

**DESIGN AND EVALUATION OF A
COMPUTERIZED DYNAMIC MAPPING SYSTEM INTERFACE**

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Executive Summary

A central premise of the research presented here is that phenomenon of interest in the study of health have geographic as well as demographic characteristics that are important to our understanding. Advances in computing technology (particularly those associated with interactivity and animation) have dramatically changed the nature of maps and the potential role they can play in health analysis. The specific goal of the research reported here was to develop and test a strategy for design of a dynamic mapping system interface directed to the analysis of multiple georeferenced variables measured at several time intervals. Two more specific objectives were initially specified: (1) to design alternative methods for displaying dynamic maps of death rate and risk factor data in a user-friendly computer system, and (2) to test these designs in an experiment where users attempt to draw inferences about changing death rate patterns and their relationship to risk factor patterns.

In meeting the project objectives, a two component prototype for geographic visualization (GVis), subsequently referred to as HealthVisA and HealthVisB, has been designed and constructed. Design followed a structured hierarchical approach (developed in previous research) that begins with development of conceptual goals, proceeds through a stage in which ways to operationalize these goals are delineated, and culminates with implementation in a selected hardware–software configuration. Conceptual goals identified for health statistics visualization are: (a) support spatial pattern analysis (for points in time), (b) facilitate an understanding of spatiotemporal processes, (c) support analysis at multiple spatial, attribute, and temporal scales and (d) address the implications of data characteristics and data processing methods for apparent spatial and spatiotemporal patterns. This framework of goals developed served as a context within which to pursue the contract objectives identified for the current research—objectives associated primarily with conceptual goal “b.”

HealthVisA emphasizes data visualization operations related particularly to meeting conceptual goal “a” and provides necessary input to HealthVisB. It is in HealthVisB where methods are implemented for displaying dynamic (and manipulable) maps of changing death rate patterns. HealthVisB is formally assessed using a combination of task analysis and verbal protocols. Nine domain experts (from NCHS and the Penn State population Research Institute) participated in the assessment, spending about one hour working with the prototype. Each participant worked through five structured tasks typical of those that an analyst would use the system for (e.g., exploration of a time series of heart rate mortality maps in an effort to uncover any systematic geographic relocations in high rate regions). This was followed by a more open-ended exploration of prostate cancer mortality. All participants actions with the system were automatically recorded. Participants were video taped while working with the system and asked to “talk aloud” about what they were doing and what they were seeing. Exit interviews were also conducted to solicit specific reactions to and suggestions about the prototype.

Based on expert feedback combined with analysis of prototype use, the dynamic mapping method implemented are successful. Participants had few problems understanding how to use the maps and tools provided and problems that did arise are ones that can be dealt with by modest redesign and/or development of brief training modules that introduce the novel visual analysis methods included in the system. Few obvious Type I visualization errors (seeing false patterns) occurred, but a number of Type II visualization errors (missing real patterns) were noted. For the latter, differences in success at noticing spatiotemporal patterns relate to differences in strategies adopted for use of the exploratory tools provided. One example of a clear difference in success with different strategies relates to the two general approaches adopted for considering time series (manual stepping through time with a VCR style control and observation of a looping animation). Three of the four participants who favored animation over manual stepping through dates noticed a distinct shift in location of high heart disease mortality rates over the five time steps included. None of the five who favored manual date stepping noticed this shift.

Formal assessment of HealthVisB combined with additional input from staff at NCHS and results of previous research leads to the following recommendations concerning design of GVis for displaying and exploring dynamic maps of death rate and risk factor data. These recommendations are elaborated upon in the final section of this report.

1. *Include animation as well as date stepping in dynamic tools for exploring time series of georeferenced data.*
2. *Consider alternatives to choropleth maps—particularly when time series animations are to be used in analysis.*
3. *Include an alternative data classification method to quantiles—one that allows comparison of absolute magnitude across time series (for specific places and for the country as a whole).*
4. *Tutorials should be created to introduce the range of novel data analysis possibilities made available by dynamic mapping.*
5. *Dynamic focusing—classification tools are successful and should be provided.*
6. *Further research should be directed to expert use of dynamic focusing and classification tools — in order to provide some general guidelines about their effective use and to determine the most effective tool design.*
7. *Use linked views to facilitate understanding of multiple variables, multiple times, and bivariate maps.*
8. *Research is required to more fully understand the implications and applications of linked views that combine space, time, and attribute information.*
9. *Univariate color scheme guidelines developed by Brewer (1994) and Brewer, et. al., 1997) are applicable to design of maps for computer display.*
10. *Provide user selectable color schemes to support data exploration.*
11. *Color schemes for cross maps and other bivariate maps must be selected with care and additional research is required to develop guidelines for their selection in the context of manipulable maps.*
12. *Additional GIS functions should be provided that allow analysts to overlay information in order to provide more geographic context for data exploration.*

Introduction

Dynamic visualization methods offer the potential to dramatically extend the role of maps in health analysis. Mapping of georeferenced health statistics has, in the past, led to insights concerning various health-environment-behavior interactions. Insights have derived from the identification of clusters of deaths on static maps (Mason et al., 1975; Pickle et al., 1987; Pickle et al., 1990) followed by comparison of the cluster locations to the mapped distribution of potential etiologic agents (Croner et al., 1992). Spatial associations identified have prompted hypotheses about the causal relations, some of which have been verified. Examples include identification of "hot spots" of esophageal cancer in China and oral cancer in the U.S. state of North Carolina (Winn et al., 1981). Static paper maps, while somewhat successful in prompting epidemiological hypotheses, impose constraints on exploration of spatial characteristics of health-environment-behavior interactions.

The goal of this project is to develop and test a strategy for design of a dynamic mapping system interface directed to the analysis of multiple georeferenced variables measured at several time intervals. Two primary objectives have been specified: (1) to design alternative methods for displaying dynamic maps of death rate and risk factor data in a user-friendly computer system, and (2) to test these designs in an experiment where users attempt to draw inferences about changing death rate patterns and their relationship to risk factor patterns.

While the primary objectives of the research are directed to particular issues of health data analysis, the representation and interface problems are more general ones associated with GVis. In designing a system to allow analysts to interact with health statistics, three independent but related GVis issues must be address: (1) map animation (and its use for representing temporal change), (2) representation methods for georeferenced multi variate display, and (3) interactive controls through which users can manipulate parameters of individual maps, map animations, and the relationships between variables. Each of these issues has been the focus of research. Little attention, however, has been directed to their integration. Thus, in addition to designing, implementing, and testing a system to deal with health data analysis, this research provides a basis for addressing these three issues as a whole rather than independently.

This report begins with an introduction to Geographic Visualization (GVis) methods. Next, a structure for guiding GVis system design is introduced. Using this approach as a framework, the design of a prototype system for visualization of spatiotemporal health statistics (referred to as HealthVis below) is presented. Methods and results of a formal assessment of one component of this prototype are then discussed. The report concludes with a set of design recommendations for moving from experimental prototype to production system, followed by brief conclusions.

Introduction to Geographic Visualization Methods

The role of maps and mapping in scientific research and policy decisions is undergoing dramatic change—change facilitated by computer systems that have transformed the map from a static data storage device to a dynamic data exploration tool. These developments in mapping correspond to broader changes in the scientific use of visual analysis associated with exploratory data analysis (EDA) and visualization in scientific computing (ViSC). For georeferenced information, the integration of visual representation and analysis principles from cartography, EDA, and ViSC has been identified as Geographic Visualization (GVis). The dynamic (visual) spatiotemporal representation environments characteristic of GVis offer a potential for insights into problems that were difficult or impossible to address using static and nonvisual representations.

Geographic visualization (sometimes called cartographic visualization) extends traditional cartographic approaches to representing georeferenced information in two ways, by emphasizing the use of maps and other representation forms to *construct knowledge* (not just to present it) and by emphasizing dynamic maps that change in response to changes in data and/or to actions on the part of users (MacEachren and Monmonier, 1992). In addition, GVis environments typically merge visual with statistical or mathematical representation. Examples of the latter include (Symanzik, Majure et al., 1996), (Dorling, 1992), and (Dykes, 1997).

As noted above, three issues associated with GVis (map animation, multi variate representation, and interactivity) are relevant for the current research. Each is represented by a growing body of research within cartography/geography and complementary research efforts in a range of disciplines from which GVis developers have borrowed ideas and approaches. Before considering ways in which map animation, multi variate analysis, and interactivity are integrated in a prototype analysis environment, a brief overview of current understanding of each is needed. The review below is not intended to be comprehensive. Instead it focuses on aspects of each research topic that are particularly relevant to the kind of information exploration environment designed.

Map Animation

Although animated cartography has been the focus of sporadic attention within the field since the late 1950s (Campbell, 1990), it is microcomputer-based animation of the past decade that has stimulated a focused effort to address fundamental questions raised by a shift from static to dynamic maps. The research literature has expanded quickly. The focus here is on research directed to animated mapping of enumerated data (a term used here to include derived quantities, such as death rates, calculated for counties or other contiguous units). This research can be grouped into time series and non-time series animation.

Depicting a time series is, perhaps, the most obvious use of map animation. Animations of the disease AIDS by Gould and his colleagues (1990) are prototypical of time series animation applied to enumerated data. These animations have captured attention within and beyond cartography—including in the popular press. In addition to demonstrating the power of animation as a rhetorical tool, these animations raise a variety of conceptual issues related to symbolization, data classification, and color schemes (MacEachren and DiBiase, 1991). In relation to symbolization, MacEachren and DiBiase advocate a hybrid method (chorodot maps) as more appropriate than either choropleth or isopleth maps. More generally, Dorling (1992) has argued against choropleth maps (either static or animated time series) for demographic statistics of any kind. Instead, he advocates population cartograms as a base to which choropleth style depiction of other variables can be added. Whatever the symbolization form used, time series animations of classified enumerated data are often choppy and discontinuous. This problem is exacerbated if classification is applied independently to each time step (Monmonier, 1994).

With nontemporal animation of enumerated data, display order is matched to a nontemporal ordered attribute. Three subcategories are apparent. The first uses order to signify level of attribute generalization, with the map sequentially built up from the lowest to highest value (Monmonier, 1992). A second subcategory matches scene order to order of categories on a map having a fixed number of classes, thus highlighting spatial locations having similar attribute values (Slocum et al., 1990; Peterson, 1995). The third sub-category involves reordering maps from a time series according to some attribute of each time period, what DiBiase, et al., (1992) term "reexpression." One reexpression example they describe involves reordering of a presidential election time series based on the magnitude of landslide voting percentages. Krygier (1994) suggests adding sonic representation as a device to help users decipher these reexpressions.

Multivariate Representation

Like animation, multi variate representation has a long history in cartography prior to the advent of dynamic computer systems (or computers in general). DiBiase et al. (1994) provide a comprehensive review of multi variate representation methods emphasizing those for three or more variables. Here, as above, we restrict attention to representation of quantitative data aggregated to enumeration units.

A basic choice for multi variate analysis is between multiple views (each of which depicts one variable) and composite views in which variables are integrated. The idea of small multiples has been suggested as effective by several authors (e.g., Bertin, 1983; Tufte, 1983). Small multiples allow an analyst to easily examine each variable independently, but the disaggregation of information, along with small size needed to fit many views on a page or screen, may make comparison of variables a difficult task. In their SlicViewer system (a system that allows analysts to generate small multiples as well as composite maps, DiBiase, et al., (1994) found that climatologists preferred integration of variables into a single view. As Bertin (1983) contends, however, manipulable small multiples in which a user can group similar views may make this a powerful multi variate technique. While MacEachren (1995) points out that recent advances in computing technology make dynamic manipulation of small multiples possible, no such system for manipulating maps has yet been developed.

Driven, perhaps, by the desire of expert analysts to bring multiple variables together into a single view, several authors have addressed color schemes for such composite multi variate maps. Trumbo (1981) proposes (but does not test) color guidelines designed to highlight positive associations or to make variables separable. Building from empirical evaluation of U.S. Census bivariate color schemes by Olson (1981), Brewer (1994) has developed a more comprehensive color syntactics (system of color logic) for multi variate maps in which she distinguishes among several kinds of bivariate situations. The univariate part of this system was applied to designing maps of health statistics, and demonstrated to be effective (Brewer, et. al., 1997). Focusing specifically on correlation between variables, Eyton (1984) proposes a unique solution to bivariate data classification and a matching color scheme. The scheme uses a white-grey-black continuum to depict values along the regression line (that describes the relationship between variables) and complementary colors (red and cyan) to signify outliers. This approach appears to be very effective in displaying positive bivariate relationships. The most widely studied alternative to color for depicting bivariate enumerated data is texture (in the form of cross-line shading). Carstensen has demonstrated that crossed-line shading can be as effective as color (Carstensen, 1984) and that this representation method facilitates hypothesis generation about the relationships between variables mapped (Carstensen, 1986).

An important cognitive-perceptual issue that should be considered when choosing symbols for a multi variate map (whether color, texture, or other visual variables are used) involves a distinction between visually integral and visually separable visual dimensions (Shortridge, 1982). Integral variables (sign-vehicle components) are seen as wholes rather than as independent components—making selective attention to their individual components difficult. Separable variables, on the other hand, are seen individually—making divided attention (a focus on the conjunction of sign-vehicles as a whole) difficult. MacEachren and Brewer (1995 and in press) compared a coincident visually separable display (a bivariate map in which color attributes represented one variable and a texture overlay represented reliability of those data) with a coincident visually integral display (a similar map in which both data and reliability were depicted by attributes of color). The visually separable display proved effective in allowing the map users to recognize unreliable data without impeding their ability to notice clusters and characterize patterns in the data. A coincident visually integral depiction made it difficult for users to consider data and reliability independently.

Recently, a number of authors have suggested dynamic extensions to traditional multi variate mapping methods, designed to facilitate understanding of the necessarily complex maps that result. These extensions have their roots in EDA concepts of linked views (Becker et al., 1988; Buja et al., 1991). Linking can occur in time (when views that are adjacent in display time share some attribute that provides the conceptual "link"). Linking is also used to relate simultaneously visible views. Linking has been adapted to cartography in the form of scatterplot-to-map links (Monmonier, 1989), links among maps, scatterplots, and temporal legends (Monmonier, 1990) and links between standard maps and cartograms (Dykes, 1997). Linking is usually combined with interactive controls that allow a user to identify elements in one or more views to be linked. This and other aspects of interactivity are considered below.

Interactivity

The ability to dynamically manipulate mapped representations has the potential to substantially alter the map "reading" experience. The often passive act of map reading is transformed into an active process of information manipulation and knowledge construction. Introduction of interactivity to mapping brings questions of what to control (data manipulation, visual display, etc.) and how to control each component of a spatial information analysis system. With the later, issues to be addressed include determining the kinds of controls available to the user, the kinds of operations that can (or should) be applied at various stages of analysis, and the appropriate matches between kinds of controls and kinds of operations.

Interacting with information displays (maps or other forms) depends upon relatively recent computer technology. As a result, there are no generally accepted guidelines for design or use of interactive controls for maps (or other information displays). There is, however, a growing body of research that addresses fundamental issues of interactive information analysis. Relevant research has been conducted in a wide variety of disciplines, ranging from those with an emphasis on system design, but not necessarily on spatial information, (e.g., Human-Computer Interaction, Computer Graphics) through those whose emphasis is the representation and analysis of information (e.g., statistics), to those where representation of spatial information is the focus (e.g., cartography).

Within the growing field of Human-Computer Interaction (HCI) much of the initial HCI research dealing with interactivity focused on techniques for building interactive interfaces, with system designers finding little time to formally assess those interfaces. When assessments were initially attempted, they emphasized speed, accuracy, and ease of use ((Te'eni, 1990; Morgan, 1991; Svendsen, 1991; and Guastello, 1989). More recently, attention has been directed to the cognitive issues that underlie human interaction with computers. (e.g., (Chen and Hung, 1995)).

In the contexts of EDA and GVis, developments related to interactivity have followed a similar path. Initial research has focused on design of interactive tools, with attention to the cognitive issues of how analysts work with these tools a relatively recent addition. A few key issues from each component of research are outlined below. For more details, consult (Cleveland and McGill, 1988; Bailey and Gatrell, 1995; MacEachren, 1995).

Interactive tool development

A starting point for interactive tool development is a categorization of interaction types originally proposed by Schneiderman (1987)—into command and query languages (command-line methods typical of pre-interactive computing), natural language (spoken, typed, or written commands), form fill-in, menu selection, and direct manipulation. Direct manipulation refers to any interaction in which the user initiates a change in the display by manipulating a display element. A useful distinction can be made between manipulation of display elements that act as controls for some other part of the display (e.g., push buttons, sliders, etc.) and manipulation of display elements that result in a direct change to that display element (e.g., clicking on a map polygon to toggle between data and data reliability representations, drawing a rectangle on a scatterplot that results in points within the rectangle being highlighted – along with corresponding points in other linked graphs) (Howard and MacEachren, 1996). Systems seldom rely on a single interaction style. Different kinds of operations (e.g., manipulating a parameter of a model, selecting a data set, etc.) are logically associated with different styles.

Many of the uses of interaction implemented in GVis environments originally were developed for non-spatial EDA. Among the more important are *focusing* (highlighting subsets of data), *brushing* (highlighting specific display objects by pointing at or encircling them on the display), and *linking* (simultaneous highlighting on multiple views). Simple focusing applies to a single view and allows users to dynamically adjust a threshold, above or below which data values are highlighted. MacEachren, et al., (1993) implemented this technique as a way to allow environmental analysts to explore the reliability of dissolved inorganic nitrogen estimates for the Chesapeake Bay. A logical extension of simple focusing is dynamic data classification (Ferreira and Wiggins, 1990) in which multiple category break points (rather than a single threshold) are manipulated. A related kind of focusing is implemented in Calico, a system for dynamically adjusting the balance between two variables displayed on a bivariate map (Rheingans, 1992). In the latter case, users manipulate the display rather than the data (a method applied to one component of HealthVis—see below).

With simultaneous views, linking is usually combined with the EDA focusing technique of "brushing," where interactively selecting data in one view results in automatic selection of the corresponding data

locations in all other views (Becker and Cleveland, 1987; Carr et al., 1987). The classic example that combines focusing and linking is interactive scatterplot brushing, in which points highlighted in one scatterplot result in corresponding points highlighted in several other scatterplots that make up a scatterplot matrix (Becker and Cleveland, 1987). This idea was quickly extended to incorporate maps as well as scatterplots (Carr, Littlefield et al., 1987). Monmonier termed the extension "geographic brushing" (Monmonier, 1989) and subsequently added the concept of temporal brushing (Monmonier, 1990) in which users can "brush" a timeline as well as scatterplots or maps. Monmonier also extended the method to deal with links between maps and multidimensional scaling results through what he terms a "geographic biplot" (Monmonier, 1991). Most recently, Dykes (1997) has used the Tcl/Tk scripting/GUI language/toolkit to combine a linked map, scatterplot, and pushbuttons (for selecting variables to display). The results is an implementation of geographic brushing available on the World Wide Web. Dykes also makes use of linked views as a tool for visualizing spatial autocorrelation in a demographic data set.

Cognitive issues associated with interactive GVis

As we begin to solve initial technical problems of building interactive systems for GVis, it is important to consider the cognitive processes we are attempting to invoke through use of various interaction components and styles. This is, of course, an underlying question of all system design. Chen and Hung (1995), for example, suggest that the usability of an interface is a combined function of the users experiences (accessible through mental schemata) and the icons used to signal operations. They propose an adaptive system in which the depth and breadth of choices will vary with the user's experience.

