The Linked ArcView 2.1$^{\mathrm{TM}}$ and XGobi Environment — GIS, Dynamic Statistical Graphics, and Spatial Data

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Abstract

This paper reports on research into interactive, dynamic statistical graphics (DSG) applied to spatial data maintained within a geographic information system (GIS). We developed a bidirectional link between ArcView 2.1$^{\mathrm{TM}}$, a GIS, and XGobi, a DSG program. Multivariate data, collected at geographic locations, is passed from ArcView to XGobi and can be dynamically analyzed. The relation between the points in XGobi and the spatial locations from where they were collected is maintained so that points in either ArcView or XGobi can be brushed and the corresponding points in the other application are identified immediately. Special features (or flavors) of the link are the handling of multivariate attribute data, spatial cumulative distribution functions, variogram–cloud plots, spatially lagged scatterplots, and multivariate variogram–cloud plots.

1 Introduction

This paper contains work on a bidirectional link between a geographic information system (GIS), ArcView 2.1$^{\mathrm{TM}}$, and an interactive dynamic graphics program in the X Window System$^{\mathrm{TM}}$ environment, XGobi ([SCB91]). This link has been designed to combine the strengths of ArcView (displaying, querying, and manipulation of spatial data) and XGobi (manipulation of scatterplots and tools for the exploration of multivariate data such as linked brushing, identification, the grand tour, and projection pursuit). The link is intended to be used for the exploration and analysis of multivariate spatial data, collected at geographic locations.

Data that is stored in ArcView can be dynamically passed into XGobi through the link. Then, interactive queries made in either XGobi or ArcView are shared between both programs. For example, if a group of points is "brushed" with a different color and glyph (plotting symbol) in XGobi, the corresponding points in the ArcView plot are shown similarly. The first features of the link were the handling of multivariate attribute data and spatial cumulative distribution functions. Later, additional spatial plots, i. e., variogram–cloud plots, spatially lagged scatterplots, and multivariate variogram–cloud plots, have been added.

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 ([SMC96]) and forest health monitoring ([MCC$^+$96], [MCCS96], [CMSC96]). The example on precipitation data, first presented in [SMMC96], reappears in Section 3 of this paper.

The major intent of this paper is the presentation of the user interface of the link. Please refer to the literature (e. g., [CCMS94] and prior publications on this link) for a discussion on the importance of combining dynamic statistical graphics programs and geographic information systems. There, you will also find overviews on related work in linking exploratory techniques and GIS's and on similar software products. Lessons, learned in building this sytem that are useful in general for building other systems for spatial data analysis, can be found in the literature on this link as well. A technical description of the implementation of the link has been given in [SMC96] and [SMMC96]. The software and documentation can be found on the WWW under the URL `http://www.gis.iastate.edu/XGobi-AV2/XGobi-AV2.html`.

There exist two other software links that have been built for similar purposes. Klein and Moreira built a link between MTID and XGobi by calling XGobi as a subroutine, to be used for examining image data interactively ([KM94]). And recently, Anselin and Bao have built a link between the spatial data analysis software SpaceStat and ArcView from similar motivation as us, to provide exploratory data analysis tools for spatially referenced data ([AB96]).

In Section 2 of this paper, we will introduce the five flavors of the link: *Vanilla*, *Chunky Monkey*, *Strawberry Sundae*, *Cherry Garcia*, and *Wavy Gravy*. An example follows in Section 3. We finish this paper with a discussion in Section 4.

$^{\mathrm{TM}}$*ArcView 2.1* is a trademark of Environmental Systems Research Institute, Inc.

$^{\mathrm{TM}}$*X Window System* is a trademark of MIT.

