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User Interfaces for Spatial Information Systems: Manipulating the Graphical Representation

MAX J. EGENHOFER & ANDREW U. FRANK

Computerized information system, spatial data, data handling, graphic display

A b s t r a c t : Computerized information systems tailored to handling spatial data are emerging as sources of spatially related information. New methods for managing spatial data in computer systems are being developed for utilizing and exchanging spatial information. Human concepts of spatial data and the means of communicating with spatial information systems are the focus of the present investigation. The relationship between operations for manipulating graphical representation of spatial objects and how these representations are observed is discussed.

[Die Veränderung der grafischen Darstellung in Benutzerschnittstellen für raumbezogene Informationssysteme]

K u r z f a s s u n g : Im Informationszeitalter wächst die Bedeutung von Computer-Systemen, die als Quellen geographischer Information dienen und für die Behandlung räumlicher Daten zugeschnitten sind. Die Verwaltung räumlicher Daten in Computer-Systemen ermöglicht neue Formen, die Daten zu nutzen und auszutauschen. Die Auffassung räumlicher Konzepte und die Kommunikation zwischen Benutzer und Informationssystem ist Gegenstand der vorliegenden Arbeit. Sie zeigt einen Dualismus zwischen Operationen zur Manipulation der grafischen Darstellung räumlicher Objekte und entsprechenden Operationen zur Überprüfung der Darstellung durch den Benutzer.

Contents

Authors' address: Dr. M. EGENHOFER, Dr. A. FRANK, National Center for Geographic Information and Analysis, Department of Surveying Engineering, Boardman Hall, University of Maine, Orono, ME 04469, USA; electronic mail: MAX@MECAN1.MAINE.EDU, FRANK@MECAN1.MAINE.EDU.

1 Introduction

People exchange spatial knowledge in their everyday life. The most obvious way to convey spatial information is by natural language — both in spoken and written form. For example, someone may verbally describe how to get from Boston to the University of Maine with the instruction «Drive north on Interstate Highway I-95 and take Exit 50». Other techniques have also been developed to convey spatial information if no immediate contact — verbal or visual — exists among the persons communicating. The representation of spatial information in graphical form is one example. For instance, one may use a map to determine which route to follow from Boston to Bar Harbor.

Besides this common use of geographic knowledge, entire industries and professions, from urban planners to geologists, rely heavily upon spatial information. Driven by their need for more complex, up-to-date and accurate spatial information, storage of spatial information has evolved from analog form, i.e. paper maps and handwritten or typed records, to digital representation stored in computer systems. Such a computer system, dealing with information about the geometry and location of spatial data and its relation to other objects, is called a *spatial information system*, and the data, collected in these systems, is often referred to as the *spatial database*.

Research on spatial information systems is relatively new. It has emerged from computer processing of various types of spatial data. The desire to analyze combinations of spatial data and to reveal otherwise hidden information is the justification for spatial information systems. The use of computers as a tool to efficiently store, access, and manipulate large amounts of data expands the capabilities of traditional methods of processing spatial data. Traditional filing cabinets and paper maps contain information prepared independently of the users' particular needs. Conceptually, the collection and storage of information are not separate from its representation on paper so a user has only a single view of the spatial information. All users must be satisfied with this single representation, therefore, its format is usually very general. When applied to a specific project, these general-purpose representations frequently show either too little or too much information.

Spatial information systems provide an exciting opportunity to overcome this shortcoming because they may serve as a repository of diverse spatial knowledge in a single system without any one user having to deal with all the data in the system. Instead, users may select whatever subset interests them and request information about it in the preferred form for their individual use.

In this paper we investigate how spatial data, in particular its graphical representation, influences interaction between user and system. Of particular interest are the concepts people have about spatial data and the operations that allow them to manipulate and examine the graphical representation of spatial data. Chapter 2 gives an overview of the architecture of spatial information systems, concentrating on user interfaces for spatial data handling. How users manipulate the representation of spatial data is investigated in Chapter 3. The corresponding operations needed to examine the representation are introduced in Chapter 4. A series of snapshots of the user interface in Chapter 5 demonstrates these ideas in a simulated GIS user interface. Finally, the conclusions in Chapter 6.

2 User Interfaces for Spatial Information Systems

2.1 Architecture of spatial information systems

A spatial information system integrates a database management system which provides various services to a programmer, such as storage and retrieval of data, standardized access to data, logical access independent of the physical storage structure, concurrent access to data by multiple users, and definition of consistency constraints that are automatically enforced (FRANK 1988). The encapsulation of data protects it against loss or unauthorized access. Simultaneously, the management system makes it available to a multitude of users. Together, management system and data are called a *database*.

