propagate 'use error' (Beard, 1989). This paper argues for refinement of current interactive graphics modes to adopt 'proactive' tools that will extend and facilitate GIS users capabilities.

CURRENT NEED FOR IMPROVING VISUAL TOOLS

Capabilities are at hand now to improve visualization tools in GIS environments. Currently available tools incorporate multiple modes for presenting information, including text and graphics and animation, sonification and video capture. Multimedia presentations are intended to expand the information processing channels available to viewers. Examples of geographic multimedia applications include electronic atlases such as produced for the State of Arkansas by Richard Smith, and Rhind et al's (1988) Domesday Machine.

Hypermedia is a special form of multimedia, in which documents contain a collation of disparate media forms presented on a single presentation device, typically a computer. Hypermedia extends multimedia by linking the multiple channels of information transparently. That is, users can select a mode of information presentation they prefer, and can make logical leaps in a thread of database query that may not have been anticipated by system designers (Barker and Tucker, 1990 p. 20). Hypermedia provides an excellent example of proactive software functionality.

Chronology of Hypermedia Development

In 1945, President Roosevelt's Science Advisor developed the concept of a "memex", a tool for linking any two items in large collections of information (Bush, 1945). Bush (1945, p. 106) stated that the human mind operates most efficiently by association and 'logical leaps' as opposed to following a single logical sequence. Systems offering query by association are considered easier to learn and to use in the context of the natural structure of human memory proposed by current semantic network models (Lachman et al, 1979; Smith and Weiss, 1988).

Hypertext has remained the most commonly encountered form of hypermedia. Engelbart (1963) developed the NLS (oNLine System) at Stanford that incorporated hyperlinks into a text database. Other hypertext systems have included Nelson's XANADU system and Van Dam's Hypertext Editing System (Conklin, 1987). Brown University's Intermedia Project exemplifies more recent systems extending hypertext capabilities by incorporation of links with graphics displays. Apple Computer's HyperCard package, marketed in the last decade, provided a first attempt to merge hypertext functions with multimedia including graphics, crude animation, and sound. Additionally, HyperCard included a scripting language (HyperTalk) for linking text, graphics and sound using an index card metaphor. Scripting capabilities are fundamental to proactive graphics: GIS users should be able to script the paths they choose to follow for internal and external data representation. To date, these capabilities are not readily available.

Following and expanding upon HyperCard, other scripting languages have been developed, including Kaleida SCRIPT-X developed jointly by Apple Computer and Toshiba Corporation. The Macintosh product Macromedia Director combines animation functions, a graphics editing module and a hypermedia scripting language (LINGO) with sound channels and video capture; this product and this platform continue to be the choice for many professional multimedia and hypermedia producers. Cartographic adoption of animation authoring tools has begun to reappear in the literature after a 10-15 year moratorium (Weber and Buttenfield, 1993; MacEachren and DiBiase, 1991; Gersmehl, 1990), although to date the animations are illustrative, and do not incorporate proactive functions. One exception to this is a hypertext document under development at NCGIA-Buffalo (Buttenfield and Skupin, 1993) designed as an online browser for federal digital data product specifications. In its current version, scripting capabilities are exploited, but are not yet available to users. This means that while an infinite number of paths might be traversed through the Browser, users must reconstruct their path each time they browse -- they cannot 'script' a particular path to follow in future browsing, nor document where in the browser they have traveled so far. The author's vision for fully operational proactive graphics incorporates these functions as minimal system requirements.

Applications of Hypermedia to Information Systems

Examples of hypermedia systems in current use are widespread. At the National Gallery in London, a hypermedia tourguide system gives visitors access to museum holdings, with online images of paintings arranged by artist, by nation, or by century. Visitors can select the artwork they wish to see and request a hardcopy map of the museum guiding them to the art they have selected. In other domains, hypermedia packages are used in large office complexes to configure heating/cooling systems, and to install and maintain integrated software, such as the VAX VMS operating systems (Horton, 1991). Hypermedia systems maintain links across distributed networks, such as 'anonymous ftp' and some online bulletin board systems (Martin, 1990). In every case, the information at issue exists in multiple formats, and decision support is based on associating a full range of information presentation modes.