There is little known about how interface parameters will affect the schemata that a user brings to spatial analysis or how expertise (and associated knowledge schemata) will influence the use (or usefulness) of various interface forms. A step toward answering the latter question is a series of experiments dealing with GIS use by novices versus experts (McGuinness, 1994). In these experiments, users participated in two interactive problem scenarios in which a GIS was used to explore data. The first scenario focused on the relationship between environmental and social variables and machine peat cutting in Northern Ireland. The second focused on the relationships between health and various deprivation indices, also in Northern Ireland). In both cases, users were asked to provide comments in writing about the relationships among the variables of interest. As they worked with the GIS, what they did with the system and when each action occurred was recorded. After completing the scenarios, users were asked to view a video of their sessions and comment on what they were doing at each stage and why. In both experiments, experts were found to be more systematic in analysis of variables (usually displaying maps of all available variables at least once and often replotting the same combinations of variables). When faced with no limit on the number of variables that could be simultaneously added to the map display (in the first scenario), experts were more conservative, being more likely to depict pairs of variables in sequence than many variables together. Although they seemed to be more systematic in their approach, experts did not spend much more time on the tasks than novices, nor did they generate more maps.

Evans (1997) has also considered the issue of expert versus novice system users. In her case, the goal was to assess an interactive system designed to provide users with land use maps (derived from remotely sensed imagery) and information about reliability with which land use at each map location is categorized. She was interested in whether both groups of users could make effective use of the reliability information and whether the novices and experts would use different information exploration strategies when faced with a flexible display that allowed them to consider land use and categorization reliability independently or together. Both novices and experts were able to interpret information provided by the maps (with no significant differences in accuracy of responses to objective questions). The experts, however, seemed to take advantage of the system flexibility—exploring the representations (and the system itself) more completely.

A Structured Approach to Prototype Design

The research highlighted above is directed primarily to representational and cognitive issues of implementing mapping/GVis systems. Designing and building a system also requires attention to issues prior to implementation. System and interface design should be approached at multiple levels in an effort to prevent particular hardware and software characteristics from dictating system goals or what a system is actually designed to do. An effective multilevel strategy is to direct separate attention to what the system is for, what it needs to be able to do, and how it works. Howard and MacEachren (1996) review literature relevant to these issues and propose a hierarchical approach to GVis system and interface design. Their approach has been used to guide our prototype design process. The stages of this approach are defined specifically as *conceptual* (the level at which what and who the system is for are considered), *operational* (the level at which conceptual goals are subdivided into a set of discrete operations applicable to the data), and *implementational* (the level at which methods for achieving the operational goals are addressed—within particular, hardware, software, and problem context constraints).

As noted above, the research contract that prompted this project defined quite narrow objectives related to design and testing of an environment for display of time series mortality data and associated risk factors. The broader objective of research on mapping sponsored by the NCHS, however, is to facilitate incorporation of geographically referenced representations at various stages of health research. Thus, we approach the task of identifying conceptual level goals and associated operational level "operations" with these broader objectives in mind. This results in a prototype capable not only of meeting the specified contract goals but also of evolving to address anticipated demands of analysts; analysts who will be increasingly aware of dynamic mapping's potential for facilitating visual thinking.

Conceptual level

At the conceptual level, several categories of goals can be defined for GVis. These range from domain-independent use goals, through domain-specific reasons for a system, to narrow task objectives within a particular application context. In relation to GVis use, MacEachren and Kraak (1997), building on earlier work in statistics by Tukey (1980) and in geography by DiBiase (1990), propose four goals: exploration, analysis, synthesis, and presentation. The project reported here emphasizes exploratory visualization. Within the project's application domain of health statistics analysis, the most general goal is one that underlies all uses of mapping and GIS for health data analysis—to understand the spatially varying factors that lead to mortality and disease and the variation in those factors for different at-risk groups in the population. Together this domain goal plus the emphasis on exploratory stages of research leads to a practical goal for the environment being designed—to develop dynamic GVis methods and tools that enhance the ability of health/statistics specialists to recognize (and draw inferences about) mortality rate patterns, risk factor patterns, relations between risk factors and mortality, and change in both mortality and risk factors (and their relations) over time.

Within these general goals, a set of application-specific sub-goals can be identified that relate to specific aspects of exploratory analysis. At this stage, these conceptual-level sub-goals can be characterized as ones that (a) support spatial pattern analysis (for points in time), (b) facilitate an understanding of spatiotemporal processes, (c) support analysis at multiple spatial, attribute, and temporal scales and (d) address the implications of data characteristics and data processing methods for apparent spatial and spatiotemporal patterns. Each is elaborated below.

- Spatial pattern analysis: key operational objectives for tools to be implemented are: (1) identify "hot spots" of mortality (clusters in geographic space) and sort real from false hot spots; (2) facilitate the search for relationships between mortality clusters and potential risk factors.

- Spatiotemporal analysis: goals identified include: (1) explore spatial diffusion of mortality (due to various causes, and for various at-risk groups); (2) facilitate the search for change in geographic co-variation (between mortality and risk factors) over time.
- Multiscale analysis: goals relate to aggregation and disaggregation of attribute, geographic, and temporal aspects of information, and include: (1) facilitate exploration of data as a whole as well as data parsed into constituent groups (by gender, age, race, etc.); (2) facilitate multiresolution analysis (spatially and temporally).
- Metadata and methods of representation: In an effort to minimize visualization errors (Type I: seeing false patterns, and Type II: missing real patterns), we have identified a set of conceptual goals addressing the data characteristics and the methods for representing these data, as well as the background of the users for whom the system is being designed (see MacEachren and Ganter, 1990 for discussion of Type I and II visualization errors). The conceptual goals include: (1) build upon specialized expertise of potential users (e.g., in statistical analysis) to introduce methods for exploratory GVIs with which they may be unfamiliar; (2) facilitate an understanding of data reliability.

Operational level

As noted above, achieving a specific conceptual level goal generally requires subdividing the goal into a series of sub-goals, each of which can be met by applying a particular operation to particular information. The task at the operational level of system/interface analysis is to identify these operations. While it is never possible to completely disentangle operations as concepts from their possible implementation given available tools, the intent at this stage is to determine what procedures should be available for application to information, not how to implement them. Building from the categories of conceptual goals delineated above, the following operations and their subcomponents have been identified as desirable for a full working system (only categories 1 and 2 are incorporated directly in the current prototype):

- spatial pattern analysis and comparison
 - highlight the high and low values
 - enhance visibility of regions or clusters
 - relate data in geographic and attribute spaces
 - explore association between mortality and risk factors
- spatiotemporal analysis
 - examine time sequences (of mortality or risk factors)
 - examine time series for selected attribute ranges (of mortality or risk factors)
 - compare change over time for two variables (mortality and risk factors)
- multi scale/hierarchical analysis
 - search for scales at which processes take place (relate patterns at county, HSA, and state levels)
 - identify appropriate temporal scale
 - support aggregation and smoothing over time
 - parse data by demographic categories
- metadata and methods representation
 - depict data reliability
 - manipulate parameters of data processing and symbolization

As with the conceptual level, this "typology" of operations is a tentative one that will evolve over time.

Implementational level

At the implementational level of prototype design, the first step was to examine existing software environments to determine whether any one environment was suitable for prototype design and testing (and perhaps for future system development beyond the prototype). The full range of conceptual and operational goals identified above played a role in selecting a development environment. The most important criteria, however, were the initial objectives of (a) designing alternative methods for displaying dynamic interactive maps of death rate and risk factor data and (b) testing these designs in an experiment where users attempt to draw inferences about changing death rate patterns and their relationship to risk factor patterns. Thus the goals of the prototype are less comprehensive and somewhat different than for a full system that the prototype and its testing may lead to. The need was for an environment that facilitated rapid prototyping and assessment of the representation and interface options developed, not necessarily an environment that was ideal for full system implementation.

Characteristics of NCHS data were also a factor in selecting our rapid prototyping environment. Data available for the project consisted of mortality rates and related demographic statistics aggregated to the 798 Health Service Areas (HSAs) for the conterminous U.S. The mortality rates were available for only five time steps. The geographic component of the data (HSA boundaries) was provided in a standard desktop GIS format (ArcView shapefiles).

A review of several potential development environments found none that would allow easy implementation of all operations identified above and, at the same time, allow quick alteration of the form in which operations were implemented. As a result, the development environment selected combines ArcView (with its Avenue scripting language) and Macromedia Director (with its Lingo scripting language). Operations associated with pattern analysis and pattern comparison (of multiple variables at one time) have been implemented in ArcView. Operations associated with spatiotemporal analysis have been implemented in Director. At this stage, operations dealing with multi scale analysis and the representation of metadata and methods have not been implemented (since these are not requested in the contract).

ArcView is suited to the pattern analysis/comparison functions because it integrates geographic with attribute information and has flexible query tools for spatial queries, attribute queries, and their combination. In addition, it has an integrated object-oriented programming language (Avenue) that makes a wide range of system features possible. ArcView is not, however, suited to temporal analysis because it does not incorporate time in its data structure nor does it support animation. Director, while having no data query or processing features, is an appropriate test platform for spatiotemporal maps because of its flexible animation tools and because the software makes it easy to keep track of the order and duration of all user actions. It is, however, not an appropriate environment for developing the full prototype because it does not have database capabilities nor does it include support for georeferencing.

The exploratory space-time-attribute data analysis operations implemented in the ArcView – Director prototype are described below. The goal here was to develop principles for design of a full system, not to make a decision about particular software environment in which to build it. Thus, to put the focus on the methods and tools implemented (rather than on the two software environments used) and to simplify discussion, the prototype components will be referred to as HealthVisA and HealthVisA (with component “A” the part built in ArcView and component “B” the part built in Director). Discussion is grouped by category of operation (thus by components “A” and “B”).

HealthVis Prototype Construction

Spatial pattern analysis and comparison (HealthVisA):

Based upon goals delineated for the system, the review of previous literature presented above, and experience of the PI with design of dynamic mapping environments, the decision was made to develop a prototype environment that incorporates dynamically linked choropleth maps and scatterplots. The key to this dynamic linking is to treat each point in a scatterplot as an entity linked to a corresponding feature (HSA) in the map, and to be able to highlight that point (or groups of points) and have those manipulations reflected on the map. ArcView provides considerable flexibility in choropleth mapping and includes a chart module that can generate scatterplots. It became quickly apparent, however, that the chart module of ArcView 3.0 was not robust enough to produce dynamically linked and brushable scatterplots and maps. Creating user manipulable scatterplots, then, was a precursor to further addressing the operational subgoals associated with spatial pattern analysis and comparison.

Implementation of dynamic scatterplots was accomplished by creating a view into which each scatterplot point was "mapped," reading two fields of data from the polygon attribute file associated with the layer being displayed on a map (in this case HSAs), and assigning the values in one field to the scatterplot X axis and the values in the other to the Y axis (in the view created). When the script has processed the list of HSAs, the result is scatterplot in the form of an ArcView "point theme," with one point corresponding to each HSA...

One reason for creating scatterplots is to gain the ability to construct scatterplot matrices by creating multiple scatterplots of related data and arranging them on the computer screen in a simple matrix. In order for this to be effective, however, it is necessary for the scatterplots representing different times to have the same axis scaling. The data range for all possible death rates in all possible years must, therefore, be used to determine the axis range. In the prototype, this is achieved by allowing the user to pick multiple fields for the range of values that will be used in setting up each axis (figure 1).

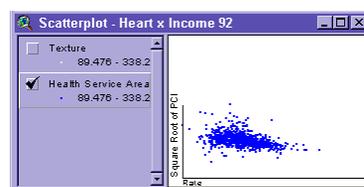


figure 1. example of a typical scatterplot in the prototype

A side effect of giving the user flexibility in creating a scatterplot is that this process can be somewhat cumbersome. For instance, to create a scatterplot, users must first choose the field that will be used as the X axis, and then choose all fields that will be used to set the range of values for which the axis will be scaled. These same parameters will then be chosen for the Y axis. Finally the user will be presented with the range of possible values for each axis, and then prompted to choose an appropriate transformation for each axis. In addition, the user is provided with the opportunity to enter a name for the scatterplot and a label for each axis. The result in ArcView is a new view with the user-provided name of the scatterplot. Within the view is a theme with the a set of points and four graphic objects; one line and one label for each axis. This script is integrated within the ArcView interface using a button.

Highlight highs & lows - focusing

The first operation implemented is simple focusing applied to a single mapped variable (either a mortality cause or a potential risk factor). Focusing addresses the operational goal of highlighting extreme values. The focusing implementation presents users with a map display for which they can dynamically adjust a threshold above (or below) which enumeration unit values (e.g., mortality rates for HSAs) are highlighted. Focusing, as implemented here, allows the user to slide a break point along the X axis of a scatterplot, and have the shaded regions of a two-class map reflect which side of that break point they are on. The tool is particularly useful for isolating the highest (or lowest) values on the map. Thus, focusing also addresses the operational goal of facilitating spatial cluster recognition, by allowing the user to search for spatial clusters of extreme data values.

Enhance regions & clusters - dynamic data classification

A logical extension of simple focusing (which essentially manipulates a class break point for a two-category map) is dynamic data classification. Dynamic classification allows the user to insert more than one break point into the scatterplot, and to then manipulate those break points so that they are reflected in the category representation of the map. Dynamic classification through scatterplots, then, allows the user to find geographic clusters of like values by “focusing” on value ranges that are not in the extreme high and low ends. Since most data classification methods (whether the default quantile approach or alternatives such as Jenks’ classification method that optimizes variation within and between classes) are aspatial, homogeneous regions (clusters) may be hidden (a type I visualization error) because similar adjacent values might end up in different categories. Manipulation of class break points allows the user to see the impact of data classification methods on apparent map regions and to explore the data in an effort to enhance the visibility of any regions or clusters that might be present.

The first step for implementing dynamic classification was to create initial class breaks, and have them applied to the appropriate data theme in the map, as well as in the scatterplot. ArcView 3.0 has a number of built in data classification techniques. In the prototype, users can choose any of them to determine the initial class breaks. Information about the classification scheme, including the number of class breaks, the scatterplot axis on which they occur, and the type of classification method being initially applied, is collected from the user (using pop-up dialog boxes). The classification scheme is then applied to the scatterplot, and, using object tags, to its linked map. The class breaks are represented on the scatterplot as lines perpendicular to the axis along which the data is being classified. Each one of these lines is a graphic element in the view that the user can drag to a desired position along the data range. Dynamic classification is available only when the active document is a scatterplot view (see Figure 2). Since it is possible that the axis of the scatterplot has been transformed, the value returned from the class break may need to be inversely transformed to its original scale. This is accomplished by checking the object tag of the appropriate axis of the scatterplot, and retrieving the information about the transformation applied.

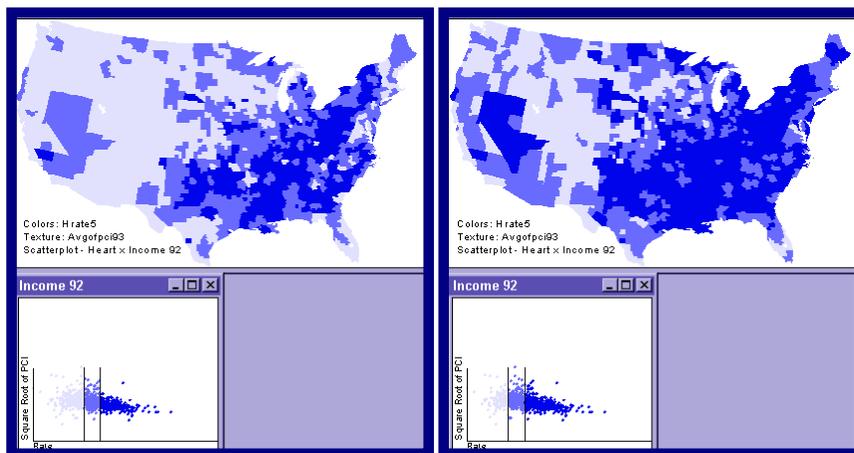


Figure 2. Two snapshots depicting the use of dynamic classification. The user has picked up and moved lines on the scatterplot representing break points between data categories. The result is a reclassification of HSAs on the map so that fewer are in low categories.

Because it is possible to have multiple scatterplots with different classification schemes at any given time, labels are added to the map to indicate which scatterplot and classification scheme it currently represents. These labels, and the classification of the map are updated whenever the user applies the focusing/dynamic classification or brushing tool in any given scatterplot.

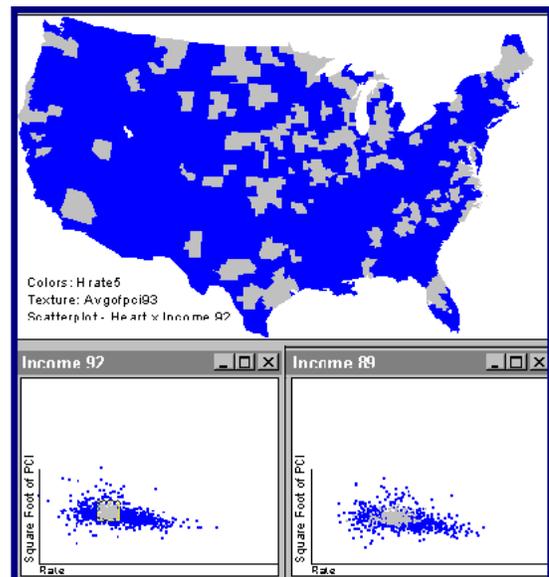
Relate mortality & risks - scatterplot brushing

Since relationships between mortality rates and potential risk factors (both reported as aggregate rates, or other derived measures, per HSA) are of primary importance, linked geographic brushing has been

implemented. Brushing is the ability to highlight certain entities in one visual display and have them appear highlighted in a corresponding display. It supports the operational goal of relating data in geographic and attribute space. Geographic brushing has been implemented in a number of experimental visualization packages (Monmonier and Gluck, 1994; Dykes, 1997), but to our knowledge, this is the first such implementation in a commercially available GIS package.

For each pairing of mortality cause with risk factor, users can highlight any points of a scatter plot to determine their location in geographic space or highlight any HSAs on a map to determine their location in bivariate (or multi variate) attribute space. In a variant on previous implementations of scatterplot brushing, time can be incorporated in the analysis by making one axis of the scatterplot matrix represent time. The geographic representation linked to the scatterplot matrix, in addition to showing the location of highlighted data, is a bivariate map that depicts the two variables making up whichever scatterplot has been most recently brushed.

Figure 3. A 1 X 2 scatterplot matrix with associated map. The region at the center of the left scatterplot was “brushed” and the corresponding points in the scatterplot on the right are highlighted, along with their HSAs on the map. The selected points are at the middle of the range of heart disease and income for 1992. These particular HSAs seem to be clustered in the upper Midwest and Great plains plus Texas, eastern Appalachia, the far west and Maine. Heart disease mortality across these locations has become more similar (and more average) between 1989 and 1992.



