Handling Complexity in GIS Interface Design

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Abstract. This work presents a proposal for an interface for a GIS, which is aimed at handling the complexity of the different data models and representation structures needed to deal with geographic information on the computer. We discuss the requirements for such interfaces, analyse the benefits and drawbacks of existing systems, and propose a new interface, to be used in the next versions of SPRING, a geographical information system developed by INPE.

Keywords: Geographical information systems, GIS interface design.

1 Introduction

One of the most important concerns in GIS design is simplifying the user's learning curve. Many current GIS implementations present the user with a bewildering amount of functions, which confuses both the novice and expert. As a consequence, the GIS user community has been divided into specialists on specific systems. This problem is seen as a significant impediment for a greater use of GIS technology.

This situation is partly caused because the current generation of GIS does not support conceptual data models, which provide powerful abstractions. Most implementations force the user to understand about the intricacies of graphical data structures, who in reality represent the same mathematical entity.

To address this problem, there have been important advances in GIS modelling which have resulted in GIS solutions such as SPRING (Câmara et al., 1996) and ARC/INFO-8 and in interoperability proposals such as OpenGIS® (OpenGIS Consortium, 1998). These models have been able to deal with the inherent complexity of geographical data and associated computer representations.

Despite the advances in data modelling, GIS interface design still plays a crucial rôle in determining user's acceptance of a solution. Therefore, the advances in data modelling need to be reflected on the system's interface, which should serve as a guide to the user, avoiding - whenever possible - explicit referral to computer representations and allowing the user to concentrate on the geographical data.

As observed by Mark and Frank (1992), GIS interfaces need to address the issue of how people understand the concept of "space". GISs based on a single spatial concept are easy to learn and to use but also limited in functionality. GISs that include more than one spatial concept showed complex user interfaces and are considerably more difficult to learn.

This paper addresses this problem, from the point of view of designing a user interface, based on an object-oriented GIS data model which is representative of the current state-of-the-art. The challenge is to propose an interface, which adequately conveys this data model, without posing a complex learning task on the user.

From a practical point of view, this paper outlines an initial proposal for an companion module to SPRING, a GIS solution developed by INPE which is available on the Internet. This new module, which is tentatively called *SPRINGExplorer*, aims at providing a friendly interface for various spatial data analysis functions.

SPRING and *SPRINGExplorer* are based on a conceptual model which includes both the *field view* and the *object view* of geographical reality, enabling the system to deal with images, entities, networks and surfaces in a single environment.

The rest of this work is organised as follows. In section 2, we review the general requirements for GIS interfaces in the context of spatial data analysis. In section 3, we propose a new interface design for SPRINGExplorer. The work concludes with a brief section on implementation considerations for the proposed interface.

2 GIS Interface Requirements

We consider two types of requirements for GIS interfaces: general design ideas and specific functional requirements for spatial data analysis.

Generic design guidelines for GIS include (Mark and Frank, 1992):

- A look and feel which is consistent with other applications in the target user environment. In practice, this means a degree of agreement with applications such as Microsoft Office, which the user is likely to be using together with the GIS.

- Functions must be easily accessed and executed, and the menu should not simply be a torrent of cascading options.

- The number of concepts in a system is related to the effort to learn the system. It would therefore be worthwhile to analyse the conceptual structure of a program and redesign it carefully to reduce the total number of concepts.

- There are different four classes of GIS users, Novice users want an intuitive, easy-to-learn system; casual users normally cannot remember arcane commands; expert users prefer direct ways of performing the desired tasks. The GIS interface should cater for a compromise between these groups.

In the specific context of spatial data analysis, we consider, along the lines of Anselin (1998), the following processes that are interconnected (see figure 1): *selection, exploration, manipulation and explanation.*

The *selection process* includes the translation or conversion of spatial data from a database into graphics. It involves query operations on a geographical database, by means of interactive menus or spatial languages. The data presentation techniques at the selection level include simple thematic mapping by means of non-spatial statistics (e.g. quartile range mapping).

Exploratory spatial data analysis can be broadly defined as a collection of techniques to describe and visualise spatial distributions, identify atypical locations (spatial outliers), discover patterns of spatial association (spatial clusters), suggest different spatial regimes and other forms of spatial instability (Anselin, 1999; Bailey and Gatrell, 1995).