It seems obvious to apply hypermedia to the interrelated data types common in GIS and Spatial Decision Support Systems (SDSS). Multiple modes of information characterize the nature of geographical data. Tabular, numeric and cartographic information each serve an important role in GIS query, analysis, and display. To date, system designers have not incorporated multimedia and hypermedia methods in GIS functionality. Hypermedia may empower viewer flexibility by incorporating conventional with experimental modes of data presentation, enabling the viewer to choose. Hypermedia links in GIS databases may remove constraints to explore information in a predetermined sequence or by

isolated commands. Integrated with GIS techniques, hypermedia should provide proactive command for steering computations, interactive modeling, and queries.

The added challenge for GIS functions is the integration of internal and external data representation, discussed above. GIS users should be able to manipulate external representations (map or chart displays) to modify internal representations (database contents and pointers). Human acuity for visual pattern recognition lends itself readily to understanding spatial patterns. Much of GIS user activity involves making maps, changing maps, and compositing maps. The continuing insistence of GIS system designers that users must learn some arcane syntax of typed commands to perform map operations such as buffering and overlay is incomprehensible, given current state of knowledge and technology in other scientific disciplines. Why should users be forced to separate spatial data manipulation from map manipulation? This is the driving force justifying adoption of proactive graphics, and the major distinction between hypermedia tools and proactive tools.

Applications of proactive tools in GIS that appear both implementable and beneficial (in the sense of enabling better access and use of information) include four areas of activity.

- For **spatial query**, which in most GIS systems revolves around combination of Boolean text strings, a hypermedia system might allow proactive selection ('point-and-click') of map objects or spreadsheet data objects to be expanded upon, literally, numerically, or iconically.

- For **spatial modeling**, hypermedia tools may provide proactive modification of parameters, and alert researchers to drifting values in sensitivity analysis, optimizing for equity or efficiency according to user choice.

- For **cartometric analysis and display**, hypermedia tools might steer computations, or demonstrate the impact of a particular algorithm in a particular domain.

- For **online documentation**, hypermedia systems exist now, in the form of online help systems and online system manuals. Personal computer users are commonly familiar online help files accompanying workstation software (e.g.., UNIX user's manual, Macintosh and DOS-Windows' WORD).

PROACTIVE GRAPHICAL TOOLS

What is needed to fully integrate the user into the GIS process is provision of visual tools enabling **proactive** user involvement, as opposed to **interactive** involvement. There is a need for graphics for view by people whose knowledge of a particular dataset is deep, and whose interest in developing cartographic or system expertise is overshadowed by an interest in an immediate application or domain of inquiry. These include planners, natural resource managers, and social service providers, to give some examples. In some use situations (e.g.., environmental emergency planning), the time available to become facile with system use is quite low, in contrast to the level of training required to learn most GIS command languages.

What is Proactive Visualization?

The term **proactive** is used here in its conventional sense, that refers to 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, and 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. A fully operational proactive computing environment incorporates a scripting language that allows users to implement their own commands. In GIS environments, where so much of the information stream is visual, proactive computing becomes nearly synonymous with proactive visualization, where users actively manipulate images and icons to enable system commands or database queries, and to steer modeling and computation (Parsaye et al, 1989).

Examples of Proactive GIS Tools

The first example demonstrates proactive query of map features for automatic scale changing, involving real-time coordinate simplification with viewer control. A second example demonstrates automatic feature identification. A third example simulates a location allocation model, with real-time selection of candidate facilities coupled with system adjustment of routes and additive capacities. These are not a comprehensive taxonomy, but they do provide examples of query, analysis and display in a GIS context.
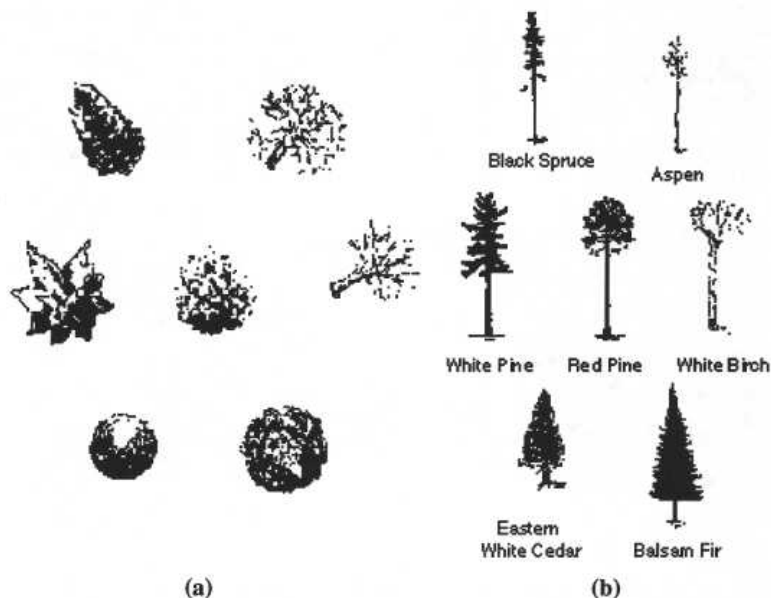