The brushing tool is implemented in this prototype as a user-defined rectangular box that allows the user to select the points on a scatterplot, or features on the map, that are of interest... In this prototype, brushing has been implemented so that not only are a map and a scatterplot linked, but the map and any scatterplot that was created based on that map are linked. Figure 3 is an example of scatterplot brushing where the points selected in the lower left scatterplot are also highlighted in the other scatterplot and the map. The multiple linked views provide an opportunity for multidimensional brushing of a scatterplot matrix, where entities can be added or subtracted from a highlighted set using visual selection in any scatterplot or in the map display. For instance, a user who wanted to see the geographic distribution of outliers on three plots could select the outliers in one plot, move to the next plot and add the outliers from that plot, and then move to the third plot and add those outliers. This final selection set would be highlighted in all three plots as well as the associated map.

Explore associations - bivariate maps

As mentioned above, scatterplots are good tools for viewing relationships between variables in data space. Similarly, bivariate mapping is a tool for viewing the relationships between variables in geographic space. MacEachren and Brewer (in press) developed a symbolization method for visually separable bivariate map representation using texture overlay. Their method allows a color scheme to be overlaid with a hatch pattern of adjacent black and white lines. This representational method is equally discernable on light or dark colors, and is thus particularly suited to the generation of bivariate maps with a complex color scheme representing one variable, and the texture overlay representing the presence or absence of another variable (e.g., high risk).

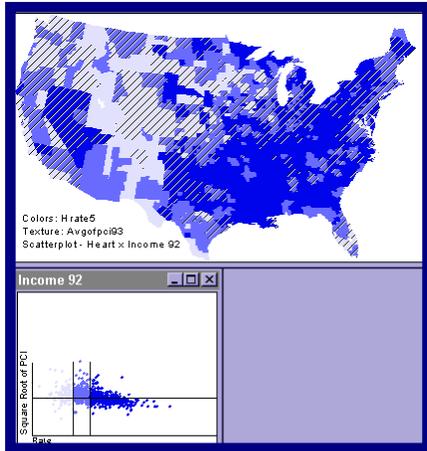


Figure 4. Example bivariate map with mortality cause depicted by color lightness and the above-threshold HSAs for the risk factor (per capita income) depicted with a black-white texture overlay. All class break points are user controlled.

Because of the interactivity of this prototype, and the belief that a visually separable representation would be useful, we chose to use the texture overlay method to represent the data on the Y axis of the scatterplot. This was done by adding a second theme to both the scatterplot and the map. On the scatterplot, this theme is classified along the Y axis, and is symbolized using different colors because the texture overlay cannot be implemented with point data. On the map the theme is symbolized using the texture, and can be turned on or off as the user desires. Since the representation method chosen for the Y axis is binary, focusing, but not dynamic classification, can be implemented on that axis. The implementation of this dynamic classification of a bivariate map through the use of a scatterplot supports two operational goals: a) the goal of relating data in attribute and geographic space and b) the goal of exploring relationships between mortality and risk factors. Focusing using the Y axis and the texture overlay is illustrated in Figure 4.

Spatiotemporal analysis (HealthVisB):

The prototype component designed in Director presents users with an interface organized around a single manipulable map (figure 5). Surrounding the map are tools that allow the user to control spatial, temporal, and attribute features of the display. Spatial manipulation is limited to selection among three boundary choices, using a button that toggles among: U.S. outline only, U.S. plus states, or U.S. plus HSAs.

Several controls relate to attribute information. At the top left of the display, three pull down menus allow users to select a mortality cause to view (the left menu), select a risk factor to view (the right menu), and select a classification scheme to apply to either or both. When the risk factor is turned off, users can select among several map symbolization options for the mortality cause data: a 7-class diverging scheme, a 5-class diverging scheme, and two implementations of focusing---a 2-class binary scheme with a user controllable break point having a 5% step size, and a 2-class binary scheme with a user controllable break point having a 1% step size (figure 6a). Risk factors can be selected only when classification of the mortality cause is turned to "off" or "2-class controllable break points at 5%." In both cases, risk factors are depicted using a 2-class binary scheme with a user controllable break point having a 10% step size.

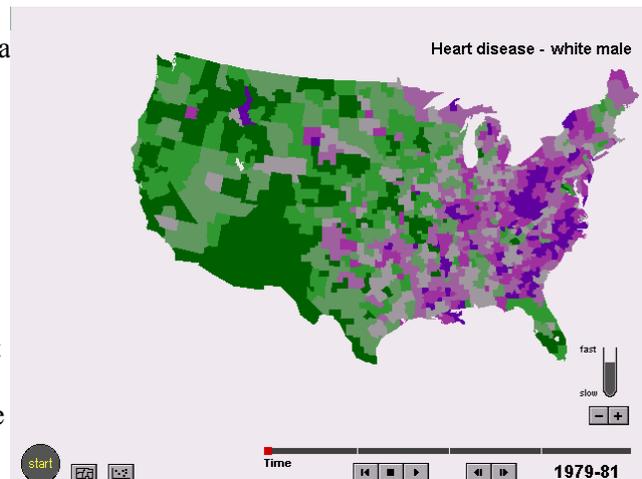


Figure 5. The default display in HealthVis-b. A 7-class map (of heart disease mortality) is displayed with the temporal controls below right and the toggle buttons below left. Pull-down menus are at the top left (not visible in this image).

When a cause (set to a 2-class controllable break point having a 5% step size) and a risk factor are both turned on, the resulting display is what Monmonier (1992) has called a "cross map" (figure 6b). Cross maps integrate two variables on one map using a two-by-two classification (resulting in four map classes).

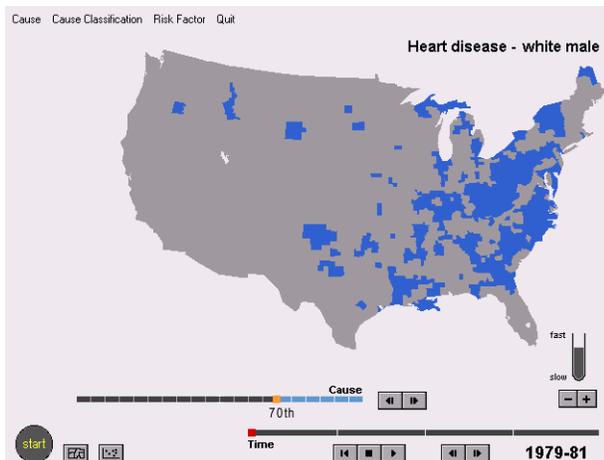


Figure 6a. Focusing in which the mortality cause break point is set to the 70th percentile. High heart disease rates are clearly clustered in the east, particularly northern Appalachia and the eastern seaboard from Maryland south.

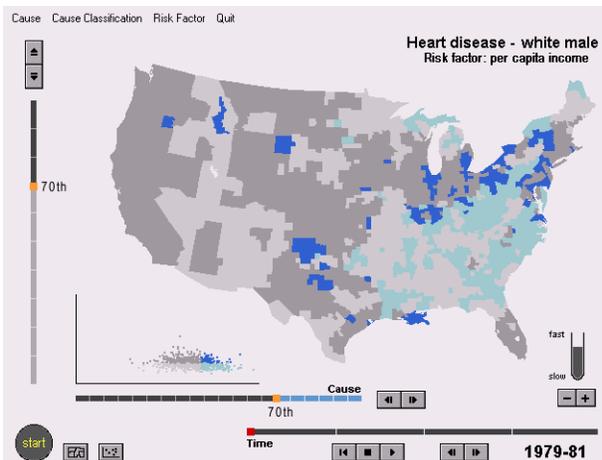


Figure 6b. Bi-variate focusing (displayed on a cross map) with mortality cause focused to the 85th percentile and the risk factor focused to the 80th percentile. It is apparent that virtually no HSAs in the top 20% for income are in the top 15% of heart disease mortality.

Although bivariate maps with more than two classes for each variable have been produced in print (and the seven rate class by two reliability class maps tested by MacEachren and Brewer were demonstrated to be effective, 1995), maps with more than six or seven categories are not easy to interpret (Olson, 1981). This difficulty is likely to be accentuated when change over time in variable relationships is being examined (an activity that the prototype is explicitly intended to support). In contrast, the cross map is fairly easy to interpret and the addition of interactive controls of the two data break points it is based on makes this simple map a powerful exploration tool.

When the 4-class cross map or any of the 2-class map forms are selected, users can manipulate the class break points dynamically (an implementation of focusing, as described above) in one of two ways. For both the cause and the risk factor, VCR-style forward and reverse arrows are positioned at the end of a bar that represents the full range of data with an appropriate number of steps (20 or 100 for the two cause classification choices and 10 for the risk factor). Clicking the arrows shifts the class break point by the specified increment. Alternatively, users can "grab" the marker on the bar and drag it directly to the percentage break point desired. The final control over attribute information provided is a simple button that toggles the scatterplot representation between on and off.

Temporal controls, located at the bottom right of the display, are modeled on those suggested by Kraak, Edsall, and MacEachren (1997) and subsequently assessed by Edsall, MacEachren, and Kraak (1997). Tools include several VCR-style buttons, including start and stop buttons that control whether a time series animation is running or not, frame-by-frame advance/reverse buttons that allow users to step through time, and a rewind control. Additional temporal controls include an animation pace control and a direct manipulation time bar that allows users to grab the time marker and move it directly to specific times without stepping through intervening years.

Examine time sequences - interactive animation

All variables in the prototype are represented by five time steps, each of which is a three-year average. The mechanism provided to facilitate examination of these series is the set of temporal controls described above. These controls implement three of the four categories identified by Rheingans (1991) for interactive control of a sequence of linked views. Rheingans's categories recognize two components of control having two states each: smoothness of transition between views (discrete or smooth) and level of

manipulate given to the user (over just pace of a predetermined sequence or "complete control" that allows the user to control both pace and order in which views are displayed). HealthVisB implements both discrete and smooth control of pace (through the advance-reverse buttons and the pace slider, respectively), and discrete adjustment of a "complete control"—provided by the ability to grab the time marker and move it directly to a desired location. Smooth complete control would be represented by a feature that allows a user to grab the time marker and slide it through the times (with displays updating immediately rather than waiting for the user to release the marker before updating the screen).

Examine time sequences for subsets of data - focusing + interactive animation

The tools for dynamic manipulation of class break points on the various two-class maps retain their settings across maps. Thus, once focusing is set, the setting is retained for all time steps. This allows an analyst to focus on high or low values, then animate (or step through) the time series in an effort to identify spatiotemporal patterns for the subset of data focused upon. This method of visual analysis works for both univariate maps of mortality and bivariate maps of morality crossed with risk (in the latter case, both settings remain fixed across the time series).

Compare change over time for two variables

Focusing controls are not only consistent across time steps for a variable, but are retained by the system as a user moves among variables. As a result, two variables can be compare by switching back and forth between them, while focusing on any subset of the data. When classification is set to 5- or 7-class maps, of course, the system retains that setting as well, facilitating comparison of the full pattern.

Prototype Assessment

Since very little is known about how analysts might apply dynamic mapping tools to data exploration and/or hypothesis generation, a narrow controlled experiment designed to measure success of tools for specific tasks was deemed premature. The number of available tools in the system matched with the number of likely exploration tasks results in a set of combinations that numbers in the hundreds. Without having a better sense of general system usability, of the kinds of questions that domain specialists might use the system to address, and of the typical strategies for system use that might be applied, it is impossible to develop a representative subset of tool-task combinations to test. Thus, assessment of the prototype emphasizes a detailed (but largely qualitative) analysis of system use by a small number of domain specialists.

The goals of this assessment are to (1) evaluate interpretability of map symbolization and interactive controls; (2) document system performance limitations; (3) begin to develop an understanding of strategies used by domain specialists for exploring spatiotemporal information; (4) characterize system use effectiveness. Based on this assessment, recommendations are made for design of a complete GVis environment targeted to exploration of space-time-attribute components of health statistics and for training or tutorials that might be required to help domain experts (who may not be geographic information analysis experts) integrate these new exploratory technologies into their scientific methods.

Prior to a formal assessment of the prototype, an initial version was pilot tested at Penn State, then demonstrated to NCHS staff who provided detailed feedback. Following adjustments based on this input, a revision was distributed to NCHS staff, Marc Sebrechts, Department of Psychology, Catholic University, and Douglas Hermann, Department of Psychology at the University of Indiana for further

comments. Based on more pilot testing and feedback received, a version of the prototype was prepared for formal testing.

To facilitate the assessment goals delineated above, a module was added to the prototype that logs all user actions by time and type of action (e.g., each time a user clicks on the date-forward arrow, the time of that click is recorded, in 60ths of a second, along with a label representing the control clicked on). Each user's interaction with the prototype can be reconstructed and overall strategies can be characterized.

Methodology

The strategy developed for assessing the prototype involves a structured task analysis of expert system use for a series of typical data exploration tasks. Participants solicited for the assessment are a select group of domain specialists; individuals who are doing research on the analysis of health data and/or demographic data to which health statistics are typically related. The nine participants who participated were each asked to use the prototype to explore mortality and related statistics. These data exploration sessions lasted between 45 minutes and one hour. During each session, the participants' exploration was constrained (and made relatively comparable across participants) through a series of six structured exploration "tasks" of increasing sophistication.

All subjects worked with the same three data sets for mortality (heart disease, lung cancer, and prostate cancer for 1979-81, 1982-84, 1985-87, 1988-91, and 1992-95) and a pair of possible "risk factors" for the same years (per capita income and unemployment). During each session, information collected about system use included both system generated logs of all interactions (as described above) and verbal commentary from participants. Solicitation (and subsequent analysis) of verbal comments is based on principles of protocol analysis. Subjects were asked to comment (as they worked) on what they were doing (i.e., system interactions), and what they were seeing (map and system interpretations). They were specifically asked not to justify their actions or to make recommendations about the system or map (until the end of the session).

Participants included five individuals from NCHS and four individuals for the Penn State Population Research Institute (PRI). All can be considered domain experts (in either epidemiology, biostatistics, demography, health policy analysis, or medical geography), three are senior PhD students, and the remainder hold a Ph.D. Only one had significant expertise in application of mapping or GIS to health or related statistics. Since the participants were not Geographic Information Science experts, it was important to provide them with a fairly detailed introduction to the prototype and demonstration of its use prior to having them work with the system.

Each session was lead by the PI, who introduced the system, presented each task, answered any participant questions, and conducted the exit interview. All sessions were videotaped. The "script" below was used as a guide to this introduction/demonstration. Following the initial system demonstration, participants spent three to eight minutes experimenting with the system. Then, for each of the six tasks, participants were handed written descriptions (tasks 1-6 below), one at a time and could refer back to them as often as needed. A copy of the "informed consent" form is included as Appendix 1.

Script for prototype demonstration

Introductory comments

Thank you for agreeing to participate in our efforts to develop a dynamic computer mapping environment. What you will be working with today is a prototype system that is in "alpha" development stages. It is not a complete environment for exploratory spatial data analysis. We have, at this point, implemented a few basic features for

displaying and manipulating maps of disease and risk factors and interacting with time series of these maps. The version has only a few sample data sets in it.

Our goal today is to learn some things about what works and what does not. We will do this in several ways. First we will demonstrate the system. Then we will ask you to try it out, talking aloud about what you are doing. As you work with the system, then, we will prompt you to tell us what you are doing (not why, just what) and we will prompt you to do so from time to time by simply saying "keep talking." After this introduction, we will ask you to address a series of fairly specific questions about a couple of the data sets. During this portion of the session, we will provide brief written instructions to follow as you consider groups of two or three related questions – again, talking aloud telling us what you are doing as you go along. By this point, you will have used most or all of the data exploration features of the system. We will then ask you to take a look at another set of mapped data, exploring any aspect of these data that you find interesting. Finally, we will ask you for your opinions about the system, what worked well, what did not, what additions or changes you feel would be useful, etc. If you have any questions at this point, please ask them.

Guide for demonstration (used by investigator to standardize the system demonstration)

- provide an introduction to the study and explain the participants rights as a volunteer subject, getting them to read and sign an informed consent form.

- tell subject what comes next:

If you have no questions, I will begin with the system demonstration. Feel free to stop me at any point if something I say does not make sense. Remember, you will have a chance to provide detailed opinions at the end of the session (about the system and its interface), so we ask you to hold any critique until after you have worked with the system.

- systematically demonstrate features of the system using the lung cancer data
- start application
- access the heart disease data
- show the difference between 7 and 5 class maps
- show the boundary toggle
- show the 2-class 5% focusing control and how to use it (arrow keys & pointer)
- show the 2-class 1% focusing control and how to use it
- switch to the 7-class maps and show how animation works
- show how to adjust the animation pace
- show how stepping through time works
- show how to move to a time by grabbing the time pointer
- switch to the 2-class 5% map to show how animated focusing works
- select a "risk factor"
 - turn off the mortality cause and show focusing and animation of the risk factor
 - turn the mortality cause back on (2-class 5%, noting that this is the only one that works with a risk factor on), explain the cross map symbolization, then show an animation of the cross map
 - show the toggle for turning the scatterplot on and off
- switch back to the 7-class map and ask the subject to try each control and to talk aloud as they do so
- Explain what comes next:

Now, one at a time, I will ask you to use the map exploration system to consider aspects of several maps. For data collection purposes, this part of the session is divided into discrete "modules," each dealing with specific data sets. For each module, you will be given a short written list of things to look for or to evaluate on the maps. When you have read the list and are ready to begin – but not until then – click the "start module" button. When you have completed the module, click the "exit module" button and I will give you the next list of things to consider.
- Ask participant to switch chairs and to try out the system. Prompt them to experiment with various tools until they seem to understand basic system operation. Answer any questions they have and offer suggestions if they seem to be confused about any controls.

Instructions for task modules (items 1-6 provided to participants as shown, one at a time)

- Reset the display to 7-class map of heart disease and proceed with the six modules:

We will begin with heart disease. Here is the first aspect of heart disease that we would like you to consider. With this and subsequent lists, please read the instructions and ask for clarifications if necessary before clicking the "start module" button. Remember to talk aloud while working.

1. Consider heart disease for white males
 - a. where are the lowest mortality rates located?
 - b. where are the highest mortality rates located?
 - c. where are the national median mortality rates located?
 – Start the module and remember to talk aloud [remember to click "exit module" when you are done]

2. Continue with heart disease for white males, but now
 - a. examine the time trend and describe any geographic changes in location of high, low, or median mortality rates over time
 - b. consider whether there is any change in the number of clusters or size of clusters over time
 – Start the module and remember to talk aloud [remember to click "exit module" when you are done]

3. Compare the time trend of heart disease to that of lung cancer (both for white males), focusing on
 - a. similarity or difference in location of highest mortality rate areas over time
 - b. change in geographical correspondence between the two mortality causes from time 1 to time 2 (do the patterns become more or less closely matched over time)
 – Start the module and remember to talk aloud [remember to click "exit module" when you are done, then turn the "cause classification" to "off"]

4. Now, we would like you to examine a potential risk factor that may be associated with heart disease. Select the "risk factor" of per capita income.
 - a. examine the location of highest and lowest values at the initial time period
 - b. consider the overall geographic distribution of per capita income and the changes in that distribution over time
 – Start the module and remember to talk aloud [remember to click "exit module" when you are done]

5. Now, consider heart disease for white males as it relates to per capita income
 - a. consider similarities and differences in their spatial distribution
 - b. and any changes in the similarity over time
 – Start the module and remember to talk aloud [remember to click "exit module" when you are done]

6. Now that you have tried out most parts of the system, we would like you to consider a third mortality cause, prostate cancer for white males. What to examine here is completely up to you. Explore the data looking for what interests you (including comparing prostate cancer to other causes of mortality and/or to the two risk factors currently in the system) – and continuing to talk aloud

– Start the module and remember to talk aloud [remember to click "exit module" when you are done]

Following the six tasks, each participant was asked to discuss their reactions to the system. The statement below served as a guide to this exit interview (this "script" was used by the investigator, but not given to the participant)

Now, we would like your opinions about the system you have just worked with. We are interested in any feedback you can give us. In particular, we would like your ideas about features you found useful, features that were not useful or were confusing in some way, and any suggestions you might have for improving the system

Data processing and analysis methods

A combination of interaction logs and verbal protocols can yield a rich set of information about how a system is used and how information seen on the maps is interpreted. A first step was to transcribe verbalizations from the videotape. The transcription process created an initial parsing of verbalizations into units based on clear pauses or shifts in topic (e.g., from a description of tools that the participant was using to a description of a map pattern). Once a draft transcript was created, the video was watched again to identify transcription errors and to tag each verbal unit with its start time (from the beginning of the session). These start times served as a link that made integration with system log files possible.

