Dynamic Graphics in a GIS: A Bidirectional Link between ArcView 2.1™ and XGobi — An Update

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Abstract

This article reports on a bidirectional link between a Geographic Information System (GIS), ArcView 2.1™, and an interactive dynamic graphics program, XGobi. ArcView 2.1 allows calls to external procedures via Remote Procedure Calls (RPCs) and it also enables external programs to invoke ArcView 2.1 functions using RPCs. These features enable us to provide a bidirectional link between ArcView 2.1 and XGobi. Our link combines the dynamic, interactive strengths of XGobi for visualizing high dimensional data with the map handling tools of ArcView 2.1, specifically to explore spatial data. This article presents information about the technical realization of the link and it addresses substantial questions such as security and concurrency issues. However, the main focus of this article is to address a new audience in addition to the statistical community. To achieve this goal, several parts have been reused from previous publications on this topic by the same authors.

1 Introduction

Interactive dynamic graphics programs have proven their usefulness for the exploration of high–dimensional data. When those data are collected at spatial locations, it becomes necessary to include the locations as part of the analysis. This leads very naturally to the integration of a Geographic Information System (GIS), to be used for the display of spatial locations and concomitant geographic variables, with a dynamic graphics program, to visualize and explore the corresponding data space. This type of link has been constructed between ArcView 2.1, a GIS, and XGobi (Swayne et al., 1991), an interactive dynamic graphics program in the X Window System™ environment.

This work is preceeded by Symanzik et al. (1994), in which a unidirectional link between the GIS ARC/INFO™ and XGobi is described. The subsequent release of ArcView 2.0™ provided both a more appropriate environment in which to implement the link, as well as technical solutions to the implementation of the link in both directions via Remote Procedure Calls (RPCs). A first technical description of the implementation of the link between ArcView 2.0 and XGobi was given in Symanzik et al. (1996a). Several sections of Symanzik et al. (1996a) have been reused for the current publication with the main intent to address a new audience in addition to the statistical community. However, we will provide an updated description of the link, now based on ArcView 2.1 and XGobi. The literature overview and the description of available software products includes changes and new releases over the last two years.

We will start in Section 2 with motivation for why a link like this is desirable and a description of the type of tools that are made available. Section 3 will describe the technical realization of our bidirectional link using RPCs. Security and concurrency issues related to the link will be discussed in Section 4. An example of how this type of link can be put to use will be given in Section 5. We will conclude by describing possibilities for future work.

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2 Integration of Interactive and Dynamic Graphics Tools into a GIS

Integrating a GIS with a dynamic graphics program is only one approach for including spatial locations in graphical analyses, though we feel it is an important one. In this integration approach, the ability to keep sample locations in their geographic context is considered paramount. Often, concomitant geographic variables can provide information that location alone can not provide. For example, two sets of locations might be separated by a mountain range resulting in changes in the process that are manifested in the collected data. Sometimes these changes are subtle; if the analyst can see clearly the geographic division in sample locations, further exploratory analysis might reveal the differences in the data.

A link between a GIS and a dynamic graphics program is intended to provide functionality that is not provided separately by the GIS or the dynamic graphics program alone. While GISs provide sophisticated capabilities for the input of spatial data, its management (storage & retrieval), and the display of maps, graphics, and tables, their capability for statistical analysis is generally limited and dynamic graphical analysis is nonexistent. Recently, some suggestions have been made to redress this imbalance (e. g., Openshaw, 1991; Anselin and Getis, 1992; Ding and Fotheringham, 1992; Fotheringham and Rogerson, 1993), while others have incorporated some dynamic graphics tools into systems that lack the full features and flexibility of a GIS (e. g., Haslett et al., 1991). Also, new software packages for spatial data analysis such as VARIOWIN (Pannatier, 1996) have been developed. Although most dynamic graphics programs can plot the coordinates of spatial locations, they do not have the capabilities of producing high quality maps that provide a geographic frame of reference. Together, ArcView 2.1 and XGobi share their strengths and produce a product that is more than the sum of its parts. Other examples for a link between independent geographical programs and statistical graphics programs are the interface between the image program MTID and XGobi (Klein and Moreira, 1994), used for the exploratory analysis of agricultural images, the linkage between the spatial data analysis software SpaceStat and ArcView 2.1 (Anselin and Bao, 1996), and the commercially available S – PLUS® for ARC/INFO™, developed by MathSoft.