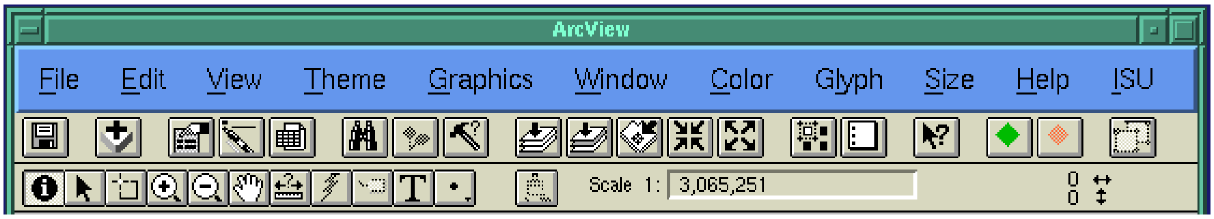

Figure 1: The *View* Document GUI for the *Vanilla*, *Strawberry Sundae*, *Cherry Garcia*, and *Wavy Gravy* Version of the Link. The *Menu Bar* contains additional pulldown menus that allow the color/glyph/size to be set. The *Button Bar* contains three additional buttons: 1) a green diamond that initiates the link; 2) a red diamond that terminates the link; and 3) a copy object icon that clones the XGobi window. The *Tool Bar* contains an additional brush tool that allows points to be brushed in ArcView.

2 The Flavors of the Link

The link has five special features (or flavors as we call them). The first flavor, *Vanilla* (or the multivariate link), passes the (multivariate) data associated with each spatial location into XGobi where it can be analyzed. The second flavor, *Chunky Monkey* (or the CDF link), asks the data analyst to indicate one (or two) attributes and then calculates and displays the (univariate or bivariate) empirical spatial cumulative distribution function (CDF) of the related data. It is possible that multiple regions (up to 10) can be specified for CDF prediction and display by interactively drawing a polygon on the screen. The color of the polygon is used to identify the CDF for that region The third flavor, *Strawberry Sundae* (or the variogram–cloud link), calculates and displays variogram–cloud plots. These plots can be interactively explored, for example for spatial dependence of the data set. The fourth flavor, *Cherry Garcia* (or the lagged–scatterplot link), creates and displays dynamic lagged scatterplots. This is another approach for the initial exploration of spatial dependence in the data set. The fifth flavor, *Wavy Gravy* (or the multivariate variogram–cloud link), calculates and displays a special type of variogram–cloud plots. These plots can be used to look for asymmetric, multivariate spatial dependence. Linked brushing is available for all flavors.

These flavors of the link make the combination of ArcView and XGobi a powerful tool for the exploration of spatially referenced data. In each of the following subsections we will describe the particular features of one flavor.

2.1 Using the *Vanilla* Flavor of the Link (The Multivariate Link)

The *Vanilla* flavor of the link allows the data analyst to pass (multivariate) spatial data (associated with a point theme in ArcView) into XGobi where it can be explored. ArcView's graphical user interface (GUI) for this version of the link contains several additions to the *View* document GUI (Figure 1). The *Menu Bar*, the *Button Bar*, and the *Tool Bar* have been modified.

Initiating the Link The green diamond button on the *Button Bar* is pressed to initiate the link. Before the link can be initiated, a point theme must be made the only active theme. A label point theme can also be used to analyze polygon data. Active theme entries in the *View Table–of–Contents* have a raised appearance. When the link is initiated, all of the visible, numeric fields in the attribute table of the active point theme are passed into XGobi and the XGobi window is initiated. You can control how much data is passed into XGobi by setting the visible fields in the *Table Properties* dialogue. When initiated, the user will be prompted to specify a field that will be used as row labels in XGobi. This is the field that will be used in the XGobi *Identify* panel, and typically is some sort of an identifier.

Brushing in XGobi Once initiated, any color/glyph/size brushing conducted in the XGobi window will be automatically passed to ArcView, which brushes corresponding points. Both transient and persistent brushing are allowed. Points can also be erased using XGobi erase brushing.

Brushing in ArcView Brushing in ArcView is done using the *Brush Tool* on the *Tool Bar* (Figure 1). When this is the active tool, the user can define a polygon on the *View Display*. Any points within the user defined polygon are *persistently* brushed in the current color/glyph/size and this brushing information is passed to XGobi, which brushes corresponding points. The current color/glyph/size are set using the *Color/Glyph/Size* pull down menus.

Cloning the XGobi Window The XGobi window can be cloned (by pressing the *Copy* icon on the *Button Bar* or from within XGobi) for additional flexibility in the analysis process. Any cloned XGobi windows communicate with the initial XGobi window via the normal XGobi X event based communication mechanism ([SMC96]). The original XGobi window also continues to communicate with ArcView. Thus, brushing in any of the XGobi windows or the ArcView window will automatically be passed to all of the other windows.

Terminating the Link The link is terminated by pressing the red diamond button on the *Button Bar*. This terminates the initial XGobi window. Any cloned XGobi windows must be exited separately.