MacSHAPA, a software environment for exploratory sequential data analysis was selected as an appropriate tool for organization and analysis of the combined verbalization and system log data (Sanderson, et. al, 1994). It was necessary to reformat both the verbal transcripts and the log files in order

to make them compatible with MacSHAPA. In the case of the transcripts, time errors were corrected as well (these errors were introduced by videotape player clocks that are less accurate, and much less precise, than computer system clocks). When imported into MacSHAPA, data are organized in the form of a spreadsheet in which rows represent time during a session and columns represent categories of "event"—a verbalization by the participant, a response from the investigator, or an action logged by the system (figure 7). The logged actions were stored in redundant ways to facilitate analysis (columns labeled event, event_merge, event+, object, action, choice, and parameter). Additional, initially blank columns were inserted for addition of codes characterizing each verbalization unit and for investigator comments about a participant's verbalizations (columns labeled codes and interp respectively). During this processing, many of the units were further subdivided in order to separately identify instances that fit the codes developed (e.g., to separate an instance of confusion about a system control from an instance of control use).

macsp4				
p		codes		event
70	00:12:55:30	46	00:12:55:30	
So for lung cancer, as far as I'm concerned, it doesn't move at all. Mostly a phenomenon in the south of the country, what constitutes high, high southeast of the country.		patternid_c		
71	00:13:01:00	47	00:13:01:00	
All right, so then what I'll do is do the same thing for heart disease. That's pretty interesting. "		action		
				129 00:13:01:30 cause:selected:heart

Figure 7. Small portion of MacSHAPA spreadsheet, from three of the 12 columns. The participant verbalizations (P), codes assigned to these verbalizations, and events recorded in the system log file. Time stamps are used to synchronize columns to one another (upper right of each cell). Events in each column are numbered consecutively (upper left of each cell).

MacSHAPA offers a variety of tools for exploring complex sequential data. The subset used extensively are described here. A series of linked examples is provided using the actual data collected and progressing in a manner typical of many of the data explorations that are summarized and discussed in the next section.

Timelines

For any column of information, it is possible to generate a timeline report. These reports have the form of interactive graphs in which each category of information in the spreadsheet column is represented by a line plot depicting times at which each event took place (figure 8). In the example, some interesting features to note are that the participant used risk factor focusing repeatedly during module four, that they used the date stepping buttons frequently throughout the session, and that they did not use any of the animation features until the end of module six (perhaps as an afterthought).

In addition to the version shown here, timelines can be generated for subsets of data from a column (selected using the cycle or filtering tools described below), or for data from multiple columns at the same time. Timelines can be scaled and they can be generated to represent each event individually or to groups strings of repeated events together.

Each timeline has a spreadsheet-viewing tool that provides a mechanism to easily explore interesting situations highlighted by patterns of activity seen on the timeline. As illustrated in figure 9, the spreadsheet-viewing tool includes a marker that can be dragged to any location of interest. This results in the spreadsheet scrolling to the location in time indicated and those cells closest to this time being highlighted. In the example, the timeline viewer has been moved to the center of a cluster of marks

indicating that the participant repeatedly used the date stepping tool in response to the prompts of task

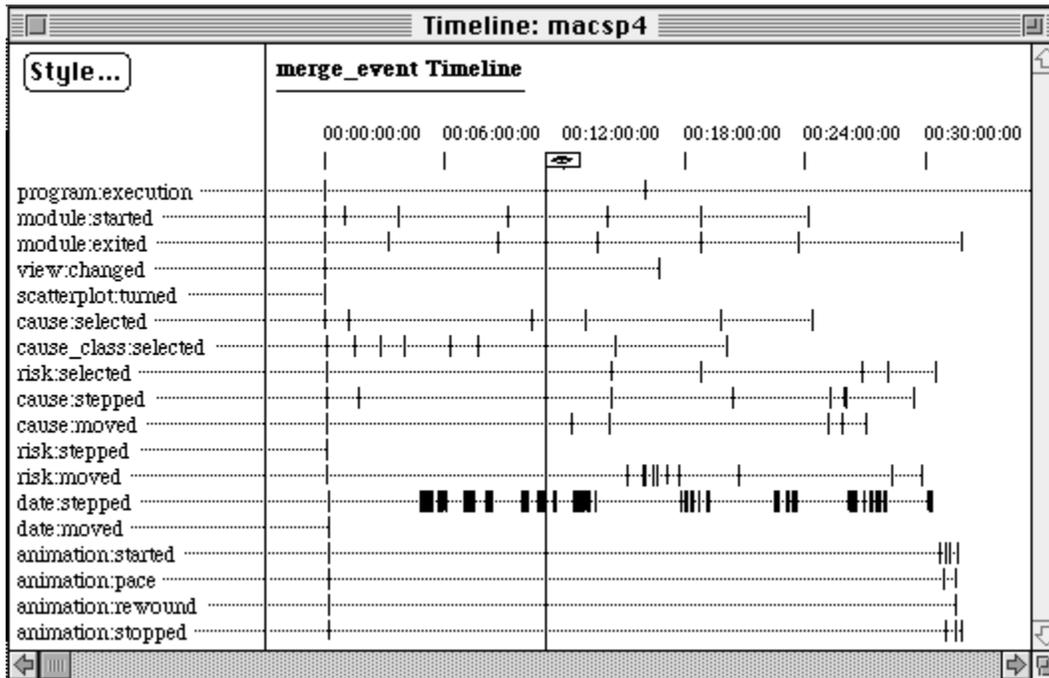


Figure 8. A MacSHAPA timeline representing all actions by participant 4. Time is depicted on the X-axes and each timeline depicts a kind of action.

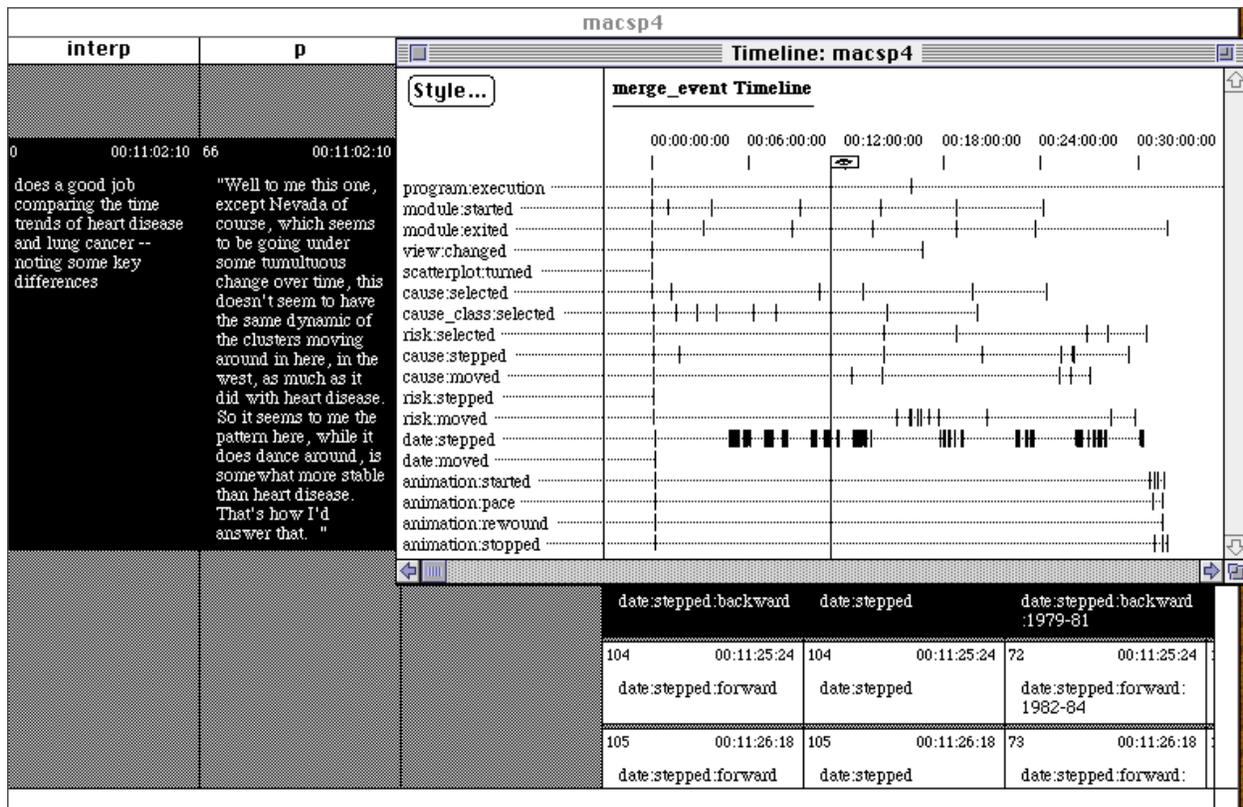


Figure 9. Use of the time viewer to scroll to and highlight events and comments near a particular point in time identified as interesting on the timeline.

module three (comparison of heart disease and lung cancer patterns over time). From the spreadsheet, we learn that the participant was stepping backwards and forwards in time (back to the initial time, then forward repeatedly). The highlighted portion of the participant verbalization column (labeled P) shows us that the participant was examining changes over time in lung cancer and comparing those changes to what had been observed for heart disease. The cell highlighted under "interp," indicates the comment I coded to note my interpretation of the situation.

Cycles

The "cycles" report facilitates analysis of subsets of information contained in a spreadsheet column. The subsets are defined as any event within the specified column that happens between instances of two other events (specified as "from" and "to" events). For the present data, cycle reports were particularly useful as a tool to examine participant strategies for dealing with questions within each of the six task modules. The example in figure 10 illustrates the dialog box in which parameters are set. In this case, the "choice" column is selected as the source for the from and to events and "three" is selected as the item to use for both. "Three" is the marker recorded in the system log file to represent the start and end of module 3. The "merge-event" column of the spreadsheet is selected as containing the events to report (between times indicated by every instance of "three" in the choice column). The report is output as a horizontal tree (the default). In this case, the report is a very long tree with only one branch (that must be scrolled through to examine (figure 11).

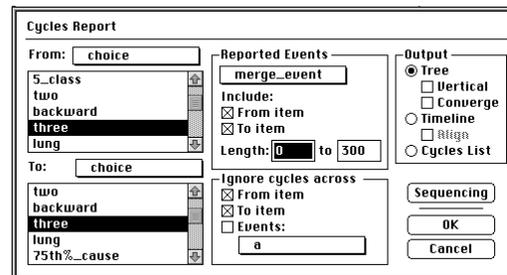


Figure 10. Dialog box for specifying a cycle report. The choice column is specified as the column within which to look for "from" and "to" events -- three is selected in both, thus finding events between the start and end of module three.

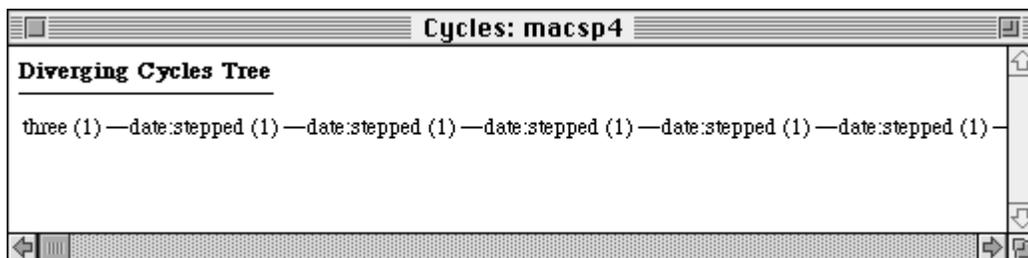


Figure 11. Result of a cycle report -- a horizontal "tree" diagram depicting all events between the from and to events specified. If there was more than one example of the from and two events in the column searched, the tree would have branches.

Once a cycles report is generated, subsequent reports of other types will be based on the subset of information specified. Thus, it is possible to zoom in on the timeline generated above to explore the participants activity in more detail. As can be seen in figure 12, this zooming in (combined with positioning the viewing tool to the same location as in figure 9 above), makes clear that the date stepping action came at the end of a cluster of other closely spaced actions.

Content

Generating a "content" report further explicates the activities that are being used as an example here (figure 13). This report, provides a tabulation of the frequency of all events within the subset of data currently specified (which can range from the entire spreadsheet, through a complete column of the spreadsheet, to a subset of one column—as defined by a cycles report or by filtering, described below). For our example, the content report is quite short because the participant (between pressing the button to initiate task module three and pressing the button to end the module) used only three system controls. He

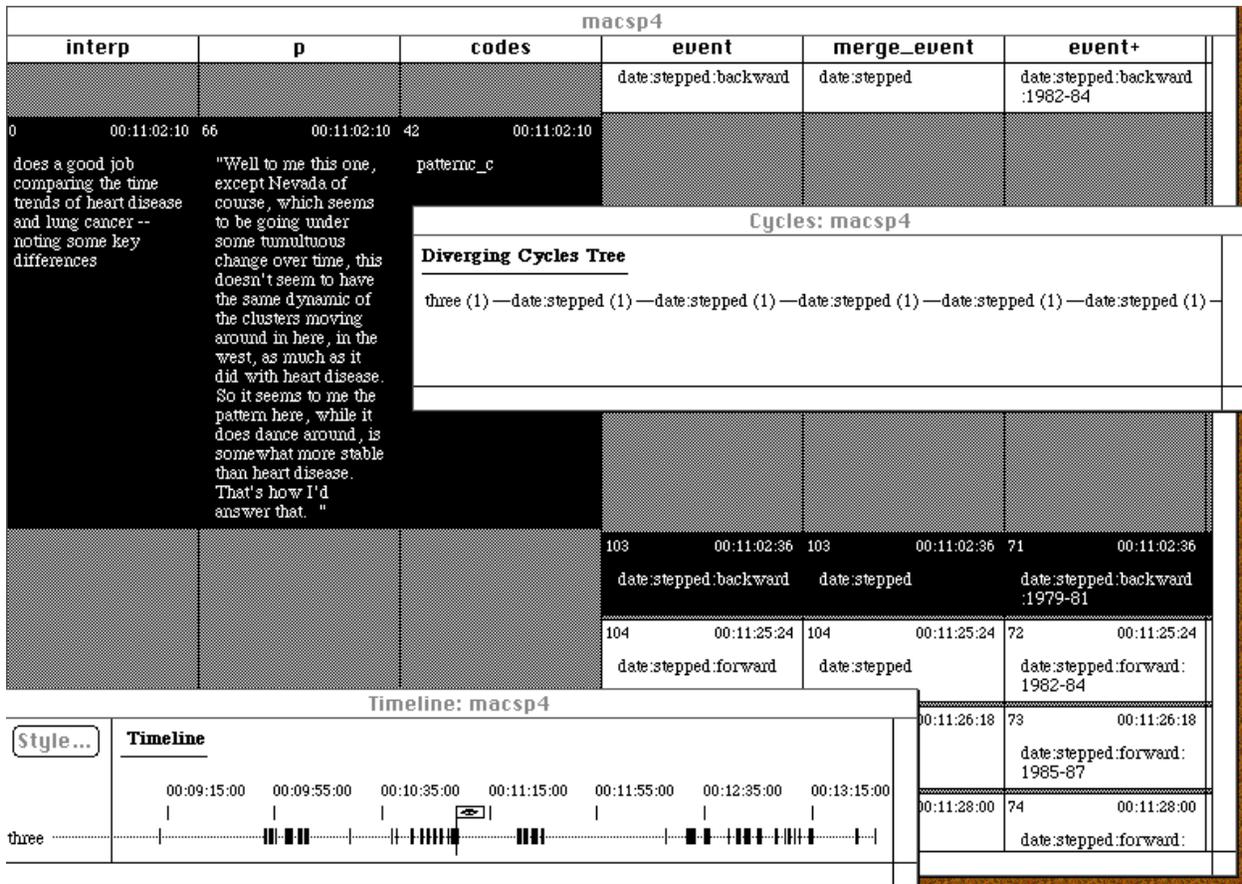


Figure 12. Use of a timeline generated for the cycle report that selected events between the beginning and end of module three. Use of the timeline viewer allows the analyst to find the location on the timeline that matches the location from the full timeline that prompted this query.

or she switched between heart disease and lung cancer twice, used the cause focusing tool once (to move focusing from a 50-50 split to the 75th percentile), and stepped the date (either forward or backward) 56 times.

Listings

Finding that the participant used the cause focusing tool once prompts a search for the circumstances of that use. While it is possible to scroll through the spreadsheet looking for this event (or to do a query searching for it), the task is one that a "listing" report is also well suited to. A listing (figure 14) is just that, a list with one action per line, each line including an action number, onset time, offset time, and the action as specified in the spreadsheet. For the present data, offset times were not recorded, so the a default duration on one second is assumed. Examination of the listing finds one use of the cause focusing tool (specifically the cause slider, identified in the spreadsheet as cause:moved) in the latter third of module three. This action occurred after the activities examined thus far (with an intervening pause, another flurry of date stepping, and about 30 seconds of discussion).