The specific tools made available by the link include the resident capabilities of both ArcView 2.1 and XGobi, as well as the ability to do linked glyph and color brushing between the two systems. The capabilities of ArcView 2.1 include the display and manipulation of sample locations and other geographic information. XGobi provides an array of graphic options including univariate and bivariate plots, three–dimensional rotation, higher–dimensional rotation through the grand tour, and projection pursuit. The link allows the analyst to brush points, in either ArcView 2.1 or XGobi, with a color and a glyph and to see where the corresponding points are located in the other application. Thus, outliers in an XGobi plot can be brushed to see where they were collected, or a spatial region in ArcView 2.1 can be brushed to see where the corresponding attribute measurements fall in the data space. The link also allows the user to clone the XGobi window. Under cloning we understand that a new XGobi process is started in a new window where the same data and external resources are immediately available. This enables the analyst to proceed with the exploratory analysis in the new window while the old view is still present in the old window and may be processed differently. Together, these tools provide a powerful and flexible environment for the graphical analysis of spatial data.

Additional tools have been envisioned as well. Cook et al. (1994) discussed some tools for detecting spatial dependencies, focusing on ideas related to canonical correlation analysis. Majure (1996a) proposes a dynamic graphical environment for the exploration of multivariate spatial dependencies. The technology that supports the link described here is also being used to estimate and visualize spatial cumulative distribution functions (CDFs), variogram–cloud plots (Haslett et al., 1991; Bradley and Haslett, 1992), spatially lagged scatterplots (Cressie, 1984; Rossi et al., 1992), and multivariate variogram–cloud plots (Majure and Cressie, 1996). Thus, the technology that we are describing can provide a platform for many additional graphical methods for spatial data.

The usefulness of the link, which allows us to display spatial locations and concomitant geographic variables within the GIS, while visualizing and exploring the corresponding data space within XGobi simultaneously, has been highlighted for several different applications such as satellite imagery (Symanzik et al., 1996a), forest health monitoring (Majure et al., 1996a; Cook et al., 1996), and precipitation data (Majure et al., 1996b; Symanzik et al. 1996b; Symanzik et al., 1996c).

Our link has been developed for DEC™ alpha-

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stations. It also has been tested on other platforms such as Sun™/Sparc™ workstations, SGI™ workstations, and workstations from Data General Corporation. A current version of the software can be downloaded from the WWW at the URL `http://www.gis.iastate.edu/XGobi-AV2/XGobi-AV2.html`.

3 The Link between ArcView 2.1 and XGobi

Since the features provided by the unidirectional link between ARC/INFO and XGobi (Symanzik et al., 1994) were useful but limited, it was natural to establish a bidirectional link between the much more flexible ArcView (first version 2.0, now version 2.1) and XGobi. This link utilizes Remote Procedure Calls (RPCs), an interprocess communications feature available in ArcView 2.0 and 2.1. The use of RPCs is a programming technique where a process on the local system (i. e., the *client*) invokes a procedure on a remote system (i. e., the *server*). In this context, the term *request* is used to refer to the client's desire to execute a particular remote procedure, and the term *response* is used for the result produced by the remote procedure (Stevens, 1990).

ArcView 2.1 allows RPCs and it also enables external programs to invoke internal ArcView 2.1 functions via RPCs. Within this environment, XGobi has been adapted to the subroutine template code provided with the XGobi source code, which previously has been used for the implementation of the XGvis software system (Littman et al., 1992), the interface between the image program MTID and XGobi (Klein and Moreira, 1994), and for our previous link between ARC/INFO and XGobi (Symanzik et al., 1994; Cook et al., 1994).