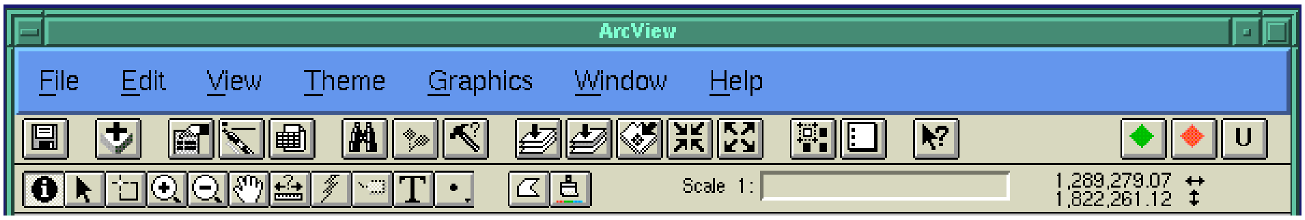

Figure 2: The *View* Document GUI for the *Chunky Monkey* Version of the Link. The *Button Bar* contains three additional buttons: 1) a green diamond that initiates the link; 2) a red diamond that terminates the link; and 3) a "U" icon that updates the CDF plots after region definitions have been changed. The *Tool Bar* contains two additional tools: 1) a region definition tool that allows regions to be defined for which CDFs will be calculated; and 2) a brush tool that allows transient brushing in ArcView.

2.2 Using the *Chunky Monkey* Version of the Link (The CDF Link)

The *Chunky Monkey* flavor of the link allows the data analyst to display and explore up to 10 regional univariate or bivariate empirical spatial CDFs at the same time. The GUI for this version of the link contains several additions to the *View* document GUI (Figure 2). The *Button Bar* and the *Tool Bar* have been modified.

Initiating the Link The green diamond button on the *Button Bar* is pressed to initiate the link. Before the link can be initiated a point theme must be made the only active theme. A label point theme can also be used to analyze polygon data. When the link is initiated, the user is prompted to choose either univariate or bivariate CDFs and then to enter the appropriate number of fields from the attribute table of the active point theme for which CDFs will be calculated. The data from this field are passed into XGobi where the empirical CDF is calculated and displayed. Initially, the CDF is calculated for the entire region defined by the active point theme.

Defining Regions for CDF Calculation After initiating the link, spatial regions can be interactively defined for which CDFs will be displayed. When the *Define Regions* tool is active, user–defined polygons can be entered on the *View Display*. As each polygon is entered, it is given a color (automatically) and the CDF for the defined region is displayed in the XGobi window using the same color. Currently, up to 10 regions can be defined. Region polygons can be deleted or modified (see *Updating Regions* below) using ArcView's object manipulation tools.

Updating Regions Spatial regions can be modified using ArcView's object manipulation tools. After a region has been modified, however, the *Update Region* button must be pressed in order for the change to be reflected in the CDF view.

Brushing in XGobi Once the link is initiated, the CDFs in the XGobi window can be brushed with different glyphs. No color brushing is allowed (because colors are used to identify regions) and only transient brushing is allowed. When brushed, the corresponding points in ArcView are brushed using the specified glyph.

Brushing in ArcView Locations in ArcView can be brushed to see where they are in the CDF plots. This is done by using the *Brush Tool* to define a polygon. The points in the CDF plots are given a larger glyph. The points in ArcView are not changed.

Terminating the Link The link is terminated by pressing the red diamond button on the *Button Bar*. This terminates the initial XGobi window.

2.3 Using the *Strawberry Sundae* Flavor of the Link (The Variogram–Cloud Link)

The *Strawberry Sundae* flavor of the link allows the data analyst to display and explore variogram–cloud plots. This type of plots is used to look for spatial outliers and to explore the spatial dependence in a data set ([HBC+91], [BH92]). In this flavor, only those points of all possible pairs of sampling locations are displayed in XGobi where the distance between locations is smaller than a user–defined cutoff distance. Among other variables and plots that can be displayed with this flavor, it is intended for variogram–cloud plots. These are plots where, for each pair of locations, the square–root of the absolute difference between attribute values at the locations versus the euclidean distance between the locations is plotted in XGobi. In data sets that exhibit a strong spatial dependence, the variance in the attribute differences will increase when the distance between locations increases. Therefore, large attribute differences for locations that are near to one another might indicate a spatial outlier. This can happen even though the values at both locations seem to be reasonable when the data set is examined non–spatially.