A database can be used to implement a variety of applications; together with the database, these different applications form an *information system*. The desire to be able to formulate ad-hoc databases queries is the motivation for *interactive query languages* through which humans formulate requests and receive — ideally instantaneously — the desired answers. Users may request information in a standardized fashion, which relieves them from programming specific access procedures for these purposes. Interactive query languages have become popular through the use of database management systems in most modern office environments and structured query languages for question-and-answer dialogue dominate in conventional, purely alphanumeric information systems. Well-known examples are SQL (CHAMBERLIN et al. 1976), for which a national standard has been produced (ANSI 1985), QUEL (STONEBRAKER et al. 1976), and Query-By-Example (ZLOOF 1977).

2.2 Spatial query languages

A language for querying spatial databases will be called a *spatial query language*. In this context, the term *query* will be understood in its normal sense, namely to inquire about data, which is different from the common use in computer science, where the term *query language* often includes the manipulation of data as well as being a means of formulating inquiries.

The usefulness of traditional database query languages for spatial information systems is limited. The incorporation of conventional query languages into spatial information systems has been hindered by the particular properties of spatial data, which diverge dramatically from those of nonspatial data (FRANK 1982; EGENHOFER & FRANK 1988). For example, spatial information systems must be responsive to user queries that use spatial concepts like neighborhood or select data based upon criteria such as distance or direction.

Similar languages with extended capabilities for treating spatial objects and properties, such as MAPQUERY (FRANK 1982), enhanced with powerful «expert system» tools, such as LOBSTER (FRANK 1984) or KBGIS-II (SMITH et al. 1987), may overcome some of the deficiencies of standard query languages and provide a framework for interaction with future spatial information systems; however, interaction with spatial data at the user interface will play an even more important role than the expressive power of a query language for the usefulness of spatial information systems.

Research in the design of spatial information systems has concentrated on the system-internal aspects of spatial information systems, such as the architecture of spatial information systems (ARONSON & MOORHOUSE 1983; SCHEK & WATERFELD 1986; FRANK 1988; GÜTING 1988), methods for storage and access to n-dimensional spatial data (TAMMINEN 1983; GUTTMAN 1984; NIEVERGELT et al. 1984; SELLIS et al. 1987; GÜNTHER 1989), and data structures for modeling spatial data (CORBETT 1975; PEUCKER & CHRISMAN 1975; FRANK 1983; HERRING 1987; EGENHOFER et al. 1989). At the same time, little attention has been paid to the interface through which a user accesses the information in such a system. It is a common, yet unfortunate opinion that the user interface is something to be constructed after the design and the implementation of the program as a whole has been completed. Such «user interfaces» are cosmetic enhancements which barely help make these systems user friendly. The reverse process — first designing the user interface, followed by the implementation of the system — is only rarely done.

The user interface of a spatial information system, as the integrating part of all applications, combines graphical and lexical representation, as well as the query language. Users articulate their instructions through a dedicated language to communicate with the system. This language must include tools for all the essential operations. The demands on such languages differ significantly from those for database applications with exclusively alphanumeric data.

3 Graphical Representation of Spatial Data

A requirement for a spatial query language is the graphical representation of query results (FRANK & EGENHOFER 1988). Humans grasp geometric concepts more easily if the spatial data is represented in graphic form. User interfaces to CAD/CAM systems, for example, have simulated conventional construction operations using ruler and compass, though some more advanced systems have been proposed using constraint-based methods (BORNING 1986; WHITE 1988). All these systems deal with the *manipulation of the geometry* of spatial objects, which is not part of the present investigation. In this paper, we are interested in the *manipulation of the representation* of spatial data, which includes the variation of objects displayed.

3.1 Varying graphical representations

In GIS applications, the same data is often presented in various graphical fashions according to the users' different views. The view of a road, for example, is different for a surveyor, a transportation company, or a cartographer; the one sees it as a parcel, the other as a classified transportation line, another as a symbolic line, and for each purpose the road must be presented differently. Such varying presentation is different from generalization. While generalization establishes different abstraction levels for an object class (BRODIE 1984), varying presentation relies upon the same geometry of an object, and alters only the appearance of the object using tools like colors and patterns.