ArcView 2.1 has been customized for this application using ArcView 2.1's Avenue programming language. Virtually all of the default ArcView 2.1 functionality is available, plus several operations that deal only with the link. Specifically, ArcView 2.1 has been modified to do the following: initiate an RPC server and client, initiate and pass data to the XGobi process, brush points and request XGobi to brush the corresponding points, and process requests from XGobi to brush points. This functionality can be described in the following pseudo code:

```
repeat
  wait for action
  case action {
    when ARCVIEW_2.1 request:
      process request
    when START_LINK request:
      initiate the XGobi process
      init ArcView 2.1 as RPC server
      init ArcView 2.1 as RPC client (i.e., connect to
        XGobi RPC server)
      send RPC request to XGobi containing the data to
        be input into XGobi
      activate appropriate GUI control buttons
    when STOP_LINK request:
      send RPC request to XGobi to shut down
      shut down RPC server
      shut down RPC client
      deactivate appropriate GUI control buttons
    when BRUSH_POINTS request:
      change the color/glyph/size of specified points
      send RPC request to XGobi to brush corresponding points
    when RPC request from XGobi:
      change the color/glyph/size of specified points
  }
until (ArcView 2.1 QUIT request)
```

Both, ArcView 2.1 and XGobi have been set up as a server for RPCs as well as a client for RPCs. This allows ArcView 2.1 (as a client) to access the functionality added to XGobi (the server). There will be a paper describing which XGobi remote procedures can be called from within ArcView 2.1. It is not possible to give XGobi the full functionality of an RPC server that automatically processes all requests from its clients since such an automation would never terminate and thus, no user action within XGobi could be processed any more. Instead, a working procedure, that is a routine that runs once whenever the X Window System event loop finds no event, has been added to XGobi to check for incoming RPC requests from clients (namely ArcView 2.1) and to process these requests.

On the other hand, XGobi (as a client) sends requests to ArcView 2.1 (the server), asking for the update of the ArcView 2.1 view in accordance with the brushing and subsetting information of points within XGobi where this information has been altered. The modified XGobi can be described via the following pseudo code:

```
init XGobi as RPC server
init XGobi as RPC client
init XGobi defaults
repeat
  wait for action
  case action {
    when RPC request:
      execute appropriate function (i.e., update XGobi
        structures, data sets, and views)
      return response (success or fail) to client
    when user action:
      process user action
      if (user action = Move_Brush_Symbol)
        make RPC call (i.e., submit brushing information)
        wait for response (success or fail) from server
        if (fail)
          print warning
  }
until (RPC request = Quit_XGobi)
shutdown RPC server
exit
```

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4 Security and Concurrency

In our bidirectional link between ArcView (2.0 and 2.1) and XGobi, security and concurrency are important issues that had to be addressed. Unfortunately, an ArcView (2.0 and 2.1) RPC server supports only one function: "1 – script execution – executes the given script and returns a string representation of the last object referenced or produced during the execution of the script" (Environmental Systems Research Institute, Inc., 1995). A string containing an Avenue script is required as an argument for the script execution. This string can be anything from a single Avenue statement through the complete text of an Avenue script. Since ArcView 2.0 only supported null authentication, there was no protection against the manipulation or deletion of entire ArcView 2.0 data bases or any of the analyst's files by an external user connected to the running ArcView 2.0 RPC server, hence a total lack of data security.

RPCs and existing security issues have been described in the technical literature, e. g., Corbin (1991). Unix authentication causes the transmission of additional fields (such as a time stamp, the name of the local host, the client's effective user and group IDs) with every RPC request. Data Encryption Standard (DES) authentication promotes secure exchange of data in a standard fashion since it encrypts/decrypts data through public and private keys associated with the effective user ID of the calling process. For both types of authentication, only valid requests are granted.

ArcView 2.1 provides at least Unix authentication. In our link between ArcView 2.1 and XGobi we make use of this authentication mechanism and process only those requests where local host and user ID match between ArcView 2.1 and XGobi (which is started from within ArcView 2.1 — thus, IDs will match for valid requests). Unfortunately, there is no verifier for Unix authentication, and so, the previously mentioned credentials are still easy to fake. Therefore, we suggest that ESRI provides an RPC mechanism for DES authentication in addition to the current null and Unix authentication for future releases of ArcView.