Because each point in the XGobi window corresponds to a pair of sampling locations in ArcView, we had to modify the brushing environment slightly in comparision to the two flavors described earlier. For each point brushed in XGobi, a line of the same color is drawn between the corresponding pair of sampling locations in ArcView. Because each sampling location can be included in up to n points being displayed in XGobi, brushing a location in ArcView causes two things to occur: First, all corresponding points in XGobi are brushed. Second, lines are drawn in the ArcView window between the brushed location and all other locations with which it is paired.

Calculated XGobi Variables

When initiated, this link calculates and passes $p^2 + 5$ variables into XGobi, where p is the number of visible, numeric fields in the attribute table of the active point theme. The visible fields can be changed in the *Table Properties* dialogue. The following variables are calculated:

A : The angle between each pair of points, measured in degrees from the X axis. This variable is used to brush various angle classes and, thus, investigate anisotropic variation.

sinA : The sine of the angle given in **A**. This can be plotted versus **cosA** (below) in an X–Y plot for angle–class brushing. This allows continuous brushing on the angle class.

cosA : The cosine of the angle given in **A**. This can be plotted versus **sinA** (above) in an X–Y plot for angle–class brushing. This allows continuous brushing on the angle class.

d : The euclidean distance between the spatial location of each pair of points, measured in the units in which the points are stored in ArcView.

g_lm : (read gamma sub l, m) where $l, m = 1, \ldots, p$, calculated as:

$$\gamma_{lm} = \mid Z_l(s_i) - Z_m(s_j) \mid^{1/2},$$

where $Z_l(s_i)$ $[Z_m(s_j)]$ is the observed value of attribute l $[m]$ at sampling location s_i $[s_j]$ for i $[j] = 1, \ldots, n$. There are p^2 of these variables.

D : The euclidean distance, in p–dimensional space, between the attribute vectors at each pair of points:

$$D = \mid\mid \mathbf{Z}(s_i) - \mathbf{Z}(s_j) \mid\mid,$$

where $\mathbf{Z}(s_i)$ $[\mathbf{Z}(s_j)]$ is the p–dimensional vector of observed attribute values at sampling location s_i $[s_j]$ for i $[j] = 1, \ldots, n$.

There are several **notes** and **cautions** about these variables:

- The number of visible fields, p, should be kept to a minimum because the number of calculated variables increases as p^2, which can consume much of your computer's memory.
- Only include relevant fields. **All** visible, numeric fields will be included as one of the p fields at each location. This includes things such as numeric location identifiers, x and y coordinate locations, etc. Any extraneous variables will cause the calculated **D** variable to be uninterpretable.
- The **A** variable is given a negative value for two special cases: 1) when a point is paired with itself (the value given in this case is -90); and 2) when a pair of different points share the same (exact) spatial location (the value given in this case is -45). The negative values for these cases make brushing easy. The values for these special cases in the **sinA** and **cosA** variables are such that they are plotted inside the circle in the plot of **cosA** vs. **sinA**.

GUI

The GUI for this version of the link is identical to the GUI for the *Vanilla* flavor of the link (Figure 1). However, its functionality is slightly different.

Initiating the Link The green diamond button on the *Button Bar* is pressed to initiate the link. Before the link can be initiated a point theme must be made the only active theme. A label point theme can also be used to analyze polygon data. Active theme entries in the *View Table–of–Contents* have a raised appearance. When the link is initiated, the user will be prompted for the maximum distance between pairs of points. Only pairs of points that are less than or equal to this distance apart from one another will be passed into XGobi. This allows the amount of the data being passed into XGobi to be reduced dramatically if the scale of spatial dependence is dramatically smaller than the area being analyzed. This can help both the speed of beginning the link as well as the interpretation of the graphics.

Brushing in XGobi Once initiated, any color/glyph/size brushing conducted in the XGobi window will be automatically passed to ArcView. For each point that is brushed in XGobi, a line is drawn between the corresponding pair of sampling locations in ArcView. The color of the line corresponds to the current XGobi brush color.