(a)   (b)

Figure 1
Photointerpretation keys often include iconic look-up tables matching
(a) overhead views with image displacement with
(b) silhouettes identifying feature shadows on flat terrain.
(Taken from Lillesand and Keifer, 1979: 132-133).

Automatic Feature Recognition (spatial query). Spatial query in most GIS systems involves forming combinations of Boolean text strings to search and select items from a database. Often the results of a query are displayed

graphically. Tomlin (1990) refers to GIS query and display collectively as "cartographic modeling". In a remote sensing application, a prototype might take the form of a photointerpretation look-up key (Avery and Berlin, 1992; Lillesand and Kiefer, 1979). The purpose of such keys is to identify features in an aerial photograph, where images are sometimes distorted or cast in shadow, or partially obscured by adjacent objects. Keys may provide verbal, numeric or iconic information. When photointerpretation keys are iconic, they often illustrate the appearance of a feature in displaced form, as on an unrectified photograph. Alternatives to this include keys illustrating the shadow cast by a feature upon flat terrain. The proactive tool in this type of application (Figure 1) would respond to a windowing or lasso command by searching a look-up table for possible pattern matches and displaying each of these. An expert system implementation could attach confidence values to each key in accordance with user-supplied information about the site and situation of the photograph.

Location Allocation Modeling (spatial modeling; example also reported in Buttenfield and Weber, 1993). The customary sequence of actions in location modeling is to input locations and capacities for nodes from keyboard and/or digitizer, and to allocate nodes to central facilities by attribute entry. Selection and modification of parameters are accomplished in batch mode; modeling runs are not directly linked to the GIS system nor to its associated database. Visualization tools are limited to illustration of solutions (Armstrong et al, 1992).

Proactive graphics may assist with model preparation and analysis, as for school bus allocations. (Figure 2). In the figure, the diamond represents a school whose district is experiencing population growth. Circles represent existing bus drop points, with shading representing the capacity of students at each location. The problem of adding additional drop points can be solved by pointing to locate a new drop point, and dragging a straight line (shown in thick black line) over to the school to be served. A dialog box allows the user to enter capacity figures. The system response is displayed in the right side of the figure.
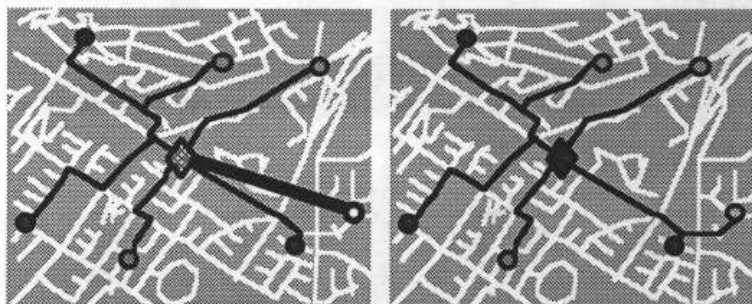

Figure 2
A Proactive Tool for Location Allocation Modeling

The allocation model selects a logical street path for the bus to follow, accommodating problems presented with the limited access highway by selecting a meaningful crossing point. Additionally, the system adjusts additive capacities at the selected drop point as well as at the intermediate points. The prototype simulates this procedure, providing a number of facility placement options that will snap into place depending on where the user points, and then provides an appropriate solution image and numeric tabulation. The number of options will depend on available computer memory, as a different solution will need to be kept in memory for each selectable option.