Manipulation of spatial data can be seen as the set of operations that create new geographical data from existing data sets. These functions are more commonly used for processing *fields*, in the line of the "Map Algebra" proposed by Tomlin (1990), but are also meaningfully related to objects, as in the case of reconstruction of surfaces from attribute data associated to polygons.

Explanation of spatial data includes methods for indicating potential multivariate relationships between variables. The more common techniques include both non-spatial and spatial regression (Anselin, 1999).

Two important additional considerations need mention, especially in the context of spatial exploration techniques: *dynamic graphics* and *brushing*.

The idea of *dynamic graphics* can be described as *the presentation of different and coherent perspectives of the same data set*. The notion of "coherence" states the fact that these views are linked, that is, changing the data set should affect all presentations simultaneously. The idea is to allow the user to explore the data set, choosing different types of presentation, in order to enhance his cognitive understanding of the behaviour of the phenomena under study (Câmara et al., 1997; Dykes, 1997).

On the context of visual spatial data exploration, the term *brushing* was introduced by Monmonier (1990) when he described the idea that selecting an object in a map would automatically highlight the corresponding elements in the other graphics. Depending on the view in which one selects the object, there is *geographical brushing* (clicking in the map), *attribute brushing* (clicking in the diagram or table), and *temporal brushing* (clicking on the time line). As such, the user gets an overview of the relation among geographic objects based on location, characteristics and time (MacEachren and Kraak, 1997).

Finally, there is an additional requirement, which is very often forgotten on interface design: the need for a spatial language as an underlying support for all interface commands. In this model, all interface menus and windows are transformed into statements of a GIS language, which is then used to call the system's applications.

The importance of having a GIS language has grown recently, with the increasing emphasis on interoperabilty and distributed system design. In fact, designing systems for data transparency (dealing with local and remote data in similar ways) and for using protocols such as CORBA is greatly simplified when a complete GIS language is available. The design of a GIS language is the subject of a complementary paper (Câmara et al, 1999), and this paper will assume that such a language is available, including full support for all types of GIS operations.

3 The SPRINGExplorer Interface

Our approach to the design of an appliance for spatial data analysis is to provide all required GIS functionality is available at a single interface. This allows for a more integrated processing of geographical data, and fits more adequately in a desktop environment.

Another important concern is the compatibility with popular desktop environments such as Microsoft Office. Typically, each desktop application is designed having a single window, which can include multiple documents (Microsoft Word is one example of such interfaces). By contrast, many GIS interfaces, some derived from the UNIX/Motif environment, use multiple overlapping windows, which may leads to confuse working environments.

Our basic consideration is that the user needs spatial cues to navigate, manipulate and visualise spatial data. Therefore, all data and operations are associated to icons that indicate the underlying data type. This reduces the complexity of having different data types being manipulated by the same program.

Another important (if obvious) consideration is that a user will do one task at a time. Therefore, there is no need for overlapping windows that only serve to pollute the screen space. Instead of overlapping windows, we propose the use of "folders": each folder serves one specific purpose, and the most serious challenge for interface design in this case is to decide how many folders are needed and which will be open simultaneously.

Our proposal considers a GIS interface to be divided in three "areas" (see Figure 2):

- A "*navigation*" area, where the user chooses the data to be processed and visualised, the operators to be applied to such data, and views the legend associated to such visualisation.

- A "*presentation*" area, where the data itself is presented, together with associated. graphical information. Alternatively, this area may show a data-flow diagram that describes visually a map algebra procedure. The area may also display a text listing, for presenting and editing GIS language programs.

- An "*attribute*" area, which show the attributes of the data currently being displayed (in a tabular or 1D graphical format).

The "navigation" and "presentation" areas are associated to different types of operations, by means of the idea of "folders". The *navigation area* has three folders:

- "*Data*": The data folder allows for hierarchical data navigation, similar to popular desktop applications such as MS/Explorer.

- "*Operations*": The "Operations" folder also provides a hierarchical view of the available operations for fields and objects manipulation and exploration.

- "*Legend*": The "Legend" folder indicates associated information to the data being visualised.

The *presentation area* has three different folders:

- "*View*": A 2D canvas for the display of images and maps.

- "*Algebra*": A data-flow based interface for the expression of field and object algebra operations.