The end of that verbalization episode finds the participant suddenly realizing that they had based their comparison of heart disease and lung cancer over time on a single view of the data emphasizing those locations in the U.S. that are above or below the 50th percentile in mortality rates (figure 15). The participant then decides to repeat the exploration just completed with a focus on the highest quartile of mortality. The date is stepped 16 times and a conclusion reached that lung cancer is spatially stable. The

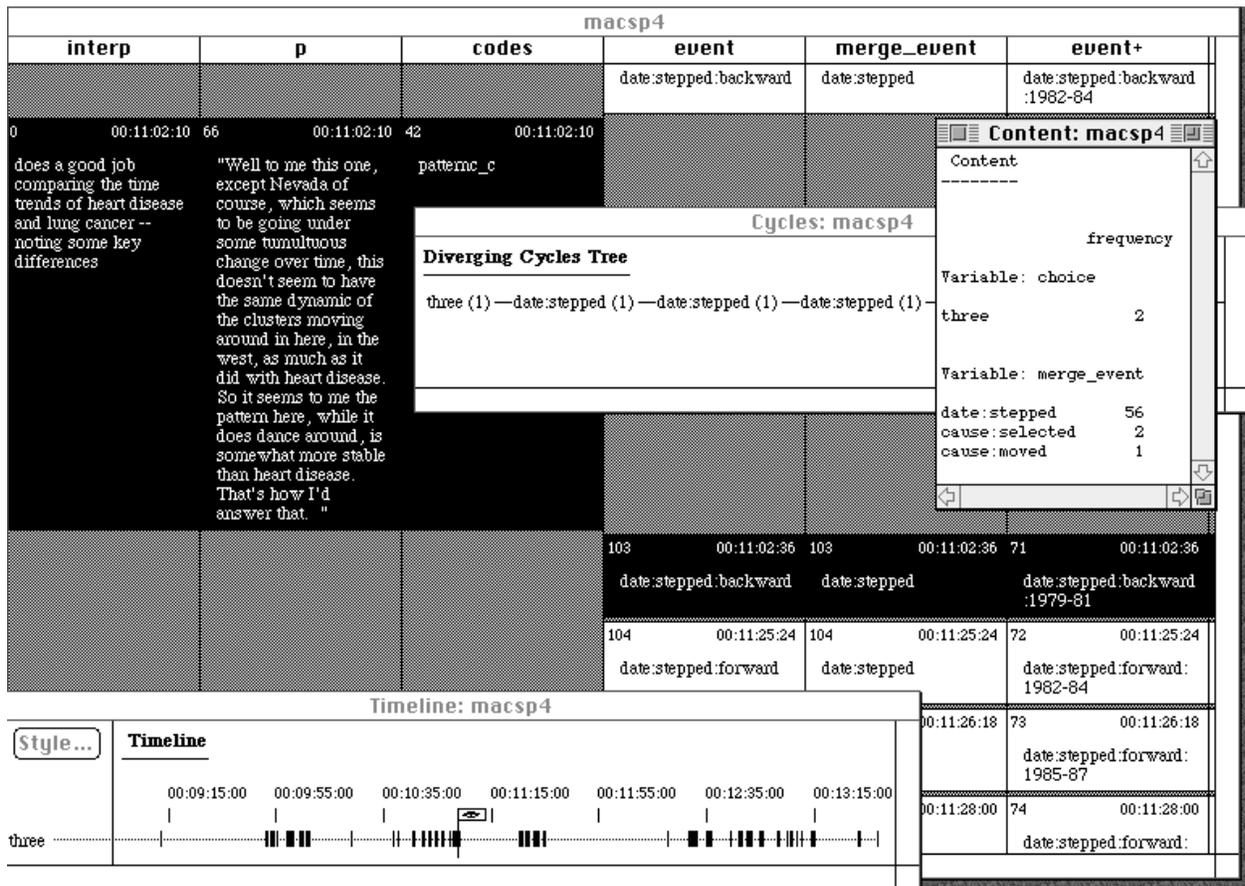


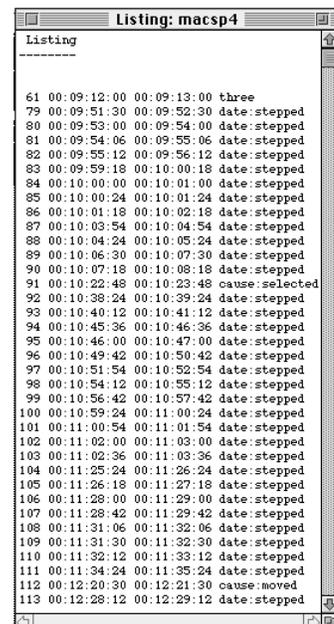
Figure 13. Here the cycle report, the timeline, and an associated content report are displayed with the spreadsheet window still partially visible.

participant then switches from lung cancer back to heart disease. At this point, the participant concludes that heart disease is "more solidly glued to the south" than is lung cancer. This is exactly the reverse of the actual spatiotemporal patterns. Based on the immediately preceding statement that it is lung cancer that does not change, it is probably safe to assume that the participant said the opposite of what they actually meant (but this kind of mistake highlights the limitations of verbal data).

Filtering

MacSHAPA includes a "filtering" module that provides an alternative method of selecting a subset of information contained in a spreadsheet column (or columns). The filtering dialog presents a list of all events of a particular data type (figure 16). For the system log data, the type is "nominal." One or more specific event categories can be "expanded" from the list (made available for selection), and within the set of expanded categories, any number can be selected from the column. Once the selection is made, any of the reporting methods described above can be applied. In this case, to follow up on the analysis described above, those instances in which the participant moved the cause-focusing tool to the 75th percentile are selected. A content

Figure 14. A listing report with events happening between the time at which module three began and the time at which it ended. Events are numbered from the beginning of the column for which the listing is generated. Onset and offset times for each event are listed as hours:min:sec:tick (with 60 system clock ticks per second). By default, since offsets were not recorded, the report has produced offsets for each event that are one second after the onsets.



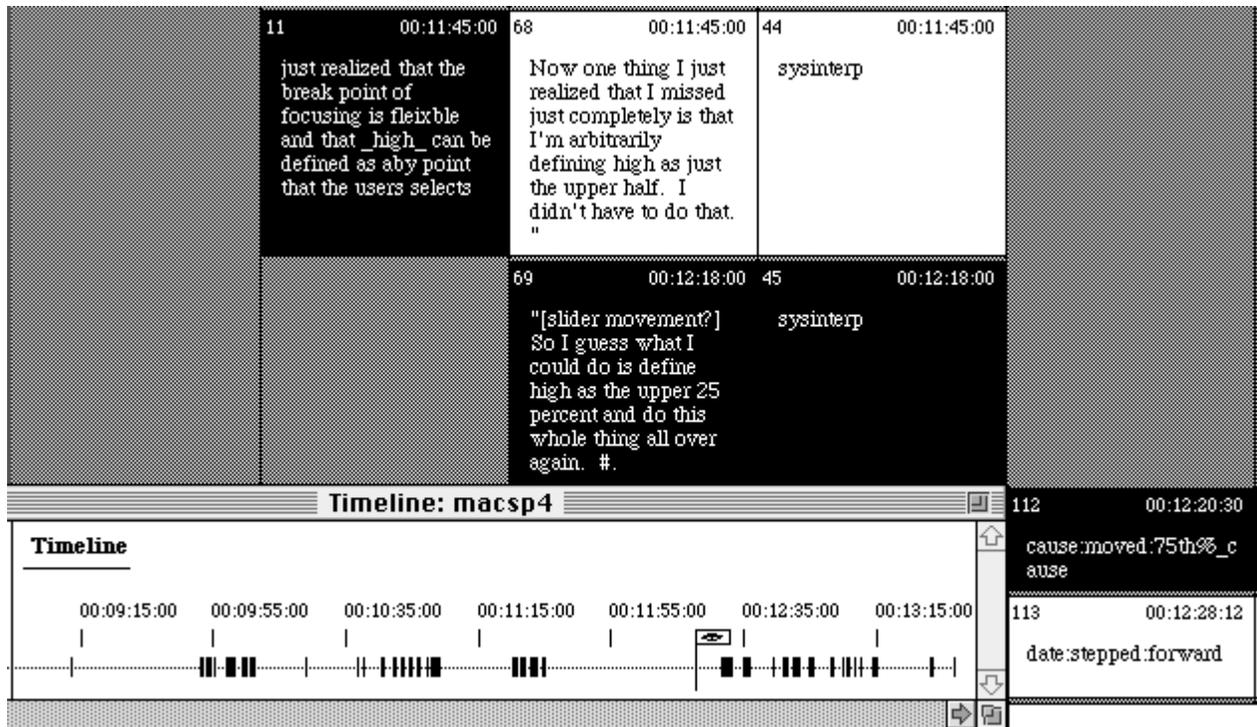


Figure 15. Spreadsheet scrolled to the cell number found in the listing for a use of the cause-focusing tool.

report on the result finds only two instances (figure 17). A listing report shows that the first instance was the one above (in which the participant suddenly realized that focusing in on the top quarter of the data set was useful). The second instance occurs during module six where participants are asked to explore a new data set in any way that they think would be used.

Discussion of methods

The examples presented above provide only a hint of the data exploration possibilities offered by MacSHAPA. There are a variety of analysis tools not mentioned at all (because they were not used with the particular data collected here). More details about MacSHAPA can be found in Sanderson, et. al., (1994) and through the Web at: <http://www.aviation.uiuc.edu/institute/acadprog/epjp/macshapa.html>.

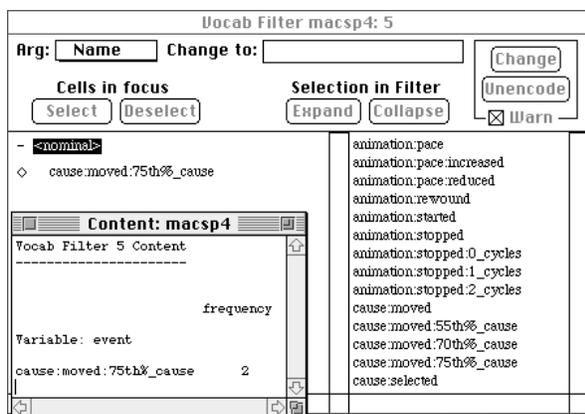


Figure 16. Filtering dialog box. Selection of a variable to expand for searching.

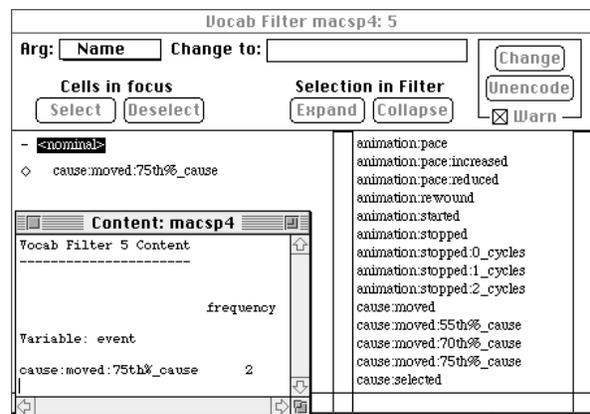


Figure 17. After selecting on "cause:moved:75th%_cause" a content report is generated, finding the action generated twice.

MacSHAPA is designed for analysis of individual time series data, not for comparison across subjects. Thus, it was used to develop characterizations of each participant and to generate summary data from which comparisons among participants could be carried out in other analysis environments. With in-depth data for nine subjects, comparison of participant strategies for using the system are presented graphically and through descriptive statistics.

Results and discussion

Results are presented in five sections. The first deals with brief details about system limitations identified. This is followed with discussion of participant interpretation of map symbolization and controls. Then, in separate sections, participant strategies and their success in exploring the data are considered. Finally, the exit interview comments of these domain experts are discussed.

System performance limitations

As discussed above, the prototype evaluated is one component of a larger system. It was constructed in a software environment selected primarily to facilitate the assessment of system use strategies and effectiveness. Limitations in system performance are, thus, significant here only as they might have an impact on an assessment of system design. Thus, the various problems encountered are reviewed only briefly.

During the course of system assessment sessions, a number of minor technical flaws in the prototype were noted. One flaw uncovered was related to manual transfer of map information from the ArcView component of the prototype to the Director component evaluated here. For heart disease, when the cause was turned off and the per capita income risk factor turned on (leaving the 2-class map of income visible), time step three showed the incorrect map (one identical to time step two). The map was replaced with the correct one in the updated prototype supplied with this report. When (if) the prototype is developed into a working environment, there will be no manual transfer of data among system modules, therefore, the kind of error encountered here will not be possible—only one of the nine participants noticed this problem..

Beyond this data processing error, there were two system performance problems discovered. First, the prototype “crashed” on a few occasions. There is no systematic pattern in these events and we have been unable to determine whether these crashes are due to a flaw in the Lingo scripting within Director or to some interaction between the software and the operating system on the laptop computer used for testing. A second system performance problem involved use of the animation stop button. When the animation is set at a fast pace, the stop button did not always react on the first try. This problem relates to low level system design issues and, thus, is not easy to fix in the current prototype. In the current prototype, the system will not react to mouse clicks when it is in the process of updating the screen (which it does with each time slice of an animation). When (if) a revised system is produced, however, this should be an easy problem to address. This problem, although encountered by a couple of participants, seemed to have no impact on their use of the system.

Finally, an error was found in some of the combined legend-scatterplots. When a univariate mortality rate map is initially displayed, the legend-scatterplot appears as a bar that serves as a map legend. When settings are selected to produce a bivariate map of mortality and risk factor, the bar legend transforms into a complete scatterplot. When the risk factor is turned off, the legend-scatterplot is supposed to collapse back into a bar legend, but in the prototype as tested, it did not always do so. No participants noticed this flaw.

Interpretation of map symbolization and interactive controls

Interpretation presented here is based on both observation of participant use of the system and their comments while using the system. General reactions to the diverging color scheme used on the univariate

mortality rate maps was generally quite positive. This was expected, because the color scheme used was the one for which performance was best in previous research (Brewer, et al., 1997). That the scheme was interpreted correctly by all participants, however, does indicate that these previous results (with paper maps) are relevant for screen display maps. The only arguably negative reaction to the color scheme was one comment that it might be useful to allow users to control the scheme, possibly switching between the present one to a simple grey scale. There were also two participants who asked for confirmation about which color represented high rates.

The later issue is probably a function of limitations of the combined scatterplot-legend (or of the rather brief instructions given about it). In an effort to conserve valuable screen space (needed for the many system controls required), the legend-scatterplot employs a minimalist design, lacking any value labels along the axes. The two participants who needed to ask about interpretation of the color scheme, would have benefitted from more careful instructions about how to interpret the legend or from addition of axis labels.

The color scheme used for the bivariate cross maps was not as successful as that for the univariate maps. While it can be argued that any bivariate map is inherently more complex than a univariate map, two problems were noted with the color scheme selected. Overall, five of nine participants seemed to immediately interpret the color scheme correctly while four participants needed to talk through the scheme (and in two cases ask for confirmation) before ultimately understanding it. Of the four who needed some time to figure the scheme out, two had trouble distinguishing the light grey and light blue colors used to depict the low end of the risk factor and mortality data. Of these, one male participant has a color deficiency. While he could distinguish the colors in the legend, the same colors in small map areas were indistinguishable for him.

Interactive controls in the prototype were of two main types, menus and direct interaction tools embedded in the map display. All participants seemed familiar with menus and encountered few difficulties with them. The interaction between the second and third menu did generate some comments and a few questions. Comments included both mildly negative reactions (about the lack of availability of the 5- and 7-class depiction of mortality when risks were considered) and tentative discussion of actions, the latter suggesting uncertainty about making desired choices. The direct manipulation controls proved to be generally successful. Most participants used most controls and there were few negative comments or mistakes in their use.

System use strategies

This section is based upon analysis of the system log files that document each action taken by participants during their session. Issues considered are the extent to which various controls are used, frequency and temporal pattern of that use, and differences in use across tasks and among individuals. Two key features of the prototype are tools for controlling the temporal and attribute components of analysis. Discussion here emphasizes use of these temporal controls and focusing tools. Much of the data examined is summarized in figure 18 (which details user interaction for each subject for each interface control over time) and figure 19 (which provides information on frequency with which each interface control is used by each participant, overall and during each of the six modules). Figure 18 is supplemented by more detailed timelines provided as Appendix 2, while figure 19 is supplemented by tables of the frequencies depicted as Appendix 3.

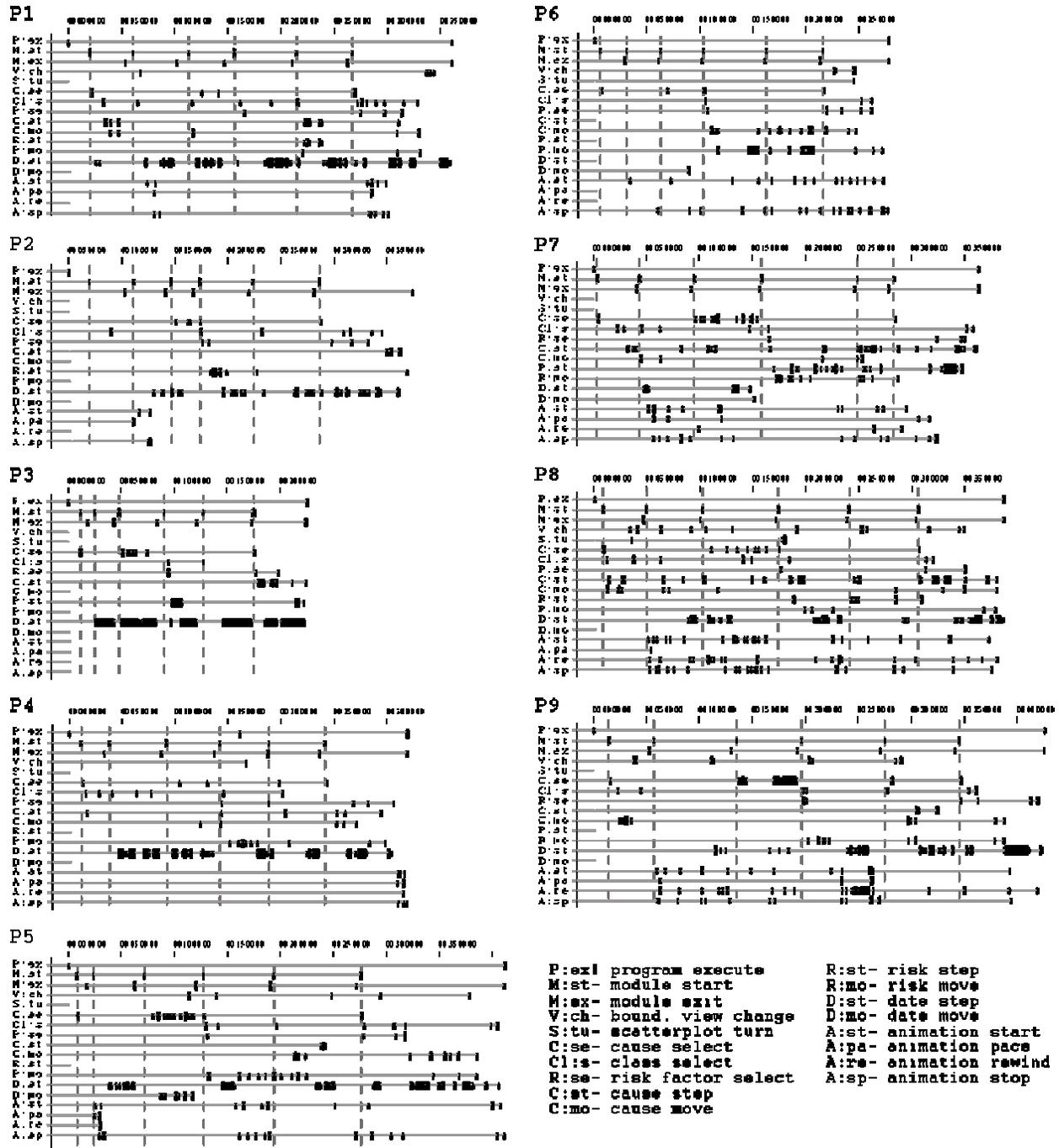


Figure 18. Timelines for the nine participants. Each set includes a timeline for every interface control, whether or not it was used. For those controls that are used, the timeline includes a tick mark for every instance of use. Due to scaling, the dark areas on the timelines often represent many repeated events.