Automatic scale-changing (cartometric analysis and display).   It is possible to model map features, by simplification of coastline detail, aggregation of buildings or small lakes, and similar operators that reduce detail. This type of transformation belongs in the realm of display, as it is the view on the database (not the database itself) that is being modified.

The prototype simulates an application where a user must decide how detailed the representation of base map features should be for a given application. The decision involves query of coordinate strings and processing by a simplification or smoothing routine (commonly the default routine is from Douglas and Peucker, 1973). Figure 3 shows a portion of Norway's Sonnenfjord. Imagine that the user has selected this portion from the rest of the coastline using a lasso command; the proactive tool responds by placing this coastline segment into a small tear-off window floating above the base map. The user can make decisions as to how much to simplify the final base map by operating on the windowed portion. Working with a subset of the coordinate file makes it possible for the CPU to generate real-time feedback.   Proactive simplification may be guided by means of a slider bar. The resulting generalized coastline is not a simulation, but a real-time computation that the users commands proactively.
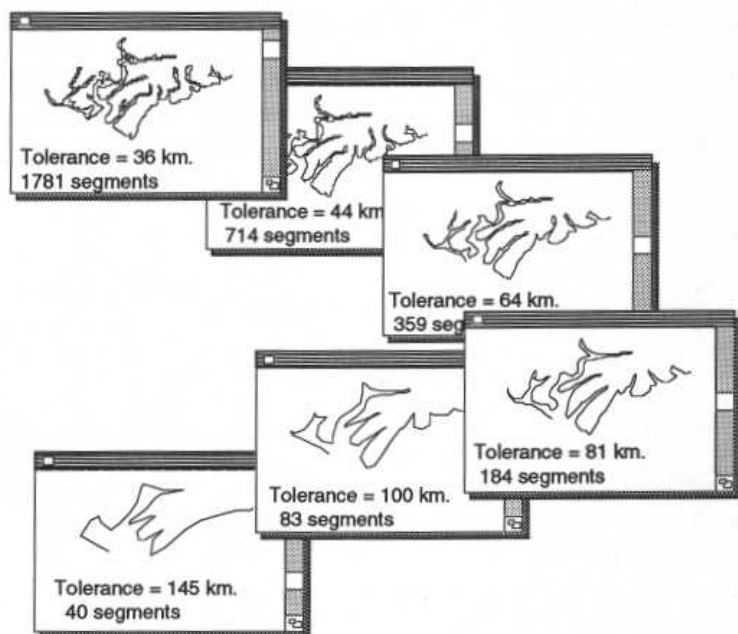

Figure 3
A Proactive Tool for Automatic Scale Changing

This is not a zoom-in with pixel replication, but a real-time query with coordinate simplification. As the user slides the scroll bar downward, the system simplifies the windowed subset of coordinates, replacing the view in the window in real-time and providing descriptive statistics (average tolerance of retained details, in kilometers, and total number of segments in this window). Once the user determines a tolerance value that looks appropriate, the system can be commanded to simplify the rest of the base map representation. Proactive visualization allows the user to see beforehand what the impact of tolerance value selection might be, without possibly wasting CPU processor cycles only to

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discover the base map is too simplified, or too complex, for the application. Variations on the prototype development include selecting a different algorithm, changing the tolerance threshold, and choosing a specific window within which the chosen simplification model and parameters should be applied.

SUMMARY

Recent developments in Geographic Information Systems (GIS) hardware and software bring opportunities for the creation of new tools for geographical research. Cartographic tools include multiple modes of presentation such as animation, sonification and video capture. Multimedia presentations are intended to expand the channels available to viewers for information processing. Hypermedia extends multimedia by linking the multiple channels of information transparently, effectively transforming the user's role from what has been termed 'interactive graphics' into what could be called 'proactive graphics'.

This paper reports on three prototype applications, demonstrating proactive spatial modeling, iconic queries, and automatic scale-changing. To date, system designers have not incorporated proactive methods in GIS functionality. Proactive tools empower viewer flexibility by incorporating conventional with experimental modes of data presentation. Proactive links in GIS databases may remove constraints to explore information in a predetermined sequence, to interact with spatial data by manipulating maps and images, in addition to or in place of conventional database SQL commands. Integrated with GIS techniques, proactive tools should provide user control for internal and external data representations.

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