The concurrency issue (What happens if at least two XGobi processes provide different update information to ArcView 2.1 at the same time?) has been solved by a built–in feature of XGobi. Only one XGobi process, the one invoked from within ArcView 2.1, provides the features of an RPC server and RPC client. The other XGobi processes that have been cloned are "regular" XGobi processes that do not support RPCs. All XGobi processes (the one invoked from within ArcView 2.1 and the cloned ones) communicate to each other through the production and consumption of XEvents. When points are brushed or subsetted, an appropriate XEvent is generated. Even if one XGobi process is delayed for a while, it sequentially processes the XEvents that have been generated by other XGobi processes. Whenever the XGobi invoked from within ArcView 2.1 processes an XEvent related to brushing or subsetting, it requests ArcView 2.1 to update its view. Due to this one–to–one link and the serialization of the XEvents, the concurrency issue has been solved.

5 An Example

The geographic area under consideration in this example is the Lake Icaria watershed, located in southwest Iowa, near Corning. This area is predominantly agricultural, but also contains Lake Icaria State Park. The scene which is shown in the ArcView 2.1 view in Figure 1 was collected on April 22, 1990 by the SPOT earth observation satellite.

A sample of the pixels in the scene has been taken in order to conduct the analysis. This has been done because, even in an area as small as the one under consideration, the number of pixels in the entire scene is still over 300,000. This makes many types of analyses computationally intensive and time consuming. The sample taken is a systematic random sample (e. g., Cressie, 1993, Section 5.6.1), in which an initial pixel in the lower–left–hand corner of the image has been chosen at random and additional pixels have been included each 10 rows (200m) in both the horizontal and vertical directions. This process yielded a systematic random sample of 800 locations. These locations, marked with different glyphs (Xs, circles, and filled boxes), are also shown in the ArcView 2.1 view in Figure 1.

The data collected is the amount of incident electromagnetic radiation in a specific range, or band, of wavelengths. For each pixel in the area of the image, there is a datum for each of the three instruments on the SPOT satellite, expressed through the variables *Icariac1*, *Icariac2*, and *Icariac3*. In addition, the variable *Clust* has been added to the data set, containing the results of a hierarchical cluster analysis.

The lower left XGobi view shows the dot plot of *Clust* with two clusters being brushed. It becomes obvious that these points fall into two corners of the data triangle of the lower right XGobi view. The ArcView 2.1 view reveals that values marked with circles are located uniquely on lake locations while values marked with filled boxes relate to locations with active vegetation.

The next steps during an exploratory data analysis might involve the brushing of the third corner of the data triangle or the selection of points from the ArcView