Temporal analysis:

Across sessions and participants, the temporal controls were heavily used. This is not surprising due to the emphasis on temporal aspects of the data in the task modules. In the first five modules (that included specific tasks), seven of eleven tasks dealt with change over time. By far, the most frequently used temporal control was date stepping, with 1581 instances to 98 instances of animation and only 9 of using the date slider. While animations were initiated only 98 times, however, there were a total of 409

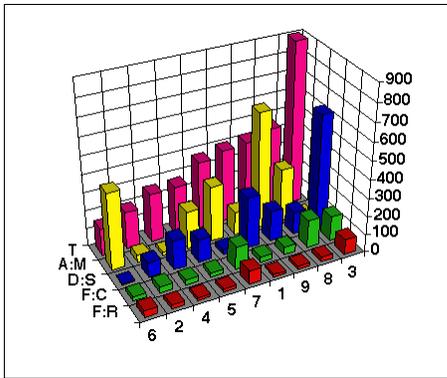
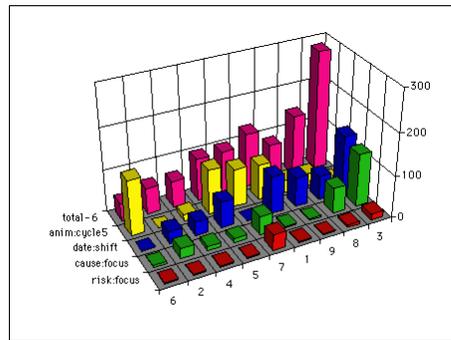
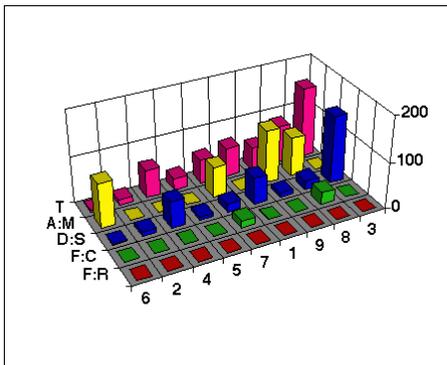
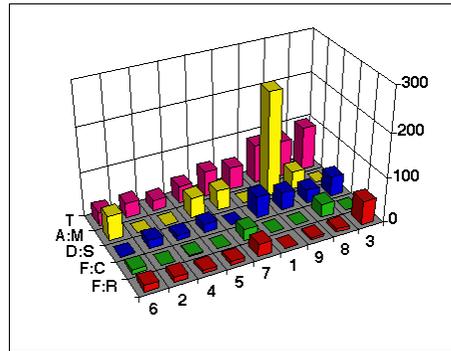
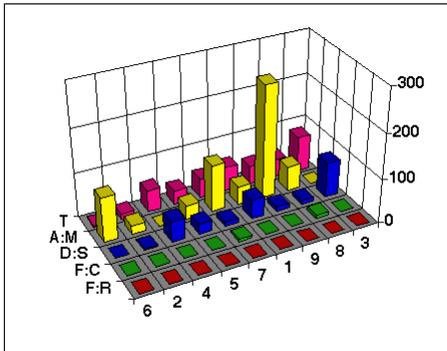
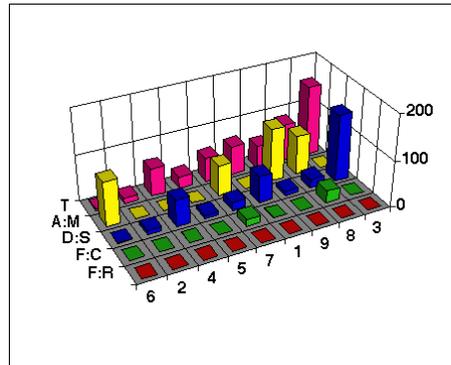
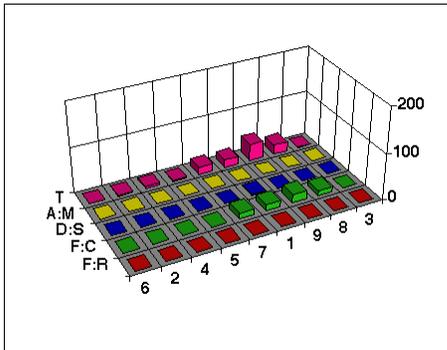


Figure 19. Plots of frequency of use for each interface control. The view at the left depicts totals for the entire session, by participant. Participants are sorted from low to high by total number of mouse clicks executed. Graphs below present the same information for each module. Order of participants matches that for the plot of overall totals.

T = total operations applied
 A:M = animation – number of cycles
 D:S = data – number of data shifts
 F:C = focus – number of focus operations on cause



animation cycles viewed, resulting in 2045 map displays during animation. Thus, more time steps were actually viewed using animation than using date stepping. Graphs in figure 18 depict this number of maps seen using animation (rather than the number of times animation was started or the number of full cycles run).

Participants differed considerably in the extent to which they relied on date stepping, animation, or both as a method for exploring temporal aspects of the available maps. Their strategies ranged from those of P3 and P4 who used date stepping much more than animation (with P3 not using animation at all), through P1 and P2 who viewed approximately twice the number of map views through use of date stepping than through use of animation. P5 and P8 used a reverse strategy and P6, P7, and P9 relied heavily on animation. One factor to note here is that four of the five participants who favored animation were from PRI and all four who favored date stepping were from NCHS.

Strategies used by individuals for examination of change over time were relatively consistent throughout the session. Comparison of temporal tool use in module six is, perhaps, the most representative of how these participants might proceed if the HealthVis prototype was developed into a production tool available for routine analysis. This module imposed no constraints on what the participant looked for, just on which mortality cause should be the central focus. By the time participants reached this module, they had used the system for at least one half hour. For this module, participants were, if anything, more extreme in their reliance on a single method of temporal exploration, with two each relying on date stepping or animation exclusively. The remaining five participants combined methods, with two (P8 and P9) reversing their overall session emphasis on animation to rely somewhat more on date stepping and P1 increasing use of animation to match that of data stepping.

Exploring and comparing variables:

The EDA technique of focusing facilitates identification of high and low values and helps to overcome some of the limitations of quantile classification noted above. Focusing was implemented here through a pair of complementary control styles, discrete stepping and a dynamic slider. Both allow the user to set a quantile break point for 2-class maps—with 10% steps in the case of the risk factor and a choice of 5% steps or 1% steps in the cause of the cause (the latter available only when the cause is examined by itself and the former available when either the cause alone or the cause plus risk factor are examined). Focusing can support multiple data analysis strategies. The most obvious is to isolate extreme values (either high or low). When comparing cause with risk, focusing can be used to determine locations that have high values on the expected risk factor and high mortality rates, or the reverse. An alternative strategy is to use the focusing tool (in particular the version that steps the threshold at a constant increment) as a way to explore the ranking of HSAs throughout the entire data set. If this is done quickly, the user can simulate an animation by data order that may facilitate the understanding of national scale spatial structure of a disease.

Although all participants made use of the focusing tools provided, frequency of use varied considerably (from 23 to 153 uses of cause focusing and from 11 to 83 uses of risk focusing). Two individuals (P2 and P3) relied exclusively on focus stepping while one (P6) relied exclusively on the slider (with two others, P4 and P5 relying on the slider for focusing risk but using both tools with cause).

Across the session as a whole, the cause focusing tool was used more frequently than risk focusing. For the open ended exploration in module six, cause stepping was used more than risk stepping by all except one participant (P1) who used both only three times. Of those four participants who used focusing 25 or more times (P2, P3, P7, P8, two each from the two organizations), P3, P7, and P8 used focusing as a sequencing tool—stepping through the data range from one end to the other and back, with no intervening actions. The remaining five participants tended to use focusing to identify and low values and to distinguish between regions above and below the national median.

System use effectiveness

This section extends from the consideration of exploration strategies presented above to address effectiveness of system use in relation to temporal and multi variate analysis. Attention here is on

participant verbalizations about what they were doing in an effort to respond to the task presented and their interpretation of the information being explored.

Session modules were designed to lead participants through a series of typical tasks, culminating (in module six) with an open-ended exploration scenario. Of the six task modules that participants completed, two are examined in detail here, one early module (the second module, which was the first to focus on time trends) and the final open-ended exploration module. The second module emphasized change over time without the complications of comparison between causes or risks. The sixth encouraged a wide range of exploration and included consideration of spatial and temporal characteristics of a mortality cause (prostate cancer), of potential risk factors (unemployment and/or income) and of the relationship among them. This module provided participants with an opportunity to integrate strategies developed during the five more narrowly focused modules and is most representative of what an expert analyst might do with the system once they had become reasonably comfortable with the various options. As above, discussion is divided into sections on temporal analysis and on exploring and comparing variables.

Temporal analysis - module 2:

Heart disease was selected as the first variable for participants to work with, because it has some clear spatial patterns that were expected to be easy for participants to identify and because it has a definite spatial change over time (in location of the largest cluster of high values) that is less easy to identify, particularly from standard 7-class maps. Since the shift is primarily in location of the top 20-25% of mortality rates, this space-time pattern is most easily seen by focusing the cause to the 20th or 25th percentile and then animating the map at a slow to medium speed. Only three of nine participants noticed the shift in the core of high values for heart disease mortality (from the northeast and northern Appalachia toward the south and west). All three individuals who noticed the fairly dramatic shift in location of places with heart disease mortality in the top quartile (P6, P8, and P9) made substantial use of animation and all were from PRI.

Although participants were not particularly successful in identifying the change in position of clusters over time, several were successful in identifying a change in spatial concentration of heart disease over time. P1, P2, P3, P5, P6, P8, and P9. The pattern noticed was a general dispersal of major clusters over most of the time period with some reaggregation in the final time period (the latter noticed by only two participants). The table below provides a summary of features noted by each participant during modules two and of their strategy for investigating the questions posed.

CHARACTERIZATION OF PARTICIPANT'S APPROACH TO AND SUCCESS ON MODULE 2

P1—Did not find the shift in high rates from NE toward south and west. Recognized the Higher rates in the east but did not identify any shifts in location over time. Did note an increase, then decrease in clustering over time. Used the 5-class map exclusively. Ran animation twice (4 cycles and 2 cycles), and stepped date many times (44).
P2—Did not find the shift in high rates from NE toward south and west. Saw higher rates in the east, but came to no conclusions about space-time trends. Used 7-class map exclusively. Ran animation twice (4 full and then 1 partial cycle). Steps date only three times.
P3—Did not find the shift in high rates from NE toward south and west. Does note generally high values in Appalachia and a time trend from large to small clusters. Used 7-class map exclusively. Did not run the animation. Stepped dates 150 times.
P4— Did not find the shift in high rates from NE toward south and west, but does note a general trend from east to west. Used 2-class map when focusing on highs and lows -- but left cause classification at 50th percentile the whole time. Focuses on changes to Nevada and Maine (increases and decreases in rate over time respectively). Used the 5-class map to examine changes in the median. Did not run the animation. Stepped dates 46 times.
P5—Did not find the shift in high rates from NE toward south and west, but does note a general trend over time toward dispersion of some large clusters of high values (in Appalachia) and low values (in the SW) over time. Used 7-class map exclusively. Ran animation twice for a total of six cycles at two speeds, then switched to date stepping -- 22 times.
P6—Noticed the shift in high rates from NE toward south and west. Notes a general trend over time toward enlargement of some large clusters of high values and dispersion of ones with low values over time. Used 7-class map exclusively. Ran animation once for a total of 20 cycles. Did not change speed or use date stepping.

P7—Did not find the shift in high rates from NE toward south and west. Sees the high cluster in Appalachia as relatively stable. Seemed to focus on small sections of the map that did not happen to change much and missed the big picture. Started with 2-class map on, switched immediately to 5-class map, then switched to 2-class with a 50-50 break point, then shifted to 75th. Ran animation 6 for a total of 21 cycles at multiple speeds. Also used date stepping -- 10 times.

P8—Noticed the shift in high rates from south toward west (so saw part of the trend). Notes a change in cluster number and size over time, but does not specify what the change is. Gets distracted by changes in big units (NV). Starts with 7-class map the switches to 2-class and manipulates focusing several times, looking at low as well as high values. Ran animation 6 times for a total of 11 cycles. Used date stepping 9 times and changes cause focusing 7 times.

P9—Noticed the shift in high rates from NE toward south and west -- right away. Notes a general trend over time toward dispersion of some large clusters of high and low values over time, along with a growth of a Miss. cluster of high values over time. Also notes changes in NV over time and many other small pockets. Used 7-class map exclusively. Ran animation 6 times for a total of 51 cycles. Use date stepping 11 times.

Exploring and comparing variables - module 6:

In general, the participants understood how to use available tools and explored the prostate cancer data in creative ways. Prostate cancer mortality is much more dispersed in the U.S. than either heart disease or lung cancer. Most participants spent several minutes simply exploring various aspects of the distribution at one time and/or over time before beginning to notice the relatively weak patterns that do exist. The general tendency of high mortality values to be in the northern half of the country was uncovered by six of the nine participants (P1, P2, P3, P5, P6, P7). Two of these participants also note the strong contrast of this pattern to the other two variables examined.

Perhaps because the pattern for prostate cancer is much less obvious, several participants directed their attention to more local areas (states or regions of the country). In an effort to characterize change in these places, they adopted a strategy of watching these particular areas as they stepped through time (or ran the animation). One interesting observation (by P7, one of those who did characterize the pattern as a generally northern one) is that there also seems to be a predominance of cases in rural areas. This kind of observation could, of course be further explored if users were able to toggle a city layer on to "test" this hypothesis.

All participants attempted to discover relationships between prostate cancer and at least one of the risk factors (income or unemployment). In general, logical strategies for investigating the possibility of these relationships were used. All participants, for example adjusted both cause and risk focusing for the cross map. Among the most interesting relationships uncovered was an apparent correspondence between high income and high prostate mortality (top 15% on both) to correspond along a corridor from Michigan to Mississippi.

CHARACTERIZATION OF PARTICIPANT'S APPROACH TO AND SUCCESS ON MODULE 6

P1—Overall, use of the system is sophisticated. Many different approaches to data analysis are tried with focusing tools used sparingly (cause is stepped or moved 3 times, risk moved 3 times), use of animation 5 times at different paces and of date stepping 89 times. Assessment of the unemployment data is very good and, in spite of the fairly weak patterns in prostate cancer data, a number of key things are noted (e.g., the general tendency of high values to be in the north, the correspondence of high income and high prostate mortality rates toward the north, and the tendency of the above median unemployment - above median mortality to be in the west and in a corridor from Michigan to Miss.

P2—Has a fairly good understanding of the tools and applies them in a logical way, working systematically through various options. By using focusing, identifies the general northern pattern of high prostate rates (and separates this from a somewhat different west-east seaboard pattern of above median rates). Also identifies the strong negative correlation with heart disease and lung cancer, particularly in the first time period. Makes use of focusing, particularly of cause (with 24 uses) and of date stepping (28 times).

P3—Finds several key patterns in prostate data. In particular the "T" pattern of north and plains states, the general northern concentration and the definite contrast to lung cancer. The assessment of relationships to income are also reasonable. Never, however, looks at unemployment. Used the fewest tools of any participant (5), but had the highest number of interactions (by far). There involved considerable use of focusing (cause 125 times and risk 16) and of date stepping (126 times). The cause and risk focusing seemed to be used as a sequencing tool, with systematic stepping one way then the other repeatedly to see the attribute ranking of HSAs.

P4—Does not identify any national patterns of trends. Spends much of the time focusing on particular places (especially Maryland) and using focusing and date stepping tools to investigate where this place is in the ranking of HSAs and how that position changes with time. Uses animation three times (but rather unsuccessfully, going through only 3 cycles total and not commenting at all on patterns seen) and date stepping 32 times to look at time trends. Uses cause focusing 13 times (using both stepping and the slider) and risk focusing twice.
P5—A fairly comprehensive look at the data and logical use of tools. Looks at prostate cancer alone first (with 7-class map), then at unemployment along (making use of focusing tools). Does not, however, look at the two together. Then moves to consideration of cancer and income. Focuses on a region at a time, noting changing patterns. Makes use of focusing tools to search for both positive and negative associations between income and prostate cancer. Ultimately finds that the south tends to have low income and low rates, then speculates that this may be due to low rates of diagnosis rather than truly low rates. Following this analysis, the high-high regions are considered again, but no explanation of the changing patterns is found. During the module, animation was used 5 times and date stepping 62 times to examine time trends. Focusing was done exclusively by moving the slider rather than stepping (10 times for cause and 3 for risk).
P6—Emphasizes that the varied size of units and of clusters makes it hard to characterize any patterns. Begins by looking at cause, then adds unemployment and sees some clustering in west and east, but not Midwest. Ultimately notices the general concentration toward the north and, across last two times, in the west. Animation was used 9 times, the most by any participant. Date stepping was not used at all (the only participant who did not use this feature in module 6). Focusing was used sparingly and in all cases by moving the slider (4 times for cause and 3 for risk).
P7—Identifies the generally northern concentration in prostate cancer. The dramatic difference between other two diseases is also noted. Over time, a general consistency is seen in high values and characterizes this as mostly a rural phenomenon. Does not find any real relationships between prostate cancer and income or unemployment (a few random clusters). All temporal analysis is done by use of animation (used three times for 8, 7, and 3 cycles). Most exploration focuses on use of focusing at particular times, with cause focusing used 45 times (the slider once), and risk stepping used 36 times (the slider once).
P8—Proceeds very systematically through a set of analysis steps. Considers the full map (7-class) briefly and then spends most of the time making use of focusing controls to examine the areas with high or low value and areas of cross maps that are high-high or low-low. Does not uncover much in the way of relationships between variables of patterns in prostate cancer, but does use several interesting strategies. Among these, stepping systematically through focusing with the express purpose of watching the sequence of additions to the map (as used by Monmonier, Slocum, and others). Similarly, the method of watching a particular location (a state or two) to see the focusing level at which a disease shows up or to watch change over time is effective for characterizing these places. Analysis of PA is good and of CA reasonable (with the exception of comment about high correlations).
P9—Does not find any real pattern to prostate cancer and determines that there is no obvious relationship between it and either risk factor. Seems to have a very sophisticated understanding of the system. Does notice the general increase in unemployment clustering. Uses most controls including focusing on both variables for the cross map and animation (once for 6 cycles) as well as date stepping (70 times for the latter) and the use of the rewind button during date stepping. Seems uncertain about graph interpretation.