Brushing in ArcView Brushing in ArcView is done using the *Brush Tool* on the *Tool Bar* (Figure 1). When this is the active tool, the user can define a polygon on the *View Display*. Because each sampling location can be included in up to n points being displayed in XGobi, brushing a location in ArcView causes two things to occur: 1) all corresponding points in XGobi are brushed with the current color/glyph/size (set in pulldown menus); and 2) lines are drawn in the ArcView window between the brushed location and all other locations with which it is paired.

Unbrushing In order to remove the lines that have been displayed in the ArcView window as a result of brushing, simply brush all affected points using the default color, i. e., the color that was used when the link was started. The sampling locations in the ArcView window will always remain this color; only the lines between locations will be given colors corresponding to the brush color.

This unbrushing can be done in either the ArcView or the XGobi window.

Cloning the XGobi Window The XGobi window can be cloned (by pressing the *Copy* icon on the *Button Bar* or from within XGobi) for additional flexibility in the analysis process. Any cloned XGobi windows communicate with the initial XGobi window via the normal XGobi X event based communication mechanism ([SMC96]). The original XGobi window also continues to communicate with ArcView. Thus, brushing in any of the XGobi windows or the ArcView window will automatically be passed to all of the other windows. **Note**: This is especially useful for brushing on the angle variable, **A**. If you do this, however, we recommend that you use the initial XGobi window to display and brush the **A** variable and the cloned XGobi to display the variogram–cloud plot.

Terminating the Link The link is terminated by pressing the red diamond button on the *Button Bar*. This terminates the initial XGobi window. Any cloned XGobi windows must be exited separately.

2.4 Using the *Cherry Garcia* Flavor of the Link (The Lagged–Scatterplot Link)

The *Cherry Garcia* flavor of the link allows the data analyst to display and explore dynamic, spatially lagged scatterplots. These are a useful tool for the initial exploration of spatial dependence in a data set ([Cre84], [RMJF92]). In this flavor, the points displayed in XGobi represent all possible pairs of sampling locations up to a given cutoff distance. For each pair of locations, XGobi plots the following points:

$$(Z_l(s_i), Z_m(s_j)),$$

where $Z_l(s_i)$ represents variable l at sampling location s_i, and $Z_m(s_j)$ represents variable m at sampling location s_j.

If there exists strong spatial dependence in a data set, then the points in the lagged scatterplot that originate at sampling locations near to one another will be close to the line $y = x$. The dispersion about this line will increase with an increasing distance between sampling locations.

When we use the term "dynamic, spatially lagged scatterplot", we actually mean that the previously described variation can be explored by displaying the distance variable, **d**, in a separate (cloned) XGobi window and then dynamically brushing through the distance point cloud. The brushing behavior for this flavor of the link is identical to the brushing behavior of the *Strawberry Sundae* flavor.

Calculated XGobi Variables

When initiated, this link starts XGobi with $2p + 4$ variables, where p is the number of visible, numeric fields in the attribute table of the active point theme. The visible fields can be changed in the *Table Properties* dialogue. The following variables are calculated:

A, **sinA**, **cosA**, and **d** are calculated as for the *Strawberry Sundae* flavor of the link.

var_i : The variable named **var** at location s_i. This is $Z_l(s_i)$ in the formula for the lagged scatterplot. When plotted against **var_j**, a lagged scatterplot is formed. There are p of these variables.

var_j : The variable named **var** at location s_j. This is $Z_m(s_j)$ in the formula for the lagged scatterplot. When plotted against **var_i**, a lagged scatterplot is formed. There are p of these variables.

There are the same **notes** and **cautions** about these variables as for the *Strawberry Sundae* flavor of the link, except that the number of included variables increases as $2p$ (and not as p^2 as for the *Strawberry Sundae* flavor) and no **D** is calculated. Everything that has been said about the GUI for the *Strawberry Sundae* flavor of the link also holds for the *Cherry Garcia* flavor of the link.

2.5 Using the *Wavy Gravy* Flavor of the Link (The Multivariate Variogram–Cloud Link)

The *Wavy Gravy* flavor of the link allows the data analyst to display and explore asymmetric, multivariate spatial dependence of the data set. A complete description is beyond the scope of this paper (see [MC96] for details).