The choice of the presentation must be controllable from the interface to allow users to adopt the most appropriate presentation style for their application. This flexibility is important for multipurpose applications of a spatial data collection and the user interface must provide tools to accommodate the presentation to the individual, often subjective, needs.

BERTIN (1983) proposed a set of retinal properties, i.e., properties to which the retina of the human eye is sensitive independent of the location of the eye and the shape of the object. These properties may be applied as a basis for different types of graphical representations. Particularly important are the variations of colors, patterns, intensities, and symbols. The combination of these graphical properties is represented by the graphical specification of a spatial object and may be applied to an entire object or, individually, to parts of an object, such as its boundaries or its interior (STEINER et al. 1989).

Varying graphical representation is a means to convey visually the distinction between different classes of objects. Classification, a fundamental principle of object orientation, is the grouping of various objects with similar properties to a common class (DAHL & NYGAARD 1966). The similarity of objects is visualized by the graphical representation; dissimilar objects have significantly different graphical specifications.

3.2 Combinations of query results

Interactive graphic representation is a powerful tool for mapping systems, allowing the content of maps to be quickly modified. A traditional map is a static product — once it is printed it cannot be updated; map production from spatial information systems allows for immediate modification of drawings. Representations of objects in the database can be added, removed, or modified on a map on the screen without having to start with a new drawing.

Appropriate tools are needed to manipulate maps on the screen. Conventional query languages treat each query and its result as an entirely separate representation and do not allow for reference to earlier results. It is standard practice to overlay drawings on each other or to remove a «thematic layer» from a composite drawing. These processes provide the power of spatial information systems, combining spatial data from various sources in a way that appears to be most suitable for a user's particular application. Furthermore, individual objects on a map may be highlighted to facilitate their identification in complex representations. Imagine a city map showing streets and buildings. The user wants to find the city hall. Instead of checking each building, it is more convenient and faster to choose a specific representation for the city hall that makes it easy to distinguish it from other buildings.

The following five graphical representation commands allow a user to make the most common combinations of query results:

— NEW refreshes the viewport before drawing the next picture.
— ADD overlays the result of the current query to the existing picture.
— ERASE removes the result of the current query from the existing picture.
— INTER intersects the set of displayed objects with the query result.
— HIGH highlights the result of the current query within the current picture.

Of course, conventional systems with lexical presentation could utilize these types of commands, though tabular presentation appears to be static and seems to need such features less than graphical presentation does. It is worthwhile to investigate how users may benefit from tabular presentation with dynamic updates.

3.3 Context

A particularly important aspect of the combination of query results is context. Context on maps is spatial information the user does not explicitly ask for, but which is necessary to interpret a query result within its spatial environment. The interpretation of a graphical representation is extremely sensitive to the context in which it is shown. Unlike lexical representation, it is often not sufficient to present graphically only what was requested (FRANK 1982). Imagine a query «Show the town of Orono», where the result is only a labeled point in the center of the screen (Fig. 1a). A reasonable answer requires a context in which the position of the point can be spatially interpreted. For example, by showing the borders of the state of Maine, a user familiar with the shape of the states of the USA has sufficient information to locate Orono (Fig. 1b).

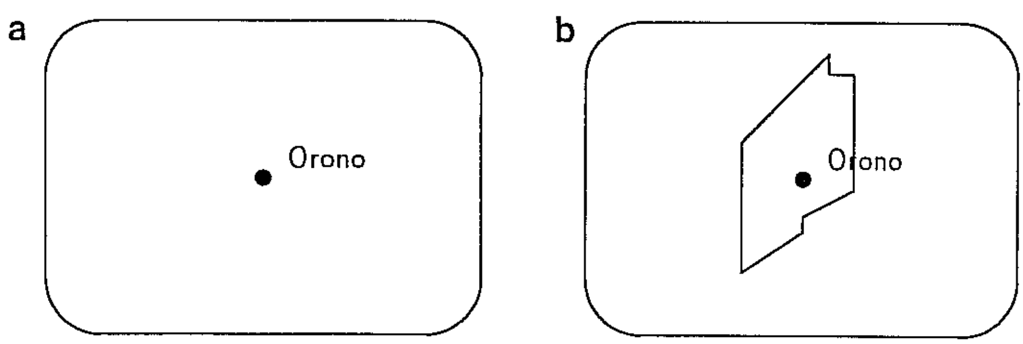

Fig. 1: A query result with (a) insufficient and (b) minimal context.