- "*Language*": A text-based interface for editing and running programs in GIS language.

The "*attribute*" area has three folders:

- "*Graph*": A 1D graphical interface for displaying items such as histograms, variograms, and correlograms.

- "*Table*": presents a table view of the attributes associated with the geographical data.

- "*Info*": used to display textual information associated to geographical data, such as description or statistics measures.

The data exchange between the folders uses two metaphors: "drag-and-drop" and "brushing". The "drag-and-drop" metaphor controls the linking between the "Navigation" areas and the "Presentation" and "Attribute" area. By dragging the *data* or *operators* from the "Navigation" window into the "Presentation" or "Attribute" window, the appropriate actions are performed.

When a data set is selected and "dragged" into the "Navigation-View" window, the data is retrieved and visualised both in this window (as a 2D map) and in the "Attribute-Table" and Attribute-Graph" windows, respectively as an attribute table and as a 1D graph. After this initial visualisation, the system will allow "brushing" operations to take place between these windows. For example, highlighting a portion of a scatterplot will also enhance the relevant points or polygons on the map.

We now discuss how the proposed interface addresses requirements of section 2. Initially, we consider the different processes involved in spatial data analysis:

- "*Selection*": involves data selection and display, with the appropriate data transformation (e.g., slicing of DTMs, mapping of attribute values to cloropleth maps). After the data is shown, the legend folder should be updated. This process involves the "Navigation-Data" and the "Attribute-Table" folder for selecting data, the "Presentation-View" and the "Navigation-Legend" folders for display. This environment is shown in Figure 2.

- "*Exploration*": used for operations such as geostatistical and spatial statistics analysis. In this case, graphical information is as important (e.g. for variogram determination) as actual 2D data presentation. The most relevant folders are: "Presentation-View" for showing the spatial statistics results as cloropleth maps, "Navigation-Legend" for presenting the associated legend and "Attribute/Graphics" for showing the associated graphics (variograms, histograms, scatter plots). This situation allows the use of "brushing" to allow interaction between the graphical and maps views of the data. This environment is shown in Figure 3.

- "*Manipulation*": this is a situation where a complex geographical analysis will be performed, involving both fields and objects. The map algebra procedures will be defined by a data-flow interface for chaining a sequence of operations. This operation includes: data selection ("Navigation/Data"), operation selection ("Navigation/Operation"), a data flow interface for linking data ("Presentation/DataFlow") and a textual interface for the corresponding GIS language ("Presentation/LEGAL"). This environment is shown in Figure 4.

We consider that the fourth process ("Explanation") to be quite similar to the "Exploration" process, with an additional provision for the choice of regression variables.

We now consider the specific requirements for "dynamic graphics" and "brushing". Our proposal addresses these issues, allowing different views to be associated with the same geographical data and for interacting between these views.

As regards the general requirements of Mark and Frank (1992), we consider that the methaphors proposed (*icons* as graphical cues for the different types of data and operations, *folders* for organising spatial information processing, *drag-and-drop* linking data and visualisation, *brushing* integration different views) are powerful means of reducing complexity and allowing non-experts to interact with geographical information.

4 Implementation Considerations

Our implementation requirements include multi-plaform portability and efficient data processing. We are currently considering different options for developing SPRINGExplorer and we are prototyping our ideas in different environments. A promising alternative seems the coupling of Tcl/Tk scripting language for interface design and C++ for data processing and algorithms. An initial work involving the development of a Tcl/Tk interface for Map Algebra operations has been developed by the authors, in cooperation with EMBRAPA (Lucena et al., 1999).