This flavor of the link is very similar to the variogram–cloud link. However, because we are focusing on the exploration of asymmetric, multivariate spatial dependence, the two variables g_{ij} and g_{ji} (from the variogram–cloud link) are combined into one variable, g_{ij}, in this flavor of the link. When this new variable, g_{ij}, is plotted against the distance, **d**, this is equivalent to plotting g_{ij} and g_{ji} end–to–end, that is, the horizontal axis for the plot g_{ij} extends to the right and the horizontal axis for the plot g_{ji} extends to the left. The resulting plot provides the data analyst with the full multivariate spatial structure in just one plot. Using this flavor of the link, it can be detected whether the structure in the plot is not symmetric about the origin, a feature often present in multivariate spatial data sets.

Note that when exploring multivariate data using the variogram–cloud link, the lagged–scatterplot link, or the multivariate variogram–cloud link, it is important to standardize the data (e.g., subtract the mean and divide by the standard deviation) to avoid spurious dependencies appearing that might be due simply to location and scale features. The brushing behavior for this flavor of the link is identical to the brushing behavior of the *Strawberry Sundae* flavor.

Calculated XGobi Variables

When initiated, this link calculates and passes $\binom{p}{2} + 5$ variables into XGobi, where p is the number of visible, numeric fields in the attribute table of the active point theme. The visible fields can be changed in the *Table Properties* dialogue. The following variables are calculated:

A, **d**, and **D** are calculated as for the *Strawberry Sundae* flavor of the link.