Expert Reactions

Following each session, participants were asked to provide their assessment of the prototype. In particular, they were each asked to comment on system features they found useful, point out any features that were not useful or were confusing in some way, and offer suggestions for improving the system. These comments were condensed and categorized into those related to suggested additions (no real subtractions from the system were suggested) and to those related to assess features that are included. Additions suggested were further characterized as those related to: data, labels for features of the interface, maps or map components, output facilities, supplementary statistics, and geographic zooming. Comments related to assessment of the prototype are grouped into those directed to: aspects of the scatterplot, the maps (data classification, color schemes, time representation and control, and symbolization type), tools provided in the interface, and the overall system. The condensed categorized comments are included in the table below.

add_data	1	major rivers if that's a possibility to put in might be interesting because for chronic diseases it probably not be of relevance, I don't imagine, but for some of the infectious diseases especially with some of this recent stuff that's been going on with this, # in Maryland
add_data	1	to layer in things other than risk factors, like to import data. Say you have data on, not just risk factors, you have data on weather, by state, or demographics, by state, or HSA.
add_data	1	Obviously having more risk... obviously having more of all of the above would be great.
add_data	1	wants Canada & Mexico

add_data	1	Some flexibility in terms of having... like combining... like if I didn't want 82-84, I wanted 82 to, whatever the next one is... 82-87
add_data	7	is there any intent of looking at rarer forms of cancer.. and if that is the case, would there be an option to aggregate data across, is there a way in which, behind the scenes, data could be aggregated across years and new rates calculated.
add_data	7	one thing that did interest me, rather than see it as a problem, was, if we're looking at this time period and then looking at a risk factor, I think I'd like to know the source of this. just because its income.. and I know you can get income from things like business pattern data... but I also know its not available for the HSA unless there's been some manipulation behind the scenes. and I guess its available for certain time points.. maybe the beginning of this time sequence, certainly 1980, but as we go to the next time sequence, is this.. does this risk factor change.. I mean, are the data that go behind this changing or is it just fixed in time at 1980 income rates? --- I don't know enough about the risk factor
add_data	8	it would be nice to have, as either a risk factor, or a cause class... I think it's a risk factor is where it would be.. a scale that would let me crank up or down managed care penetration, and see if my rate changes over time,
add_feature_labels	1	One thing I've seen in Windows which is a nice feature in terms of learning a new system is it gives you the option to have labels and icons, icons only, labels only. if the option is, when you comes on, that it's automatic to have both of them, and you have the option of
add_feature_labels	1	When you have risk factor over here, it would be nice that if.. When you select cause here, for example, you select heart disease, it says heart disease down here under cause, and if you select risk factor in unemployment, it basically labels that.
add_feature_labels	7	maybe you could toggle the labeling of any of these time bars on and off.
add_feature_labels	7	so a labeling on that axis would have been nice
add_feature_map	1	And also I'm sure that in version 2.0, you'll be able to rotate the map so you could do it 3-D, you could have a three dimensional representation instead of a two dimensions.
add_feature_map	2	I just find it hard to keep in my mind what I've just seen, without being able to see them; given that you have four time periods, and then to have one in each, you know, divide it into quarters on the screen, I mean you wouldn't need to see the detail, but just so you could see the major trends
add_feature_map	2	Or maybe if you could split the screen to somehow combine... say you could look at two at once.
add_feature_map	2	2 different causes and it would have been nice to, you know, look at them side by side.
add_feature_map	3	if you could have some little maps that you could put next to each other or I mean copy [print]; I guess I find it easier to be able to look back and forth and not have to remember anything...
add_feature_map	3	you could say oh heart disease is clustered here and if you could look at lung cancer at the same time it would be easier to compare them instead of going back and forth on two different screens [wants to have two linked views that can be manipulated over time]
add_feature_map	4	I think it would be good to have a three group classification as opposed to a five and a two.
add_feature_map	4	what might be good to consider doing is being able to delete some of the information in addition to showing all of the information. You know, instead of always showing percentile 0-100 maybe there's a way you can just highlight the top twenty-five percent and the bottom 25% and just get rid of the rest.
add_feature_map	5	I would like to be able to do a four-plex on the same screen at the same time.
add_feature_map	8	it would be nice to see the HSA boundaries with the states.
add_feature_output	2	I guess when you're actually using it, you'll be able to print out map, so you can look at two side-by-side, as opposed to... I found it kind of hard to go through and remember what I'd seen.
add_feature_output	1	I'd like to have a print feature on this
add_feature_print	6	I was thinking that this is something that.. you could .. you know, mess with these percentiles and then just print off what you wanted? That would be .. ya know, nice
add_feature_stats	2	It would be nice to have some absolute values that you could look at over time to know if the disease was going up or down.
add_feature_stats	2	I guess, I mean it would be nice eventually to be able to calculate rates,
add_feature_stats	4	It's sometimes hard to know what is meant by high and low. it might be useful to add some suggested delimiters, some suggested cut points on what's meaningful for high and low.
add_feature_stats	7	are you thinking of selecting a health area and being able to query the rate.. and actually get an individual value
add_feature_stats	7	I guess, one of the things that I would like to see.. something more about ..a lot of rates.. I mean, the rates in the rural areas are driven by small numbers, perhaps.. and so I'm not sure there is any way that information could be added in... so that whether or not there's confidence in
add_feature_stats	7	I'd definitely, I'd like to know more information about the data.. even just like the mean and you know like a SD type statistic might be useful .. maybe you could swap, maybe you could just switch between a graph and some basic statistics.

add_feature_stats	8	to be able to say.. or to have a table here that says.. ok.. here's the national median, that's fine, but to say, I want to change my reference point to PA median.. or I want to change my reference point to the Dartmouth Atlas median..
add_feature_stats	9	I really what to know what's graphed on that axis
add_feature_stats	9	I start wishing I could look at some tables... like how many of these HSAs are high on this or high on that..
add_feature_tools	7	are you going to want to be able to select certain places in the graph and see where they appear on the map or vice versa
add_feature_zoom	1	this would be another feature that would be nice, if I could window in on this area here, and have it zoom in and then see a map of this area to see what is the ...what.... I mean if it says Navajo Indian reservation , then there's my answer. Then if it says tuba city or if it says Flagstaff, then it might give me a different impression.
add_feature_zoom	4	in addition to mapping the whole United States, is see whether or not you can click on a specific state, bring it into focus.
add_feature_zoom	5	so I see something going on in this area, I can put a box around it and explode the map in that area, so I can see what's going on. This is a wish list. ... so then you could focus in on an area, say if you were looking at the Long Island breast cancer type of things, well let me focus in on this area and let me look at breast cancer over time in these areas and was it persisting?
add_feature_zoom	7	or zoom into this region and get a graph just of that region?
add_feature_zoom	8	if I could, say, draw a box around a state, you know, and have a magnify button and be able to concentrate geographically on an area. ... it would be also nice to.. kind of drill down, into my little neck of the woods
assess_graph	1	scattergram, or what is that? About the only thing down here helped me do was remind me of what the colors were supposed to represent. But when it first came up, you know I thought it looked like a star field.
assess_map_class	9	sometimes I do find percentiles frustrating, because.. um.. you can't tell, like if lung cancer rates are going up; and there isn't an option here to look at , like, raw values [a call for N-class maps?]
assess_map_color	1	the variation in colors ... gradients in colors. sometimes if you do shades of gray sometimes it's easier to see than... Or some colors that make more sense to me. Cause right now, light blue-dark blue, light gray-dark # You had to instruct me on what they meant.
assess_map_color	3	The light blue and the light gray are a bit hard to tell the difference between
assess_map_color	7	I seem to have a lot of problems interpreting... and I'm not sure it was the combination of the colors.. when but that legend.. because of the variables for income and unemployment... I wasn't sure which end of the spectrum was the highest and lowest values
assess_map_time	2	The movie was a little too fast for me to grasp what was going on.
assess_map_time	3	it was nice to be able to see the change over time and if you could step back a bit you could pick up the pattern so I did like that.
assess_map_time	4	[animation] I made the switch at the end because I remembered I wanted to try it. ... But I did prefer doing it myself and being able to study it more static, you know, one at a time, and switching it when I was ready, rather than watching it switch.
assess_map_time	6	The neatest thing is the time...I think it encourages most people to look at time trends
assess_map_time	7	I actually enjoyed the flexibility to go back and forth and do that. um.. I liked very much the animation.
assess_map_type	1	I don't understand HSAs; I'd like to see counties too... Or SMSAs. Because some of that stuff makes sense to me; When, when I popped up the HSA thing, and I could see that's how the data's coming in... I'd like to know what an HSA is.
assess_map_type	3	I liked the ability to cross the two although it took me a minute to kind of figure out what I was seeing
assess_map_type	5	you get to areas like Nevada and it's such a broad area with only few health service areas, so whatever color dominates there starts dominating the western U.S., I mean, it's weird, it overpowers California and I know people do those weird maps [cartograms], but I find those difficult to use, too... be nice to have the smooth types of maps also available,
assess_map_type	6	Its kind of confusing at first to try to figure out how the two risk factors work together in terms of the color schematic [points to the sliders]..but, I think once you figure that out, but by playing with the percentile you can kind of, get a better idea of what you are looking at. but, I think that's normal
assess_map_type	7	the counties are larger in the west .. and they kind of flick in and out.. and they were distracting me .. when I animated the map
assess_map_type	8	[starts to suggest that it would be good to be able to manipulate class breaks dynamically on the 5- and 7-class maps, then] .. I can do that.. I'm sorry.. by.. as I'm thinking out load.. by doing what I've been doing.. and that's driving the risk factor up to the highest end that its appearing and follow it over time.. but the multi-hued map.. I was just thinking.. might be .. for presentation..

assess_sys_+	1	This is great.
assess_sys_+	2	It was great. It would actually be nice to do it on a slightly bigger screen.
assess_sys_+	2	It's very nice... It's very nice to be able to alter all of these things.
assess_sys_+	2	I would like to play around with it, I mean especially if there were more diseases.
assess_sys_+	3	I like it. It would be great if we could use it in lab.
assess_sys_+	3	I don't really find this to be difficult. I guess I'm used to Windows driven stuff so that's fine.
assess_sys_+	4	I think it's a pretty interesting system.
assess_sys_+	8	Its certainly intuitive and easy to use
assess_sys_+	8	but, as far as running the mapping.. I just love to be able to look at these things spatially.. I think that.. raw data has been the bane of all or our existence for a long time.
assess_sys_+	9	Its really pretty easy to use.. the way you can just like, [snaps fingers] change the years, or change the variable you're mapping, or like I said before.. changing the percentiles, or cut points.. that's pretty cool..
assess_sys_+	9	I don't know, like, exactly what your purpose is.. I find it fun to look at how different things are distributed over space.. umm .. so, that's interesting
assess_sys_-	3	if you're trying to look at ten, you know, changes over time in one and changes over time in another and compare all those changes in those charts, it's a little bit much to remember, maybe. But if I had this on my computer, I'd probably just print them out and look at them on my desk.
assess_sys_-	8	what I think I need, or would need, is a cheat sheet. a little thing that says.. ok .. as I'm driving up the cause classification, or driving the risk factor.. and if I could point at this and click and say the dark blue is... above 80th percentile.. and be able to sort of remind myself, what do the color codes stand for..
assess_sys_-	9	as far as finding relationships.. I guess that's hard.. it takes a lot of time and thought
assess_sys_-	9	you're asking me questions about if there's an association.. I find it very hard to eyeball that.
assess_sys_?	5	The question of what kinds of questions are trying to be answered by these. Do you have people, gee, it seems like my county's having a high rate of this, well, let me go in and see if my county has been persisting over time as a high rate. You know, people trying to answer those questions with the maps. Are the people trying to generate a hypothesis? Primarily I see it being used for hypothesis generating or by researchers, hey I need a lot of cases of this disease, where do I think I can get them because now I want to go after incident cases so I want to recruit medical centers in these areas because they tend t have higher rates over time.
assess_sys_?	7	[after a discussion of a way to see changes in magnitude of the data, P7 discovers that] you'd see it in the graph, wouldn't you. you'd see unemployment go up or down if there was some ..
assess_tasks	5	to have to lose the sight of the screen going back and forth, it was more difficult to discern what was happening, So it would have been nice to have them on the same screen so I could look back and forth, this is really just in the same area.
assess_tools_+	3	I like the state thing too.
assess_tools_+	3	and this part here was certainly really easy to understand especially since it has the years down there.
assess_tools_+	5	Looks good. I like a lot of the features you have, being able to adjust the marginals, how they're going to work. Very intuitive to use.
assess_tools_+	6	I like that you can change the boundaries. umm, or you can just get rid of the boundaries.. and it is really simple to do
assess_tools_+	6	I liked that you can click and have the time change.. that's really nice.
assess_tools_+	7	I didn't realize, for example, this was one HSA. I should have done that.. perhaps I should have used it .. now I look at this map; I mean I realized they would be larger geographical areas than in this area .. but.. um.. so I can see that I probably should have used this..
assess_tools_+	7	I like this actually [points to time bar].
assess_tools_+	8	I like being able to.. ah.. ratchet these things up and down..
assess_tools_+	8	I really like this ability.. both to make it go slow and fast.. and the ability to control that time series change .. that's really a nice factor..
assess_tools_+	9	Its nice to be able to change easily, like, the percentiles, so if you just want to look at the extreme values, you can just do that real quickly..
assess_tools_-	6	I think that you can only do a risk factor with this one particular .. break point here with the 2 classes. but I don't think that's such a big deal
assess_tools_-	7	[points to pace setting], is there ten or something.. I'm wondering if this.. I know I used it, but I'm wondering if other things are added and this becomes to busy, and this might be something you'd take out... is there a reason why you didn't have the time bar over on this side?
assess_tools_-	8	it would be nice if I could click on that and have it hold.. you know, I don't have to hold down the left mouse button..

assess_tools_?	3	I might put these down here, I don't know. I'm not used to clicking things on the left, I'm more used to the bottom. I find that a little distracting, but I like the idea of the... I wonder if they were next to each other, but That would get confusing just having to go back and forth one way.
assess_tools_?	3	this goes in five point increments and this in ten.
assess_tools_?	4	it's a pretty interesting exercise; I don't think the way I did it is the way to go. I don't think high and low is best defined by the top and the low fifty percent. It's just too amorphous. I would say I don't know. The first thought that would occur to me would be quartiles. That if I was really looking to see what constituted a real association between high lung cancer and high unemployment and I was using this system, as a first cut I would look at the top twenty-five percent and the bottom twenty-five percent and get rid of the rest.
assess_tools_?	7	maybe my geography's good enough that I didn't have to use this function [the borders]
assess_tools_?	9	I didn't use these buttons.. [markers on the sliders] I suppose you can slide them?

In general, reaction to the prototype is quite positive, with few negative evaluatory comments (the ones coded with "+", "-", or "?"). Most participants requested more data be available for use in the system, a request that has been met in part by the revised prototype submitted with this report (and would be met more completely should a decision be made to develop a production system). A number of requests were also made for descriptive statistics to accompany the maps. Beyond these calls for more data and statistics, there were a wide variety of useful suggestions related to design of maps and controls. Some suggestions for changes or additions to maps and controls are already incorporated in component A of the prototype (the component that these participants did not use).

Recommendations

Based upon the analysis detailed above, discussions with NCHS staff and others concerning both components of the prototype, and previous research (as detailed in the literature section above) a series of recommendations are made here concerning future development of dynamic mapping tools at NCHS. Some of the recommendations (based on participant feedback in the exit interviews) were anticipated under conceptual goals three and four (goals not specifically addressed by this research).

1. *Include animation as well as date stepping in dynamic tools for exploring time series of georeferenced data.* Spatiotemporal patterns that are hidden in static snapshots, can remain hidden even when those snapshots are sequenced manually. Visual space-time patterns, however, seem to “emerge” when animation is used. This is a recommendation that requires empirical validation. Based upon strategies of animation use by the three participants who successfully identified the changing location of high heart disease incidence, some control over animation pace appears to be useful, but slow, medium, and fast should be sufficient.
2. *Consider alternatives to choropleth maps*—particularly when time series animations are to be used in analysis. Several participants commented about the fact that choropleth map units vary in size and that during animations attention is drawn to any changes in large units (whether or not those changes are important. In addition, animated choropleth maps produce a somewhat disjointed animation because change from one time to another involves change in the color fill of whole map units (a problem anticipated above in discussion of previous research).
3. *Include an alternative data classification method to quantiles*—one that allows comparison of absolute magnitude across time series (for specific places and for the country as a whole). Quantiles put emphasis on spatial shifts in relative rank order of places, one important component of spatio-temporal analysis. A time series of maps classified using quantiles, however, conceals any changes in relative magnitude from one time period to the next. Some participants seemed confused about this (at least during isolated points during the session). The typical error made was to comment about increases or decreases in proportion of HSAs in the highest and lowest classes – a proportion that

quantile classification holds constant. The most appropriate complement to quantiles is Jenks' "statistically optimal" method of classification, that groups data values into classes with minimum internal variance and maximum between class variation (resulting in maps for which HSAs symbolized with the same color will be known to have similar data values and HSAs symbolized with different colors will be clearly different. While the Jenks method has this advantage, if applied independently to each map in a time series, the maps are not comparable across time. To work with time series data, this classification method must be applied to the entire set of values for all time periods. If rates change substantially over time, the effect can be maps in which some categories are empty during particular time periods (the extreme for a long time series of steadily increasing rates, as in the case of AIDS, could be an initial map with all values in class one and a final map with all values in the top category). The resulting animation would provide a dramatic picture of change in magnitude over time, as illustrated by an animation of HIV rates for the U.S. by Gould, et. al., (1991). As a result of this emphasis on change in magnitude, however, the animation may not provide much insight about change in spatial pattern over time. Together with maps using quantile classification, however, the use of maps using Jenks classification can provide a fairly complete picture of change. If users were provided with a tool that allowed for easy toggling back and forth between the two mapped representations, they would also begin to understand the substantial impact that the choice of any one classification method has on apparent patterns in space and time.

4. *Tutorials should be created to introduce the range of novel data analysis possibilities made available by dynamic mapping.* Dynamic exploratory tools for spatiotemporal analysis require training to use effectively. This was particularly clear in relation to effective use of animation to help discover space-time patterns in data. Those participants who were reluctant to use animation failed to notice a rather distinct and potentially important geographic shift in heart disease concentration. There is also a related conceptual step involved in the move from static maps with fixed classification systems to dynamic maps in which the user can control how data values are grouped. This step may require specific training in order to encourage appropriate use of the more flexible analysis methods provided and to facilitate understanding of the resulting maps. While this instruction could take the form of a series of workshops, a more flexible alternative is to develop a self-paced tutorial that introduces system controls and application to typical data exploration situations. Such a tutorial could be modeled on Monmonier's (1989) concept of "Atlas Touring," itself modeled on the earlier EDA concept of the "Grand Tour."
5. *Dynamic focusing—classification tools should be provided.* Dynamic focusing appears to facilitate spatial or spatio-temporal analysis. Both a stepping tool and a dynamic slider are useful and are favored by different users. A potentially useful addition to the focusing controls implemented here would be a variation that allows users to set more than one flexible break point (as on participant noted, it would be particularly useful to be able to highlight a group of values in the middle of the range). Such a tool already exists in part A of the prototype, as dynamic classification. There may be no need to provide high resolution focusing tools (since no participants used the 1% cause focus control).
6. *Further research should be directed to expert use of dynamic focusing and classification tools—* in order to provide some general guidelines about their effective use and to determine the most successful tool design.. While focusing and dynamic classification tools are judged to be useful by analysts, we have a limited theoretical base from which to consider the impact of such tools, and virtually no empirical evidence concerning their design or use. There is at this time, no basis from which to develop a response to one participant's request for guidelines on appropriate use of the focus tools (e.g., what settings are most likely to lead to insight).
7. *Use linked views to facilitate understanding of multiple variables, multiple times, and bivariate maps.* Linking and brushing were successfully implemented in part A of the prototype. Integration of these

tools in the temporal analysis component of the prototype would be likely to overcome some of the initial confusion about how to interpret the bivariate maps and would help make the legend-scatterplot more useful.