Sophisticated graphical representation provides an appropriate context, which depends on the purpose of the drawing, the scale, and the data density. The process of adding context can be interpreted as an intelligent query combination. When the user asks for a particular object, the system supplements the result by «overlaying» another query result.

4 Operations for Observing Spatial Data

The previous chapter discussed operations on query results and the subsequent graphical representation of the query results. A users interface to a spatial information system also has to provide the user with means to interact with the results presented graphically, particularly to assist them in the analysis of the presented results. Operations that allow the user to examine the graphical representation are complementary to operations that manipulate it.

4.1 Legend

The legend is the key to interpreting drawings produced with various colors, patterns, symbols, etc. that represent different types of spatial objects. It is the mapping of classes of objects from the visual domain onto the corresponding lexical expressions; therefore, the legend can be considered to be the observe operation of the graphical representation. From a user's perspective, access to a legend makes it possible for the representation to be understood by a larger set of users than those who selected the specific representations.

Without a legend, symbols are often difficult to interpret. For example, a map with four different symbols for cities, each representing a different range of size, requires a legend giving the meanings of the symbols. The legend is specific for each map, and each graphical representation can have a separate legend. Flexible access to the legend is required: (1) The legend must be immediately accessible via the user interface whenever information is required. Due to the limitation of the screen area it is generally not possible to have the entire legend permanently visible. (2) The interface must provide visual comparison of the legends of two maps.

4.2 Content

Provision of a lexical description of the content of the display is an operation complementary to the display operations. Dynamic changes in the graphical representation are provided by combining the results of a number of queries in a single display. However, combining the results of several queries makes it difficult to keep track of what is being presented. An essential feature in a query environment with multiple representation modes is a means by which the user can check the results on the screen after a sequence of queries. This is best achieved by showing the single query that would have produced the current drawing. For example, if a user asks for a map showing all roads and buildings and subsequently requests that all residences be removed from this drawing, then — besides the roads — only those buildings are represented which are not residences. Other methods have the disadvantage that users have to learn yet another language in which the system informs them about the content of the current map.

With traditional one-query one-representation techniques, the result is always associated with a single query and the user may obtain a description of the content of the graphical representation by recalling the last query (NIEVERGELT & WEYDERT 1979). A display resulting from a sequence of several queries is fundamentally different from the traditional production of a completely new result for each query. Instead, the representation the user sees may be used as the reference for the next query, promoting a more dynamic working style. The display may be the result of a fairly large number of additions and removals of query results, the control over which may be easily lost.

Knowledge about the composition of a display prevents incorrect or misleading assumptions about the representation. Spatial information systems produce drawings that look sophisticated and inspire confidence in the material presented; however, these systems also allow for major manipulations of the content of a drawing. Numerous manipulations can be performed which may easily provide incorrect information.

Typically, a GIS session starts with a query for an general map of the area of interest. The user pushes the NEW button and enters a query for all towns in Maine. As result, a map is displayed showing the border of the state of Maine (context!) and its towns (Fig. 3). Since this map is too crowded, the user decides to remove the smaller towns. ERASE is selected and a query for all towns with a population of less than 10,000 is entered. As result, all small towns are removed from the map (Fig. 4).

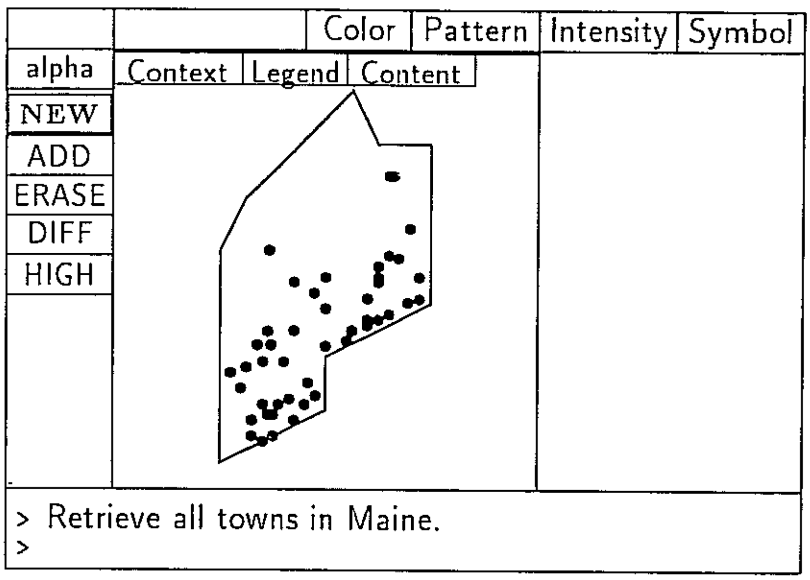

Fig. 3: The query result shown as a map.

