Practical Application of Parallel Coordinates to Hurricane Trend Analysis *

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1 Introduction

In climate studies, weather scientists are interested in discovering which environmental factors have the greatest influence on significant weather phenomena. Due to the destructiveness of recent hurricane seasons, some scientists are focusing their studies on discovering which environmental variables have the greatest impact on the intensity and frequency of seasonal storm activity using statistical regression techniques. Although complicated, such techniques are effective in screening data and providing quantitative associations.

In conjunction with these statistical regression methods, researchers have relied on simple, yet effective, scatter plots or histograms which require several separate plots or layered plots to analyze multiple variables. However, these representation techniques suffer from several perceptual issues because they were not designed for rapid or accurate multidimensional analysis. In this type of study, researchers need visualization techniques that are specifically designed to accommodate the simultaneous display of a high number of variables in order to support exploratory visual analysis.

We have applied and extended a highly successful multivariate information visualization technique, parallel coordinates [3], to the study of hurricane climate data and regression analysis. We analyzed several seasonal hurricane predictors that were provided by Mr. Phil Klotzbach of the Tropical Meteorology Project at Colorado State University. Using an advanced dynamic interaction model, we validated the notion that the parallel coordinates visualization technique enriches the scientists' ability to rapidly discover and thoroughly analyze complex patterns and trends in climate data.

2 Dynamic Interaction Model

To facilitate a deeper understanding of the climate data, we developed a parallel coordinates application with several innovative extensions to the original interaction model. This application provides many interactive features that are fundamental to the parallel coordinates visualization technique such as relocatable axes, axis inversion, and details-on-demand. Since the viewer is often interested in ways to group subsets of the data, a pair of sliders (see Fig. 1) offer the capability to perform rapid, conjunctive queries to highlight relation lines for a particular axis or a set of axes.

2.1 Axis Scaling (Focus+Context)

In displays where many relation lines are shown, it is often desirable to provide a method for interactively tunneling through the relations until a smaller subset of the original dataset is in focus. Our application provides this capability by allowing the user to modify the minimum and maximum values of the axes using the mouse wheel functionality. On the axis bar, there are three distinct areas delineated by horizontal tick marks (see Fig. 1) that are important to the axis scaling capability: the central focus area and the top and bottom context areas. When the mouse is hovering over the focus area, an upward mouse wheel motion expands the display of the focus area outward and pushes outliers to the context areas. A downward mouse wheel motion causes the inverse effect: focus region compression. Alternatively, the user may use the mouse wheel over either of the two context areas to alter the minimum or maximum values separately. As shown in the image sequence of Fig. 2, our intuitive axis scaling capability frees up space and reduces clutter thereby making it easier to analyze relation lines of interest.

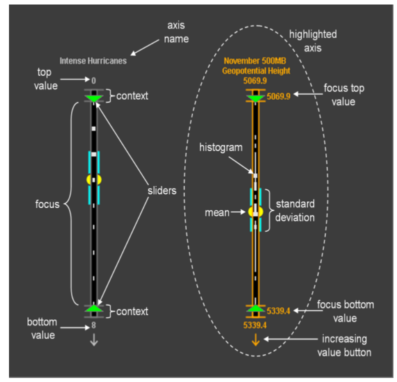

Figure 1: An annotated view of the parallel coordinate axis display widget for our application. The normal axis color scheme is shown on the left and the highlighted color scheme (used when the mouse moves in an axis space) is shown on the right.

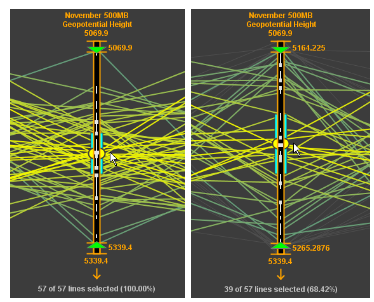

Figure 2: A screen shot of the parallel coordinates application before (left) and after (right) scaling has been performed. In this example, scaling occurred by performing an upward mouse wheel movement in the focus area which stretches the display upward and downward.