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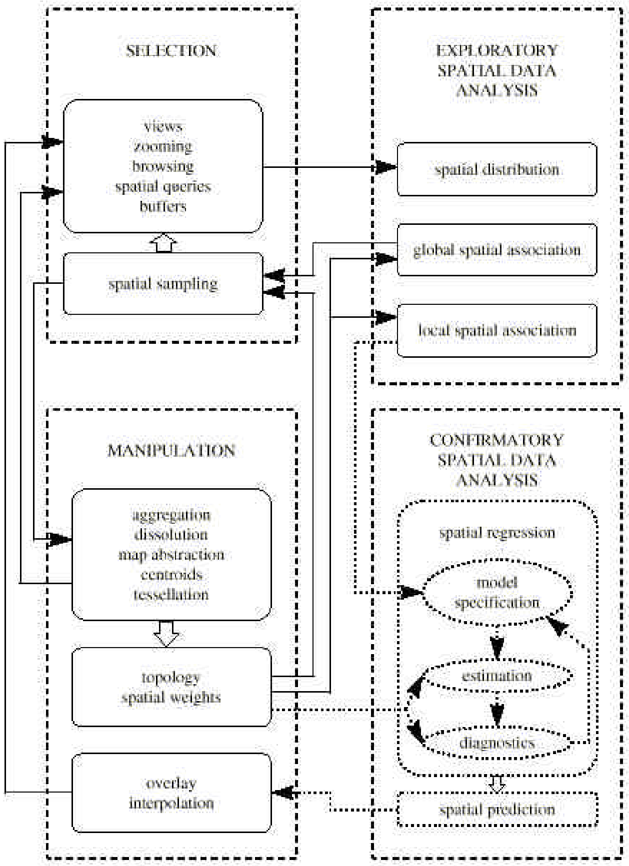

Figure 1 – Processes in Spatial Data Analysis
(source: Anselin, 1999)