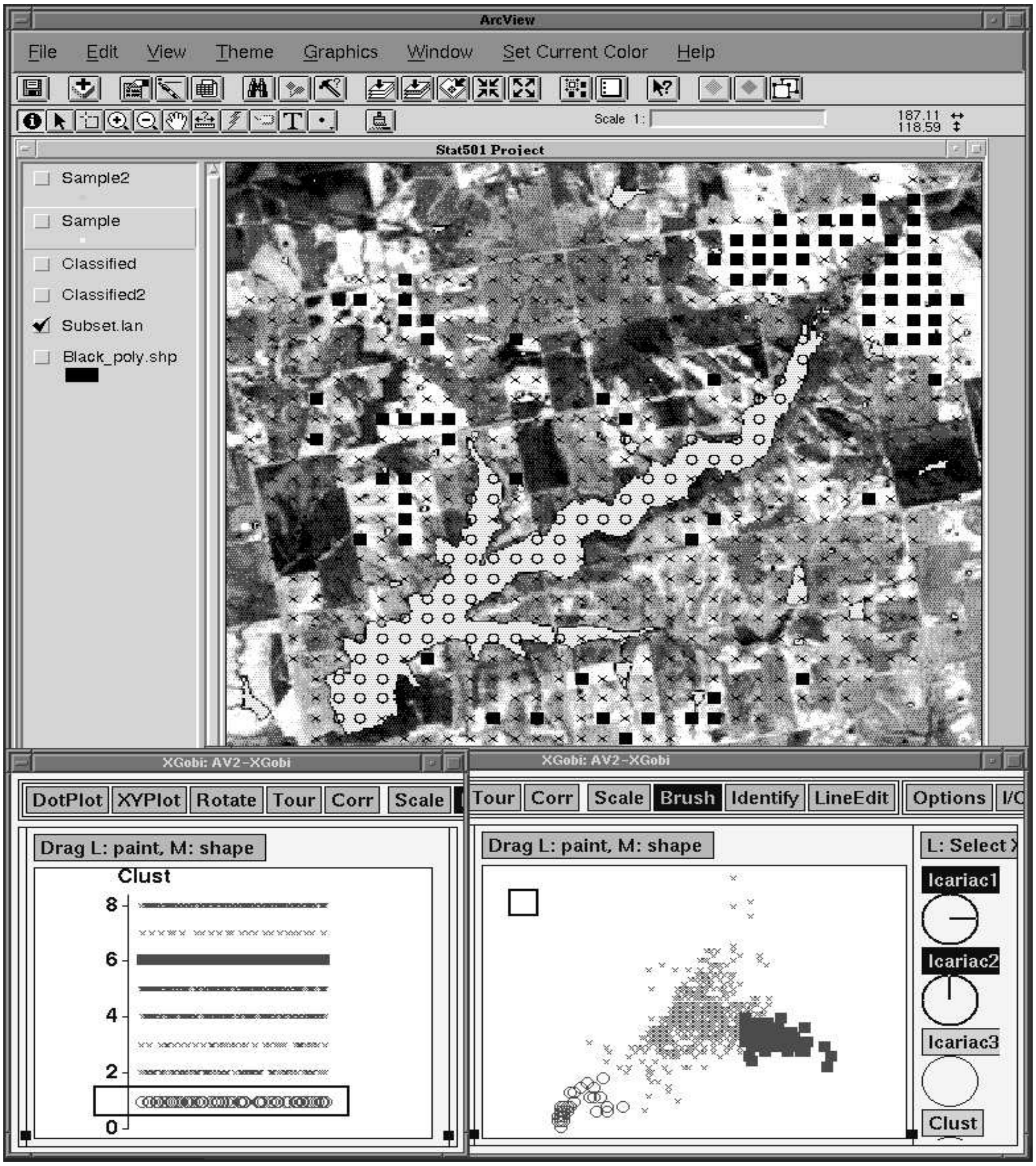

Figure 1: *ArcView 2.1 view linked with two XGobi views.*

2.1 view that are located on well–known terrain such as roads or buildings.

6 Future Work

Currently, our work is completed as far as it involves the incorporation of methods of spatial statistics into the link. Nevertheless, since the generic work required to link ArcView 2.1 with XGobi can be adapted to any graphical method of spatial statistics which can be displayed within XGobi itself, it is easy to add such methods whenever desired.

Recently, we started work on modifications of XGobi, e. g., different types of smoothers (helpful for the variogram–cloud plot). Missing values, supported by the forthcoming release of XGobi, will be supported by the link as well. We plan to implement a new type of linked brushing, called "hierarchical" linked brushing. This linked brushing is required for a future environment where ArcView 2.1 communicates with several XGobis, each of them displaying a different feature of the link, e. g., one XGobi and a cloned child for the attribute data, one XGobi for the spatial cumulative distribution functions, and one XGobi for the variogram–cloud plot.

The current linked brushing in XGobi does not reasonably support such an environment. Extensions to our Avenue code within ArcView 2.1 are required as well to allow the communication with multiple XGobis through RPCs. It is also planned to extend the link towards other statistical packages such as XploRe (Härdle et al., 1995) and S (Becker et al., 1988).

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