2.2 Aerial Perspective

Aerial perspective shading is useful for quickly monitoring trends due to the similarity of data values over multiple dimensions in

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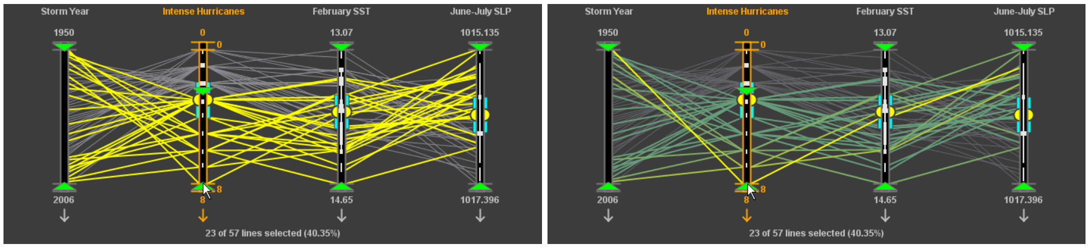

Figure 3: An example of the discrete (left) and continuous (right) modes of the aerial perspective shading capability. Lines are shaded based on their position relative to the axis focus, context, and query areas and, in continuous mode, a nonlinear color gradient effect encodes the distance to the mouse cursor. In these examples, the mouse is positioned over the bottom of the second axis which highlights the seasons with high intense hurricane activity and, in continuous mode, the most active seasons are given more emphasis.

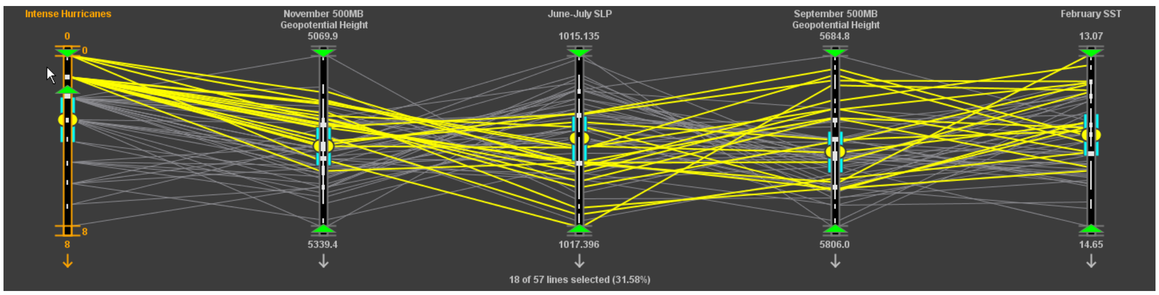

Figure 4: A plot of the most influential predictors (identified by regression analysis) for the number of intense hurricanes in a season (1950 to 2006) in which the low activity seasons are highlighted. This plots reveals the suppressing effects of cold February SST and high June–July SLP on intense hurricane formation.

parallel coordinates [4]. In our implementation, aerial perspective shading can be used in either a discrete or a continuous mode. In the discrete mode, the lines are colored according to the axis region that they intersect. If any point of a relation line is in the context regions of at least one axis, the line is shaded with a dark gray color and drawn beneath the non-context lines. If all the points on a line fall within the query area of each axis (the area between the two query sliders), the line is colored using a highly saturated lime green color that attracts the viewer's attention (see Fig. 3).

In the continuous mode, non-context lines go through an additional step to encode the distance of the line from the mouse cursor. Query lines that are nearest to the mouse cursor receive the maximum amount of saturation while lines furthest from the mouse cursor are shaded with a less saturated green-blue color. The other query lines are shaded according to a non-linear fall-off function that yields a gradient of colors between said extremes. Consequently, the lines that are nearest to the mouse cursor are more prominent to the viewer due to the color and depth ordering treatments (see Fig. 3) and the viewer can effectively use the mouse to perform rapid, visual queries.

2.3 Representing Key Statistics

To support the advanced interaction capabilities of our application, each axis also represents key statistical quantities for the relation points that are displayed in the focus region. [2, 5] For each axis, the mean, standard deviation, and the frequency information are calculated for points in the focus area. As shown in Fig. 1, the mean value and the standard deviation range are shown using two yellow half circles and two cyan rectangles, respectively. Within each axis bar, the frequency information is also displayed by representing histogram bins as small, light gray rectangles with widths that are indicative of the number of lines that pass through the bin's region (see Fig. 1).

3 North Atlantic Hurricane Season Case Study

We have employed stepwise regression with a "backwards glance" which selects the optimum number of the most important variables using a predefined significance value (90% in this study) [1]. Stepwise regression can compliment parallel coordinates visualization by isolating the significant variables in a quantitative fashion. Interactive parallel coordinates can then be used to rapidly develop a deeper understanding of the complex relationships between variables. One independent variable we studied is the number of seasonal intense hurricanes, which cause 80% of the economic damage from tropical cyclones. Fig. 4 shows that cold February Atlantic SSTs and high June–July SLP tend to reduce the number of intense hurricanes, with November 500-mb geopotential heights playing a secondary role and September 500-mb geopotential heights showing no role.

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