8. *Research is required to more fully understand the implications and applications of linked views that combine space, time, and attribute information.* While linked views have been demonstrated to be useful in a variety of context, we know little about how they are used or why they are effective (or not effective) in particular contexts.
9. *Univariate color scheme guidelines developed by Brewer (1994) and Brewer, et. al., (1997) are applicable to design of maps for computer display.* For analysis in which a distinction between values above and below the median is important and emphasis is on finding clusters of high and low values, a diverging scheme is appropriate. The purple-green scheme identified as the most successful in previous work with print maps worked well here.
10. *Provide user selectable color schemes to support data exploration.* When a second variable is added to a map there are two potential goals -- emphasis on one variable as modified by the other (where data and data reliability are combined) or emphasis on the spatial correlation between variables. When emphasis is on spatial correlation between variables, bivariate color scheme representation is appropriate. It is important, however, to provide a choice of schemes that allow an analyst to explore the potential of both positive and negative correlations between the variables. In addition, it is important to select colors that are discriminable, by those with both normal color vision and those with color deficiencies.
11. *Color schemes for cross maps and other bivariate maps must be selected with care and additional research is required to develop guidelines for their selection in the context of manipulable maps.* There has been little testing of bivariate color schemes, with particularly few studies in the context of manipulable maps. Such testing is necessary before guidelines for color choice can be developed. Issues of color vision deficiency should be taken into account in this testing and in development of these guidelines.
12. *Additional GIS functions should be provided that allow analysts to overlay information in order to provide more geographic context for data exploration.* One useful addition suggested (in part) by participants would be an ability to display HSAs and states together (rather than just toggling among HSAs, states, and no boundaries). An ability to add a city layer would also be useful. This recommendation follows from mention by two participants of rural versus urban processes as a potential explanation of patterns, and by one of the need for more geographic context to help bring other knowledge to bare on exploration. All of these possibilities and more are available in HealthVisA.

Discussion

Using the three-level approach to system design outlined above, system/interface goals were established, necessary operations on data that facilitate addressing those goals were identified, and those operations were implemented in a two-component prototype. HealthVisA[□], is a by product of work toward the contract goals of visual spatial analysis tools for exploring time series of health statistics. It, therefore, was not evaluated in a formal way. It is, however, a functional system to which staff at NCHS could add additional data over time and use in everyday analysis.

HealthVisB is not as close to being a production system as is HealthVisA. It does not include an easy way to add additional data. The version submitted with this report, however, does include data beyond that in the alpha prototype that was assessed. It would be possible to automate the addition of data to HealthVisA

through a “cast generation” module built into HealthVisB. This would be a workable, but less than idea solution to a fully functioning system, since analysts would need to switch back and forth between software environments during analysis.

While HealthVisB is not easily adapted to routine applications to health analysis (because of the difficulty of adding additional data), a tool for routine data analysis was not the goal in its development. The goal was to create an approach to design of a flexible system and to assess the specific design choices implemented. The environment within which HealthVisB was built (Director) was very successful in meeting this goal. As can be seen from the discussion of results and the recommendations above, the design strategy developed for a dynamic map-based environment for analysis of times series of georeferenced health statistics is a sound one. Focusing, animation, and other controls were understood and used successfully. The research has generated as many questions about the use of dynamic GVis tools as it has answered; but that is expected with any initial investigation of a tool or method that is dramatically different from standard methods (as the prototype is in relation to static paper maps). It seems clear that dynamic GVis environments have a potential to prompt insight about the spatial (and spatiotemporal) aspects of health and disease that far exceeds that of the traditional paper map. It is also clear that the power of such tools will increase as domain experts are prompted by GVis methods to develop new ways of thinking about their data.

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APPENDIX 1: Explanation of Study and Informed consent form

Explanation of Study

If you agree to take part in this research, you will be introduced to and try out a computer mapping environment designed to explore a range of maps depicting health statistics, environmental variables, and demographic characteristics of populations. At the end of the session we will ask you for feedback on the system. A primary goal of the research is to develop guidelines for design of an exploratory map analysis system. Once we have analyzed the data collected, a report on the research will be posted to the World Wide Web.

Specifically, what you will be working with today is a prototype system in “alpha” development stage. It is not a complete environment for exploratory spatial data analysis. We have implemented basic features for displaying and manipulating maps of disease and risk factors and interacting with time series of these maps. The version we have here today has only a few sample data sets included.

The session will follow a set plan. First we will demonstrate the system. Then we will ask you to try it out, *talking aloud* about what you are doing. For most of the session, we want to keep track of what you are doing and what you see on the maps, *not* why you are doing particular things. We will prompt you from time to time by simply saying “keep talking.”

After this introduction, we will ask you to address a series of fairly specific questions about a couple of the data sets in the prototype. For these, we will provide brief written instructions to follow – again asking you to talk aloud, telling us what you are doing as you go along. Following this structured task, we will ask you to take a look at another set of mapped data, exploring any aspect of that data that you find interesting. Finally, we will ask you for your opinions about the system, what worked well, what did not, what additions or changes you feel would be useful, etc.

With your permission, your comments will be video recorded to insure an accurate reporting and to allow detailed analysis of system use. Your interaction with the system (usually made by using the computer mouse to click on a menu item or button) will be automatically registered in the system. You may ask any questions about the research procedures, and these questions will be answered. Your participation in this research and information you provide is confidential. Your identity will not be linked to these data in any way. The only personal information we will ask you to provide is your professional specialization and gender. To insure confidentiality, we do not record your name, ID number, or any other identifying information, nor is there any coding of subjects other than that required to match responses with the particular mapping environment being evaluated. There should be no discomfort or risk in participating. Your participation in this research will take about 45-60 minutes.

Your participation is voluntary. You are of course, free to decline participation, and to end your participation at any time without penalty.

Should you have any questions about participating in our study, please feel free to ask them at this point. If you have questions after participating, they should be directed to Prof. Alan M. MacEachren, 310 Walker, Penn State University. phone: 814-865-7491; e-mail: alan@essc.psu.edu.

Thank you for your help.

APPENDIX 2: Frequency of control use by subject.

Tables provide totals for the entire session, then totals within each module.

Frequency of control use, by participant across entire session

Participant #	1	2	3	4	5	6	7	8	9	total
view:changed	10	2	9	2	9	8	10	29	28	107
scatterplot:turned	0	4	8	0	0	2	0	6	2	22
cause:selected	5	6	16	5	20	5	14	10	36	117
cause_class:selected	13	11	2	8	9	3	8	8	8	70
risk:selected	4	9	3	6	4	5	7	3	6	47
cause:stepped	19	30	136	17	6	0	120	139	26	493
cause:moved	6	0	0	5	16	22	5	13	14	81
risk:stepped	5	18	82	0	0	0	62	17	4	188
risk:moved	5	0	0	10	15	33	12	5	9	89
date:stepped	280	78	630	160	118	0	27	124	164	1581
date:moved	0	0	0	0	7	1	1	0	0	9
animation:started	7	5	0	3	13	18	16	21	15	98
animation:pace	12	3	0	6	5	0	34	2	27	89
animation:rewound	0	1	0	1	1	0	5	20	24	52
animation:stopped	7	5	0	3	13	18	16	21	15	98
animation:cycles	25	8	0	3	41	84	61	59	128	409
anim:cycle5	125	40	0	15	205	420	305	295	640	2045
cause:focus	26	31	137	23	23	23	126	153	41	583
risk:focus	11	19	83	11	16	34	75	23	14	286
date:brush	281	79	631	161	126	2	29	125	165	1599
total	374	174	889	230	241	121	344	426	387	

Tables that follow include frequency of control use, by participant across each module (as labeled)

MODULE 1

Participant #	1	2	3	4	5	6	7	8	9	total
view:changed	0	0	0	0	0	0	0	5	17	22
scatterplot:turned	0	0	0	0	0	0	0	2	0	2
cause:selected	1	1	1	1	1	1	1	1	1	9
cause_class:selected	1	0	0	2	0	0	2	2	2	9
risk:selected	0	0	0	0	0	0	0	0	0	0
cause:stepped	11	0	0	1	0	0	12	7	0	31
cause:moved	2	0	0	0	0	0	0	4	18	24
risk:stepped	0	0	0	0	0	0	0	0	0	0
risk:moved	0	0	0	0	0	0	0	0	0	0
date:stepped	2	0	0	0	0	0	0	0	0	2
date:moved	0	0	0	0	0	0	0	0	0	0
animation:started	0	0	0	0	0	0	0	0	0	0
animation:pace	0	0	0	0	0	0	0	0	0	0
animation:rewound	0	0	0	0	0	0	0	0	0	0
animation:stopped	0	0	0	0	0	0	0	0	0	0
cause:focus	13	0	0	1	0	0	12	11	18	55
risk:focus	0	0	0	0	0	0	0	0	0	0
date:shift	2	0	0	0	0	0	0	0	0	2
anim:cycle	0	0	0	0	0	0	0	0	0	0
total-1	17	1	1	4	1	1	15	21	38	

MODULE 2

Participant #	1	2	3	4	5	6	7	8	9	total
view:changed	1	0	0	0	0	0	0	6	3	10
scatterplot:turned	0	0	0	0	0	0	0	0	0	0
cause:selected	0	0	0	0	0	0	0	0	0	0
cause_class:selected	1	0	0	3	0	0	2	1	0	7
risk:selected	0	0	0	0	0	0	0	0	0	0
cause:stepped	0	0	0	0	0	0	3	5	0	8
cause:moved	0	0	0	0	0	0	2	2	0	4
risk:stepped	0	0	0	0	0	0	0	0	0	0
risk:moved	0	0	0	0	0	0	0	0	0	0
date:stepped	44	3	80	46	22	0	10	9	11	225
date:moved	0	0	0	0	0	0	0	0	0	0
animation:started	2	2	0	0	2	1	6	6	6	25
animation:pace	4	3	0	0	5	0	15	2	10	39
animation:rewound	0	0	0	0	1	0	0	4	6	11
animation:stopped	2	3	0	0	2	1	6	6	6	26
cause:focus	0	0	0	0	0	0	5	7	0	12
risk:focus	0	0	0	0	0	0	0	0	0	0
date:shift	44	3	80	46	22	0	10	9	11	225
anim:cycle	8	4	0	0	6	20	21	11	51	121
total-2	54	11	80	49	32	2	44	41	42	

MODULE 3

Participant #	1	2	3	4	5	6	7	8	9	total
view:changed	0	0	0	0	2	0	0	3	0	5
scatterplot:turned	0	0	0	0	0	0	0	0	0	0
cause:selected	2	3	7	2	17	1	12	7	33	84
cause_class:selected	1	0	0	0	0	0	1	2	0	4
risk:selected	0	0	0	0	0	0	0	0	0	0
cause:stepped	0	0	0	0	0	0	15	24	0	39
cause:moved	1	0	0	1	0	0	0	2	0	4
risk:stepped	0	0	0	0	0	0	0	0	0	0
risk:moved	0	0	0	0	0	0	0	0	0	0
date:stepped	58	8	146	56	0	0	16	20	9	313
date:moved	0	0	0	0	7	1	1	0	0	9
animation:started	0	0	0	0	0	2	2	9	2	15
animation:pace	0	0	0	0	0	0	2	0	0	2
animation:rewound	0	0	0	0	0	0	1	6	3	10
animation:stopped	0	0	0	0	0	1	2	9	2	14
cause:focus	1	0	0	1	0	0	15	26	0	43
risk:focus	0	0	0	0	0	0	0	0	0	0
date:shift	58	8	146	56	7	1	17	20	9	322
anim:cycle	0	0	0	0	0	19	13	17	23	72
total-3	62	11	153	59	26	5	52	82	49	

MODULE 4

Participant #	1	2	3	4	5	6	7	8	9	total
view:changed	0	0	0	2	1	0	0	1	2	6
scatterplot:turned	0	0	0	0	0	0	0	4	0	4
cause:selected	0	1	0	0	1	2	0	1	0	5
cause_class:selected	2	1	1	1	2	1	1	1	2	12
risk:selected	1	2	1	1	1	1	1	1	2	11
cause:stepped	0	0	0	1	0	0	23	29	0	53
cause:moved	0	0	0	1	0	9	1	0	0	11
risk:stepped	0	12	54	0	0	0	19	4	0	89
risk:moved	0	0	0	7	7	14	8	3	5	44
date:stepped	48	18	44	11	18	0	0	30	40	209
date:moved	0	0	0	0	0	0	0	0	0	0
animation:started	0	0	0	0	5	2	2	2	6	17
animation:pace	0	0	0	0	0	0	0	0	13	13
animation:rewound	0	0	0	0	0	0	0	4	11	15
animation:stopped	0	0	0	0	5	2	2	2	6	17
cause:focus	0	0	0	2	0	9	24	29	0	64
risk:focus	0	12	54	7	7	14	27	7	5	133
date:shift	48	18	44	11	18	0	0	30	40	209
anim:cycle	0	0	0	0	9	11	9	8	48	85
total-4	51	34	100	24	40	31	57	82	87	

MODULE 5

Participant #	1	2	3	4	5	6	7	8	9	total
view:changed	0	0	0	0	2	0	0	6	6	14
scatterplot:turned	0	0	0	0	0	0	0	0	0	0
cause:selected	0	0	0	1	0	0	0	0	1	2
cause_class:selected	1	1	1	1	1	0	0	0	2	7
risk:selected	0	0	0	0	0	0	0	0	0	0
cause:stepped	7	0	0	5	6	0	19	16	26	79
cause:moved	0	0	0	0	6	9	2	2	3	22
risk:stepped	5	2	0	0	0	0	7	9	0	23
risk:moved	1	0	0	1	5	16	3	0	2	28
date:stepped	38	17	150	15	16	0	0	6	34	276
date:moved	0	0	0	0	0	0	0	0	0	0
animation:started	0	0	0	0	1	4	2	2	0	9
animation:pace	0	0	0	0	0	0	0	0	0	0
animation:rewound	0	0	0	0	0	0	1	2	1	4
animation:stopped	0	0	0	0	1	4	2	2	0	9
cause:focus	7	0	0	5	12	9	21	18	29	101
risk:focus	6	2	0	1	5	16	10	9	2	51
date:shift	38	17	150	15	16	0	0	6	34	276
anim:cycle	0	0	0	0	18	8	5	17	0	48
total-5	52	20	151	23	38	33	36	45	75	

MODULE 6

Participant #	1	2	3	4	5	6	7	8	9	total
view:changed	5	0	0	0	4	8	0	6	0	23
scatterplot:turned	0	0	0	0	0	2	0	0	0	2
cause:selected	1	1	1	1	1	1	1	1	1	9
cause_class:selected	7	4	0	0	6	2	2	2	2	25
risk:selected	3	3	2	3	3	4	3	2	4	27
cause:stepped	1	24	126	10	0	0	45	58	0	264
cause:moved	2	0	0	1	10	4	0	3	3	23
risk:stepped	0	2	16	0	0	0	36	4	0	58
risk:moved	3	0	0	2	3	3	1	2	2	16
date:stepped	89	28	138	32	62	0	0	57	70	476
date:moved	0	0	0	0	0	0	0	0	0	0
animation:started	5	0	0	3	5	9	3	2	1	26
animation:pace	8	0	0	6	0	0	5	2	0	21
animation:rewound	0	0	0	1	0	0	3	4	3	11
animation:stopped	5	0	0	3	5	9	3	2	1	28
cause:focus	3	24	126	11	10	4	45	61	3	287
risk:focus	3	2	16	2	3	3	37	6	2	74
date:shift	89	28	138	32	62	0	0	57	70	476
animation:cycle	17	0	0	3	21	26	18	6	6	97
total-6	129	62	283	62	99	42	102	143	87	

□.... This report, while prepared by one individual as project investigator, relies on the contributions of many individuals. **Frank Boscoe** and **Daniel Haug** played major roles in the research. Frank translated initial design ideas for the Director/animation component of the system into a working prototype and did most of the programming necessary for building that component of the system. He also helped in data collection sessions and supervised undergraduate assistants who added data to version 2 of the prototype (submitted with this report). Dan implemented design ideas for the ArcView component of the system and did all of the Avenue programming required to implement that component of the prototype. He also took the lead on an initial written description of the exploratory spatial data analysis methods implemented in ArcView (published in the GIS/LIS '97 Proceedings). **Adria Lizka** and **Jeff Balmat** (both undergraduates in the Penn State University Scholars Program) played a major role at the data processing stage of the research, working on data input, video tape transcription, preprocessing log files generated by the prototype for each individual, checking for errors in system output, and adding data to the prototype. Finally, design of the initial version of the prototype was the focus of a graduate seminar (lead by the PI). Participants included **Frank Boscoe**, **Daniel Haug**, **Colin Polsky**, **David Brown**, **Jaishree Beedasy**, and **Mark Marrara**. All were responsible for library research reviewing literature on selected relevant topics, contributed ideas toward system design, and contributed to an initial paper describing the system (published in the Proceedings of the International Cartographic Conference).

□.... The points in the scatterplot point theme are sorted in the same order as the HSAs reside in their polygon coverage. This common order is critical for implementation of geographic brushing (discussed below). Once the point shape file is created, X and Y axis lines and labels can be added. However, it is often necessary to transform the data values on one or both axes in order to create a visual representation that is interpretable (and to create comparable scatterplots from one variable or time to another). For instance, if the X axis variable has a range of values from 0 to 1000, and the Y axis variable has a range from 0 to 1, it will be impossible to distinguish variation in the Y axis without transforming one or the other axis in order to make the ranges similar. Transformation can also be useful in searching for non-linear relationships between variables in the scatterplot. Because of this, the prototype provides the analyst with the ability to perform any one of a wide variety of transformations on either axis. Although transformation of axes requires relatively simple calculations, it is also important to store information about how each axis has been transformed. This particular function is implemented through the use of "object tags" associated with each axis line. Each object in the Avenue class structure allows the user to instantiate any other object as an attribute associated with it. This attribute is known as an object tag. The prototype relies on object tags to allow objects to carry information about themselves that is needed later. In addition, since the object tag attribute can be instantiated with any object, a list object could be used to carry multiple attributes in the object tag. In this case, an object tag of each axis line was instantiated with a list. The first element in the list was a text string identifying the line as the X or Y axis, and the second element in the list was the type of transformation that had been performed. The importance of storing this information is considered more explicitly below.

□.... Brushing was implemented by taking advantage of object tags and ArcView selection bitmaps. Selection bitmaps are a list of bits (ones or zeros) that are ordered identically to the records in a data table. Each bit, then, is a flag, indicating whether or not a given record in the data table has been selected. Since the points in the scatterplots are ordered identically to the features in the map that they are associated with, the same selection bitmap can be applied to any scatterplot as well as to the map. Since every scatterplot is a view object, just like the map, all related scatterplots and the map that they are related to are given a unique identifier in the object tag. Using this identifier, the brushing script knows which views to apply the bitmap to. The script then finds all views that have the same identifier as an object tag, and applies the selection bitmap to the data theme.

□.... Aspects of the prototype that require animation were implemented in Director. Map sets that include mortality rates at each of five time periods along with various potential risk factors were generated in ArcView and exported as PICT files for import as Director Cast members. As noted above, Director is not a GIS or mapping package and, thus, has no capability for linking a database directly to screen displays. The prototype component built in Director manipulates raster maps ("images") generated in ArcView, as well as parameters of those images. All features of the environment are implemented through Lingo scripts (Lingo is Director's object-oriented scripting language). The method used to implement dynamic focusing makes use of color palette substitution. This method requires that the computer monitor used to run the prototype be set at 256 colors (no more or less). Because Director cannot make maps directly from data, the process of adding new information to this component of the prototype is fairly time consuming.

□.... Both software environments were designed as rapid prototype---intended to test design ideas rather than to be finished analysis tools. Each component has gone through several revisions, thus they work, but are likely to have many quirks and bugs. Component A (even though a by-product rather than required component of the contract) is the closer to being a fully useable analysis environment, because it is built within a standard desktop GIS, making addition of additional data relatively easy.