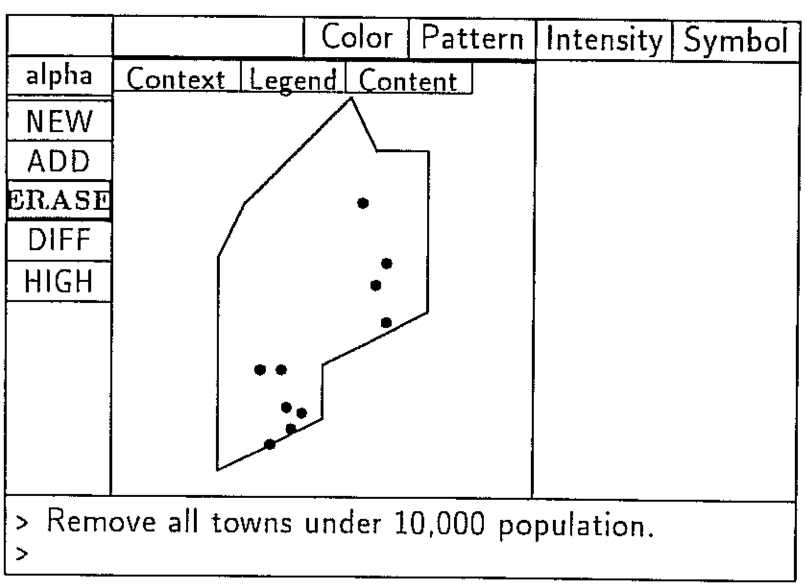

Fig. 4: The map after removal of towns with a population of less than 10,000.

A description of the current content of the map can be obtained with the CONTENT pull-down menu. It shows the currently visible objects, i.e., the state of Maine and all towns in Maine smaller than a population of 10,000 (Fig. 5).

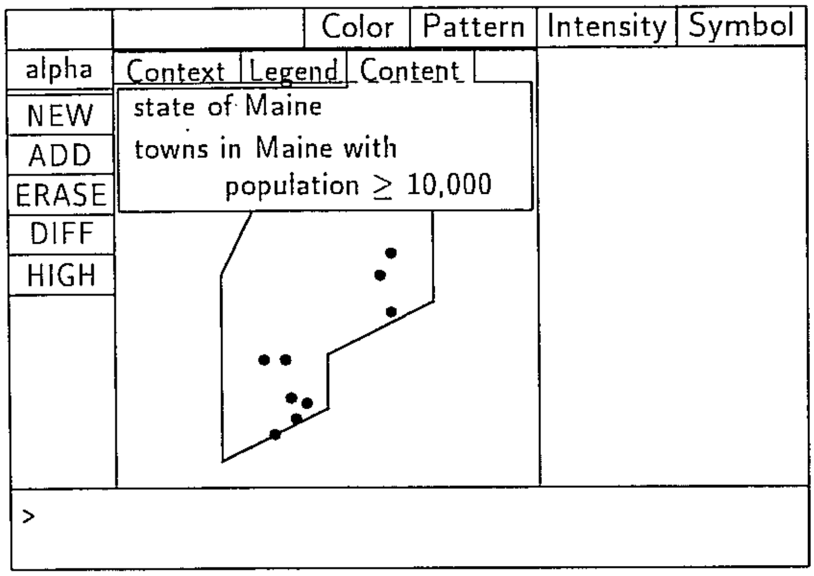

Fig. 5: A lexical description of the contents of the map can be obtained via a pull-down menu.

6 Conclusions

The design of user interfaces plays a vital role for spatial information systems. Interaction with spatial data differs significantly from the interaction with purely lexical data. Query languages for spatial information systems must incorporate techniques to handle the specific properties of spatial objects. Object-oriented, graphical representation of spatial data is identified in this paper as being important and requires the availability of various display types, such as overlay, erase, and highlighting. Methods such as "selection by pointing to objects" and selection of subareas are needed for manipulation of graphically represented spatial objects. The environment specific for representation of spatial data requires operations for selection of context and for manipulating the graphical representation. The concepts were illustrated in a series of interface snapshots.

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