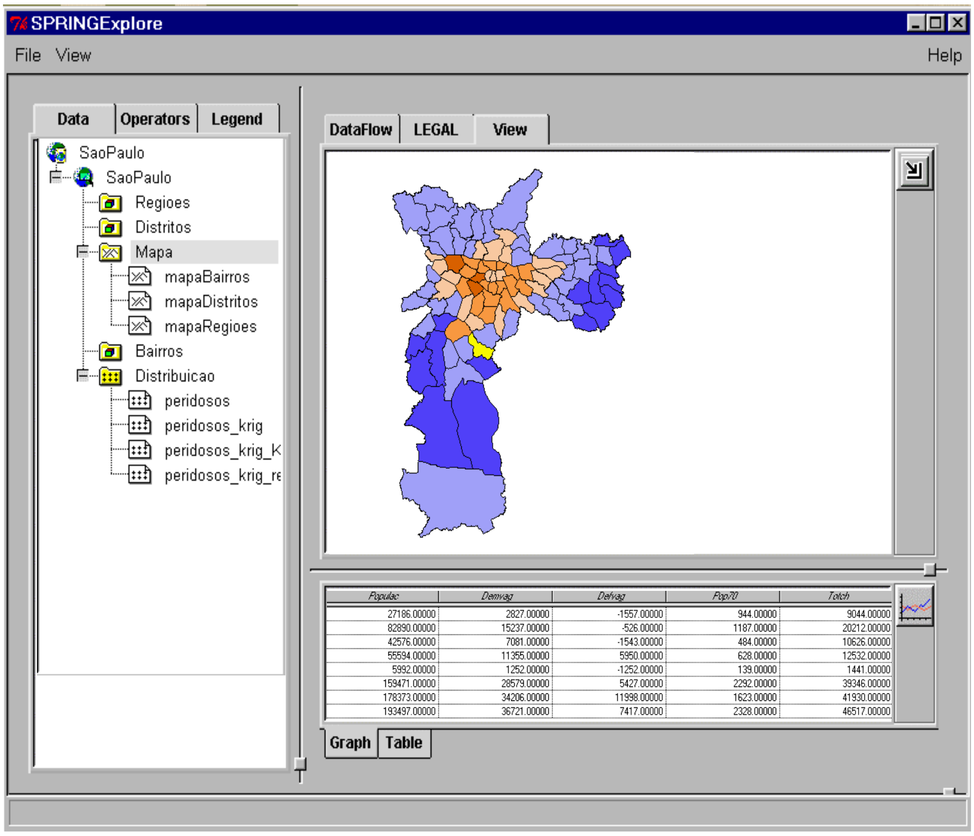

Figure 2 - Selection Process

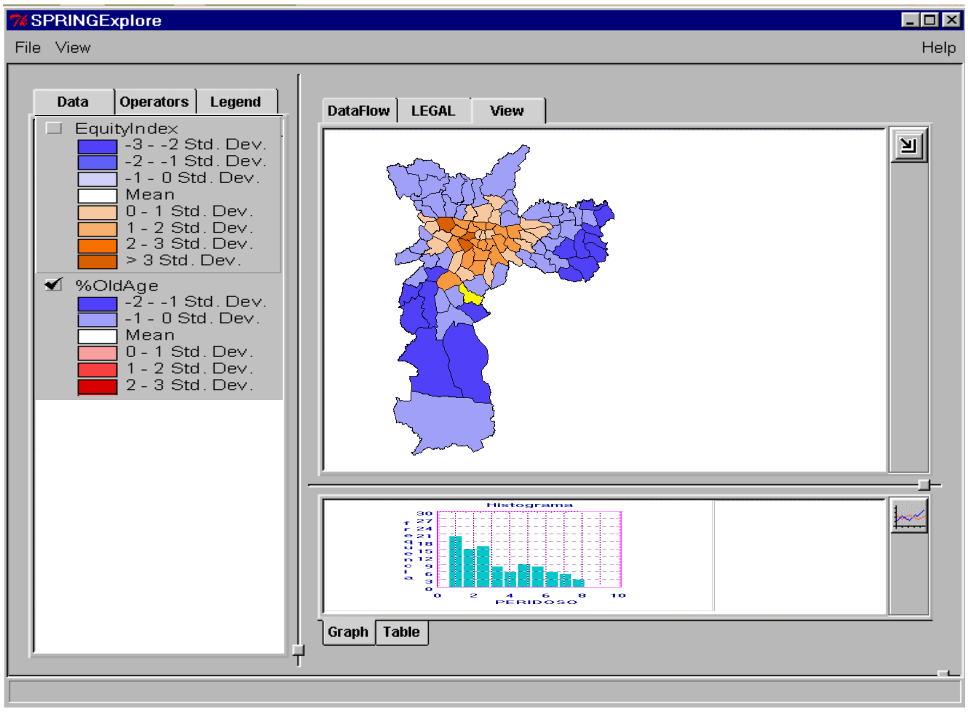

Figure 3 – Exploration Process

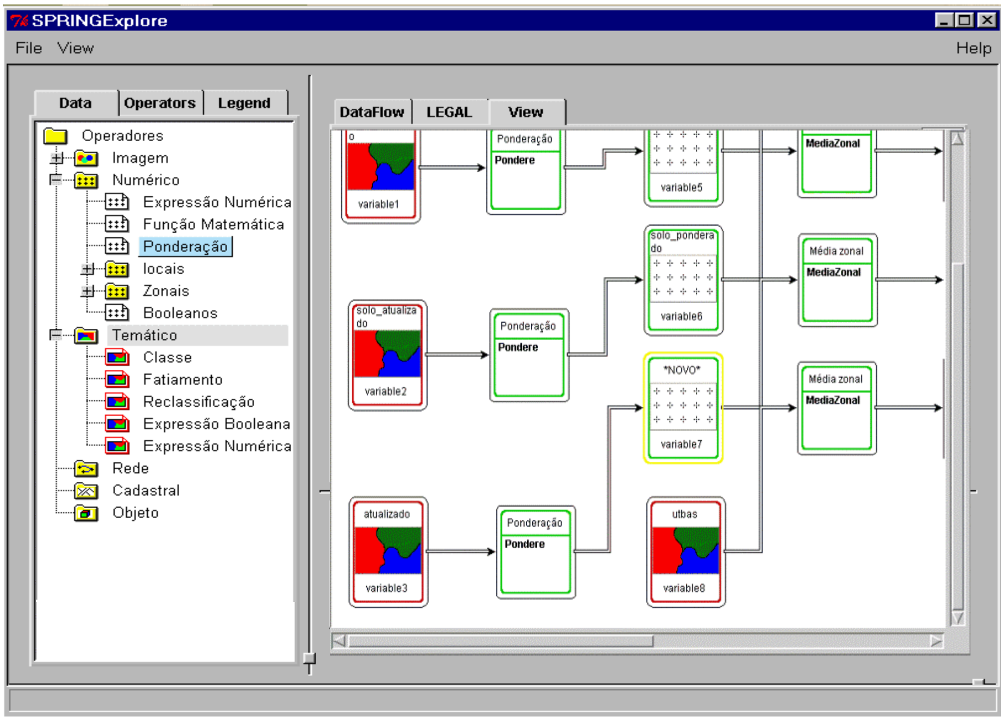

Figure 4 – Manipulation context.