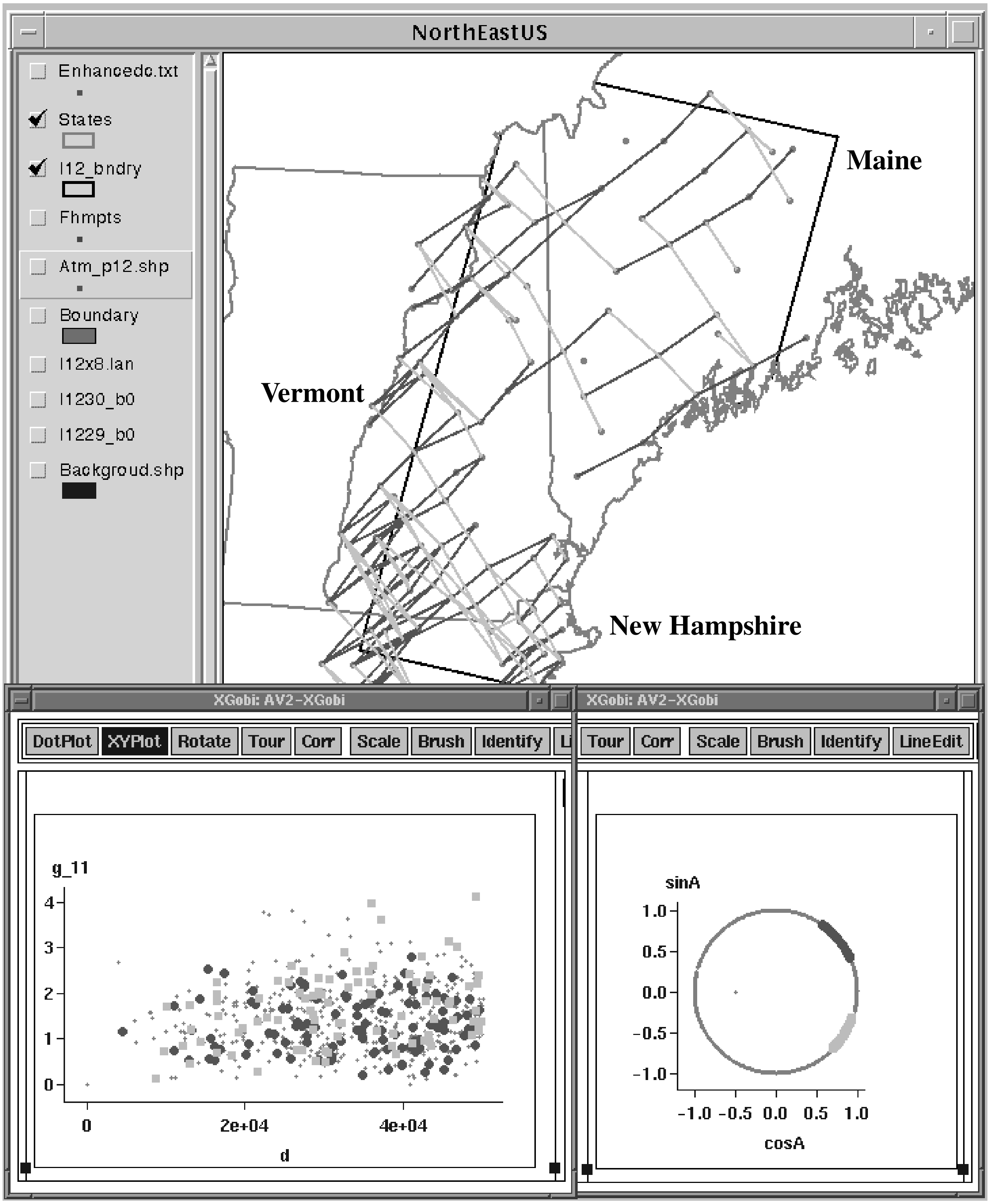

Figure 3: *Variogram–Cloud Plot (bottom left), Angle between Locations (bottom right), Map View of Sampling Sites in the Northeastern United States (top).*

sin2A : The sine of two times the angle given in **A**. This can be plotted versus **cos2A** (below) in an X–Y plot for angle–class brushing. This allows continuous brushing on the angle class.

cos2A : The cosine of two times the angle given in **A**. This can be plotted versus **sin2A** (above) in an X–Y plot for angle–class brushing. This allows continuous brushing on the angle class.

g_lm : (read gamma sub l, m) where $l = 1, \ldots, p$ and $m = l, \ldots, p$, calculated as:

$$\gamma_{lm} = \mid Z_l(s_i) - Z_m(s_j) \mid^{1/2},$$

where $Z_l(s_i)$ [$Z_m(s_j)$] is the observed value of attribute l [m] at sampling location s_i [s_j] for i [j] $= 1, \ldots, n$. There are $\begin{pmatrix} p \\ 2 \end{pmatrix}$ of these variables since we only consider pairs (l, m) where $l \leq m$. A plot of **g_ml** versus distance **d** would be symmetric around the Y axis to a plot of **g_lm** versus distance **d** where $l \leq m$.

There are the same **notes** and **cautions** about these variables as for the *Strawberry Sundae* flavor of the link, except that the number of included variables increases as $\begin{pmatrix} p \\ 2 \end{pmatrix}$ (and not as p^2 as for the *Strawberry Sundae* flavor), but it still has the same asymptotic complexity. Everything that has been said about the GUI for the *Strawberry Sundae* flavor of the link also holds for the *Wavy Gravy* flavor of the link.

3 An Example

In this example, a variogram–cloud has been plotted for precipitation values at precipitation sampling sites in the northeastern United States. This example first has been presented in [SMMC96].

In the ArcView–XGobi variogram–cloud link, the angle class can easily be changed using the linked brushing environment. In this way, data sets can be explored for anisotropic variation. Figure 3 displays a variogram–cloud plot, along with a plot of the sine vs. the cosine of the angle between locations, and a plot of the sampling locations. Two angle classes, corresponding to the NE–SW direction (dark filled circles) and the SE–NW direction (light filled squares), have been brushed. It seems that for any given distance, the average value for the SE–NW direction is higher than for the NE–SW direction. This is justified through the geography. The SE–NW direction represents sampling sites that are at different distances from the coast line while the NE–SW direction represents sampling sites that are at about the same distance from the coast line.

4 Discussion

We have provided a descripton of the user interface for an environment for graphical exploration of spatial data. The variety of links in this environment make it possible to do fairly sophisticated graphical exploratory data analysis on spatially referenced data. Some of the plotting types are familiar in spatial data analysis — variogram–cloud, lagged scatterplot, spatial CDF — and some are relatively new — multivariate variogram–cloud.

Advances for data analysis in this environment over a static plotting environment are provided in the approaches to interacting with the different types of plots. Instead of fixing a distance lag interval and then computing the lagged scatterplot, it is possible to change interactively the size of the lag using a different brush size, and move the brush to examine interactively how the dependence varies with distance. This saves deciding lags, a priori, and plotting many different pictures to lay out on a table for perusal. It is also possible to select several angle classes with a brush and examine the variogram–clouds for the different angle classes.

A significant portion of the research time was spent on learning, understanding and developing the interprocess communication code that facilitates the link between the two software packages. Now that this is fully developed, it is possible to build in and experiment with new types of links and plot types fairly quickly. One direction of future links is to extend the system in a third direction, i. e., statistical analysis software packages like S ([BCW88]) and XploRe ([HKT95]).

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